Using multiple representations to enhance understanding of molecular structure: a blended learning activity

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Abstract: *One of the challenges of teaching an introductory chemistry course is to balance the requirement of covering a prescribed set of concepts and skills with providing opportunities for students to spend time with, and apply, a single concept. In this chemistry course, students encounter an array of molecular representations including line drawings, condensed structures, ball and sticks and three dimensional space filled molecules. They must quickly become fluent in translating between these representations and in a lecture setting are likely to acquire misconceptions. To address these issues, a blended learning workshop was developed to present active learning opportunities for students in the application and extension of their understanding of molecular structure. An integrative approach was adopted by using the context of fats in the diet to demonstrate the relevance of the chemistry concepts to the student's daily lives. This involved the adaptation of a successful ChemConnections initiative (http://mc2.cchem.berkeley.edu/). Students were guided through inquiry activities involving online resources (Jmol), hands-on molecular model kits (Molymod) and a graphics application on individual tablet PCs where they drew molecular structures.*

Student learning gains and metacognitive processing were measured via three strategies incorporating the unique facilities of the teaching space. The availability of individual tablet computers enabled collection of student representations of a line structure prior to commencement of the workshop. As part of the assessment of the exercise, students were invited to submit brief reflections (via personal blogs managed through Blackboard). Students identified multiple themes regarding the aspect of the workshop that had impacted on their learning (working as groups, molecular models and the high technology facilities). Gains in conceptual understanding were explored through two post-workshop assessment tasks. A related problem was placed in PASS (Peer Assisted Study Sessions) where students worked in peer groups without instructor input, and a short answer question was included in the summative exam for the course. Students reported high confidence levels in their ability to recognise organic structures as a result of the activities encountered during the workshop. A mixed methods approach was adopted for the evaluation of the learning experience including pre- and post-tests conducted at each workshop, focus group interviews and feedback from students (post-workshop reflections, a problem set in a pseudotutorial environment and summative exam question). Data gathered has been evaluated through quantitative and qualitative analysis (SPSS and NVivo).

Introduction

The array of representations of molecular structures that students encounter as they progress through learning experiences (for example ball & stick, skeletal structures and space-filling) make it difficult for novice learners to construct their understanding of these structures (Tasker & Dalton, 2006; Wu & Shah, 2004). Simply encountering a 2D diagrammatic representation or observing the teacher manipulate dynamic 3D molecular models is insufficient. Providing students with opportunities to encounter a concept in multiple ways increases their ability to build strong conceptual models (Nakleh & Postek, 2008). The use of information and communication technologies to promote student understanding of chemical representations has become widespread (Kozma & Russell, 1997; Wu & Shah, 2004; Wu, Krajcik & Soloway, 2001). It becomes increasingly possible that we may overload novice learners through the combination of multiple instructional exercises, visual representations and the use of high technology facilities. In this study, a blended learning workshop was developed for Introductory Chemistry students to provide active learning opportunities in the application and extension of their understanding of molecular structure. Principles of inductive teaching and learning underpinned the development of the activities and elements of both guided inquiry and discovery were adopted in the instructional design (Prince & Felder, 2006). The workshop was scheduled in the university's new Advanced Concept Teaching Space (ACTS); a 100-seat high-tech room, with individual touch tablet screens for students, multiple projection screens, interactive whiteboards, and software to support the active engagement of students. The objective was to provide an activity where students could construct their understanding of molecular structure in a learner-centred environment and translate between two dimensional and three dimensional models. In addition to investigating the impact of the workshop on student understanding of molecular structure, this was an experiment in using the new ACTS facility. Therefore, the researchers also studied whether the workshop promoted student engagement and whether the technology impacted on the learning process. Therefore issues such as cognitive overload (Carlson, Chandler & Sweller, 2003) during a "one-time" activity were considered.

Methodology

The two hour workshop was designed to replace two standard lectures in an Introductory Chemistry course for 120 students and was scheduled into the advanced concept teaching space (ACTS), a new multimillion state-of-the-art facility which was designed to promote blended learning activities. To match the capacity of the 99 seat room, the cohort was split in two (students self-selected into their preferred session via a Blackboard Wiki sign-on) and the workshop was completed in two iterations. Each of the two workshops was facilitated by up to four instructors to enable smooth transitions and reduce technical hurdles for students such as using the tablet computers which they may have been encountering for the first time. On arrival, students were required to complete a brief orientation using their individual student tablet screens. This activity included a short pre-test (hosted by *SurveyMonkey*) and the creation of a line structure of 2-methylhexane using *Microsoft* Paint. The students submitted the Paint files containing these images to the instructor's hub (facilitated by *Synchroneyes*™). The structural representations produced by the students were later examined to evaluate existing understanding of molecular representations as students had previously experienced two one hour lectures where they were introduced to hydrocarbons and molecular shape. Students then proceeded to work through the remaining workshop activities framed in the context of fats in food, (summarised in Table 1 below). An integrative approach was adopted to demonstrate the relevance of the chemistry concepts to the student's daily lives. This involved the adaptation of a successful ChemConnections initiative (http://mc2.cchem.berkeley.edu/) for which Prof Stewart was a module developer. The activities were linked together under the theme of fats in the diet.

Activity	Individual or Group Task	Mode
Ice breaker and group formation: exploration of the fats and associated energy in food snacks using nutrition panels.	Group	Group Discussion
10 min Lecture: 'What is a fat?'	Individual	Didactic Powerpoint
Guided Inquiry: structural representation & formulae of organic molecules	Individual	Drawing
Model Building: construction of scaled physical models of a fatty acid and glycerol using Molymod molecular construction kits. Translation of molecular structure to 2D line structures.	Group	Hands-on (kinesthetic)
Visualisation: manipulation of multiple molecular representations through JMol (open source electronic resource http://jmol.sourceforge.net/).	Individual	ICT-aided visualisation

Table 1: A summary of the activities presented in the blended learning workshop

At the end of the workshop students were invited to complete the post-test (hosted by SurveyMonkey) and submit their workbooks which were audited for completion. Summative assessment relating to the workshop included a component for participation and a component for submission of a brief reflection in response to the statement 'What did you get out of this workshop'?

framed to elicit open responses. Students submitted their reflection via a dedicated blog on Blackboard and these were visible only to the instructor (students were informed that this would be the case prior to submission). Student gains in their understanding of molecular representations were explored through an aligned problem delivered in their peer-assisted study sessions (PASS) and also a question placed in the course summative exam. A mixed methods approach was adopted for the evaluation of the learning experience and the impact of the learning environment. Focus group interviews (N = 7) were conducted with participants who voluntarily responded to an invitation circulated to the whole cohort. There was no control group available for this study as it was intended that all the students in the course should benefit from the activities. Human Ethics approval (UQ application number 2008001508) was granted for this study. Statistical analysis tools (*SPSS* and *NVivo*) were used to analyse the quantitative (pre/post tests) and qualitative (focus group and reflections) data. Pre- and post- test data was correlated through the use of a unique student identifier involving the first two letters of their first name, the last letter of their last name and the two digits representing the date in their date of birth. A paired samples t-test analysis was applied to this quantitative data on the basis that the same participants were tested in the same environment separated only by time during the course of the workshop. The focus group sessions were transcribed by an independent party and then analysed to identify recurring themes which were coded inductively by two analysts separately to identify emerging ideas. Student reflections were analysed by the same approach. All ideas from the qualitative data were cross-referenced and repeating themes identified. These themes were used to develop the nodes for coding in *NVivo* and data is cited as number of references to factors which were identified as important by students.

Results & Discussion

The instructional design of this learning experience was motivated by the desire to provide novice learners with an opportunity to encounter multiple modes of molecular representation (two dimensional molecular structures, molecule construction kits and three dimensional virtual models) in a constructive, peer-supported environment (Wu & Shah, 2004). This design process was informed by cognitive load research literature to minimise the impact of the technology itself on the learning (Carlson, Chandler & Sweller, 2003; Kozma & Russell, 1997; Wu, Krajcik & Soloway, 2001). The provision of multiple instructors (3-4) to reduce technical hurdles and optimise transitions (using the unique facilities of the ACTS) was effective with only minor technical difficulties apparent. Activities were developed to incorporate inductive teaching and learning methods (Prince & Felder, 2006) with elements of guided inquiry and discovery in the tasks. Students progressed through a process of translating between three modes of representation of one specific molecule and were then encouraged to move between the different models collaboratively to promote development of individual mental models and reduce potential saturation of their working memory (Cook, 2006). Multiple themes emerged in this study in relation to the development of a learning community within the cohort and their perceived development of their conceptual models of molecule structure.

Learning Spaces and Learning Communities

As instructors, we are encouraged to take advantage of increasingly more complex learning spaces that are evolving in our tertiary institutions. The ACTS is a new facility which offers multiple technologies and the opportunity to combine collaborative and individual learning activities for students. The ACTS was designed as a space that would foster student-student, student-instructor, and student-course material engagement. Introductory chemistry is a course which does not have a practical component and there are few opportunities for the development of relationships between students and instructors. It was decided that the opportunity to host a blended workshop for these students in the ACTS may provide a route to enhancing the learning community. The challenge for the instructors was to become proficient in rapidly changing information and communication (ICT) technologies such as Web 2.0 applications. Instructional design was effective in that the impact of the technology did not overcome the learning experience. Instructions needed to be clear and transitions between activities also had minimal impact through careful scaffolding. It has been observed that 'intrinsic load is generated by the intellectual complexity of the learning material; extrinsic load is determined solely by how the instructions are formatted' (Carlson, Chandler & Sweller 2003). On completion of a blended learning workshop in the ACTS facility, student reflections were analysed to assess whether there was any evidence of cognitive overload as a result of exposure to new technologies in a 'high technology' room in combination with new learning activities. These reflections may be regarded as 'biased' data as they were elicited for summative marks however the question that they responded to was designed to elicit open responses and student reflections were private, shared only by the instructor. The common themes that emerged were mirrored by those in the focus groups. In terms of the learning space, there was minor evidence of a negative impact of the space or facilities on student learning. This emerged in the form of a frustration in having to tap words letter by letter when logging into their tablets computers (many observed that provision of a keyboard would overcome this hurdle).

> While the technology integrated into the room was initially impressive it turned out to be rather clumsy and frustrating, (what's wrong with a standard keyboard and mouse?) Reflection

> it's good to be able to have the option of drawing on the screen but the keyboard and mouse doesn't go astray Focus Group

Students revealed in their reflections that the impact of working collaboratively with peers in groups greatly outweighed factors relating to the impact of the learning space or technology (Figure 1, below). A preliminary conclusion was that there was a significant positive impact on student learning as a result of peer interactions. The students in this introductory chemistry course are novice learners and their perceptions revealed that the opportunity to exchange ideas and learn from one another was one of the greatest outcomes of the workshop. This was supported through feedback in the focus groups

> I think that sometimes just to talk out a problem that you've got rather than just in your head having your fight with yourself going is this right or is this not right and everyone puts in their 2 cents worth and generally come up with an answer a lot quicker or like if you are stressing out together you don't just do it by yourself. Focus Group

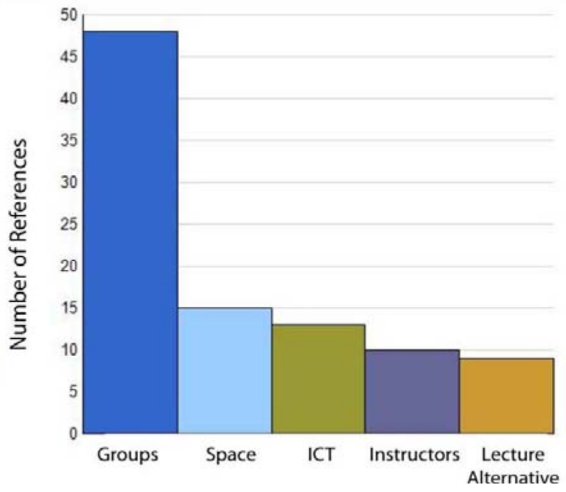

Figure 1: The number of references to each factor which was identified by students as having an impact on their learning.

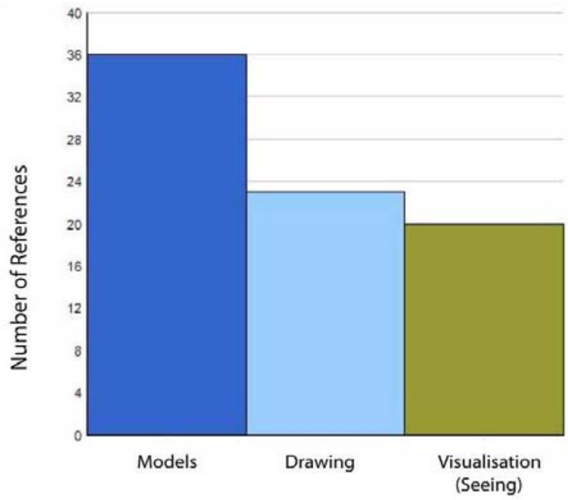

Figure 2: The number of references to each aspect of the workshop which students identified as having an impact on ability to represent molecular structures.

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This outcome supported the design proposal that the ACTS facilities aim to engender peer-peer interactions however the authors note that this success required significant commitment and facilitation by the instructors. The claim that workshop had fostered a learning community through enhanced interactions between students and an instructor was supported by the outcomes of analysis of the pre- and post test data (Table 2). The shift in student perceptions as a consequence of participating in the workshop is significant in response to how these relationships impacted on their learning (η^2> 0.14 represents a significant effect). In contrast, the role of learning through lectures or presentations from instructors was viewed more negatively but this shift was insignificant.

How much have each of the following helped you in your learning in CHEM1090 (so far)?	**Pre**		**Post**		**p**	**η^2**
	Mean	**SD**	**Mean**	**SD**		
Presentations/lectures from course instructors.	**3.85**	0.869	**3.62**	0.885	0.031	0.046
Interactions with other students in class.	**3.05**	1.090	**4.16**	0.703	<0.0005	0.501
Interactions (face-to-face or electronic) with the course instructor(s)	**2.95**	1.067	**3.79**	0.998	<0.0005	0.375

Table 2: Impact of the workshop on learning community relationships recognised by students. (Data represent a five point Likert scale and were analysed via the paired samples t-test).

It was anticipated that an active learning community would be fostered as a result of the workshop because its design had been based on authentic literature. The positive outcomes of active learning are well established (Prince & Felder, 2006) and thus application of these principles to the instructional design was validated. We have represented the students in this study as 'novice' learners in terms of molecular representations; however, Cook (2006) argues that, in terms of prior knowledge, a continuum of expertise will exist in any cohort. While students may not have possessed well developed mental models of molecular structure, their prior knowledge and experience in problem solving promoted engagement in inquiry learning and the development of the learning community.

Conceptual understanding of molecular structure

The primary learning objective of the workshop was to provide students with active learning opportunities which might enable them to increase their understanding of molecular structures and acquire skills in the translation between 2D and 3D representations. At the commencement of the workshop 65% of the students were able to draw the correct line structure for 2-methylhexane (Paint files), common mistakes included incorrect structural representation and the inclusion of too many carbons. In the post-workshop PASS assessment question which required the translation of a line structure of palmitoleic acid into the expanded structure, 60% of students translated between the structures correctly. The most common error was incorrect representation of the carboxyl functional group (23%) while correctly representing the double bond. Several students attempted to insert an additional carbon into the –OH functionality indicating that they had not acquired the concept of line (skeletal) structures. In the final exam, a question was placed which required students to name a molecule (hexane), which was provided in both line and space-filling representations, explain the difference between the two representations and finally to propose, draw and name a structural isomer. 37% of students presented completely correct responses, 43% were partially correct and 20% were incorrect. Of the partially correct responses, 98% had correctly completed the recognition and discrimination of the representations of hexane however they had failed to identify and represent the structural isomer. The lecture introduced the concept of isomers was delivered 11 days after the workshop and was designed to build on the learning from the workshop. It would appear that while students became fluent in translating between different representations, they were not able to extend the concept to the rearrangement of the atoms. This aspect of molecular structure was deliberately excluded from the workshop content to avoid overload.

The feedback from students (reflections and interviews) indicated that the workshop had enhanced their ability to visualise molecules. (Table 3 and Figure 2).

	Pre		Post		p	η^2
	Mean	**SD**	**Mean**	**SD**		
How well do you think you understand drawing structures of molecules?	**2.91**	0.830	**3.83**	0.667	<0.0005	0.550
Given the formula for a molecule, how confident are you at visualising or picturing its shape?	**2.40**	0.804	**3.39**	0.741	<0.0005	0.601

Table 3: Impact of the workshop on student confidence in molecular representations (A five point Likert scale was applied and data analysed through application of the paired samples t-test).

In particular, students indicated that the process of constructing molecules using ‘hands-on’ molecular models had helped them to discriminate the different types of bonds. This outcome aligns with accepted theory that the provision of exercises which draw on our existing schema (eg. building with blocks/lego) enable processing of molecular models and reduction of cognitive load (Carlson, Chandler and Sweller 2003). The mere act of physically constructing a molecule had a positive impact on concept construction. The benefit of using the hands-on construction models to visualise molecules was the most cited factor in student feedback from reflections (Figure 2).

> Before attending this workshop I had very little idea as to how to convert or change between condensed structural formulas, expanded structural formulas, skeletal structures and ball and stick models. After attending the workshop I found it's a very simple process and can do it with ease Reflection

There was also evidence that the process of several groups cooperating to complete a condensation reaction to form a tristearate molecule using the hands-on models promoted concept construction. Students could hold the water molecules which were produced as a result of the reaction reinforcing what had been previously an abstract concept represented by symbols on paper.

> I’m not sure about other peoples groups but it took a lot of effort actually counting the several carbons across to put this methyl group on and .. like muck it around a few times so it was like really good to make mistakes and learn from them and like when they were joining them together to make the fatty acid … stuff had to break off carbons to make water and stuff like that…. Water, sorry like hydrogens and oxygens you saw that, yeah, like you did have to break these two off and they did like make water and so, I like reckon construction too Focus Group

Students demonstrated high levels of engagement and interest across all the activities during the workshop and as such appeared to participate in a learning cycle as they constructed their understanding. Their confidence in their ability is supported further by their feedback in their reflections

> By constructing molecules with the modeling equipment (ball and stick) and using the 3D visualisational program on the internet made it easier for me to understand atomic structure, as I was able to see rather than just imagine in my mind Reflection

An interesting misconception that emerged through the focus group feedback from a single student related to visuospatial thinking and dynamic model development. He had viewed what he termed the “website” (Jmol application) 3D representation as the “correct” model and he implied that, because the hands-on “3D” model could be “twisted” or made “compact”, it was a deficient model

> like once again the 3D model makes you realise that it is in 3D… but it's very difficult to work out where, how it would sit. Because you can twist everything and it can all be either be compact or elongated so like with the website they showed like how the actual molecule would be in 3 dimension and like that was probably the most useful. Focus Group

In fact, the virtual 3D representation is a partially inaccurate model because it is linear and rigid (designed to enable correlation with hand drawn representations) and the hands-on models are mobile and fluid which make them more representative of a 'real' molecule. Students were encouraged to rotate and 'scrunch' their physical models to imagine what might prevent a molecule adopting particular conformations. It is well established that many students may possess cognitive difficulties in visuospatial thinking (Wu and Shah 2004) and when faced with dynamic models, they may not build connections. The single occurrence of this event in this study perhaps indicates that the combination of molecular representations has enabled students to acquire visuospatial abilities.

Summary

The combined evidence indicates that students gained in their confidence and their ability to recognise and translate between different representations of molecular structure. However, the application of their knowledge to related ideas such as isomerism did not occur in the subsequent assessment tasks. The blended learning workshop provided a positive learning experience which promoted active learning through peer interactions and multimodal representations of molecular structure. There was strong evidence of the development of a learning community fostered by the ACTS learning environment.

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