Chemistry Education Research and Practice

PAPER

View Article Online
View Journal | View Issue

Cite this: *Chem. Educ. Res. Pract.*, 2015, **16**, 293

What are we going to do about a problem like polymer chemistry? Develop new methods of delivery to improve understanding of a demanding interdisciplinary topic

G. Cavalli,[a] I. Hamerton[a] and S. Lygo-Baker*[b]

Received 30th September 2014, Accepted 4th February 2015

DOI: 10.1039/c4rp00203b

www.rsc.org/cerp

Following collaboration between two chemistry lecturers and an academic developer an attempt was made to enhance the learning of students within a chemistry module through the adaptation of the delivery of content material. This paper reports a piece of practitioner led research which considered how effective the approach developed was upon the level of student understanding and the process through which this occurred. The module delivery was altered from an emphasis on the transmission of knowledge through a traditional lecture format, to rotating small group problem based sessions and the use of concept maps. Student feedback and higher grades achieved appear to demonstrate it was effective.

1. Introduction

This paper reports on the development of a piece of inter-disciplinary collaboration based on the implementation of a combination of pedagogical innovations to teaching an optional polymer chemistry module to a combined class of final year undergraduate students following BSc and MChem programmes. The decision to make changes to the delivery of a module that had been running for 8 years came as a consequence of discomfort from the teaching team which consisted of two lecturers. A collaboration with an academic developer led to an articulation of the discomfort, which appeared to be three fold. First, there was concern that the traditional approach for teaching the module, based around a series of two one-hour, weekly lectures, was felt not necessarily to be the most effective approach for the learners. Second, the teaching staff found that the traditional approach was no longer challenging for them and may have been having a negative effect upon their own approach within the learning environment. Third, the nature of the module was interdisciplinary and this provided a significant challenge. The teaching team were interested to investigate whether an alternative approach could alleviate some of the traditional difficulties faced in interdisciplinary teaching (Godemann, 2006).

Despite lecturers being in the most appropriate position to describe knowledge in relation to the learning being approached, it has been suggested that they often struggle to find suitable 'entry-points' for the learners (Preszler, 2009). This was a position described by the two lecturers. This is perhaps not a great surprise. Lecturing staff who have been successful in their journey are attempting to relate back to a position where many learners are struggling with conceptual knowledge that has subsequently come to be understood by the teacher. Relating back to the uncertainty felt by the learner can be challenging for a teacher and yet is vital given that 'teachers regulate the learning out-comes of students through their teaching activities' (Virtanen and Lindblom-Ylanne, 2010, p. 356). In addition, the subject of the module required interdisciplinary understanding, which is known to be challenging for learners, particularly as they undergo socialization into the discourse of a particular dis-cipline which may have a tendency to narrow down rather than branch out (Woods, 2007).

It is likely that the learners are also on a very different trajectory than that experienced by a lecturer. The different cognitive maps held make relations between a lecturer and student potentially troublesome and connections difficult to formulate. The lecturers in this study noted that they wanted to be able to more effectively connect the students directly with the knowledge, rather than always through them, as had been the traditional approach (Palmer, 1998). They were able to articulate a disjuncture they felt was apparent and were keen to adopt an alternative approach in an attempt to enable the students to connect and to engage themselves as learners within the process.

1.1. Situation

"The continued growth of the polymer field in the chemical world has meant that educators are now faced with the challenge of finding innovative ways to introduce these materials within

[a] *Department of Chemistry, University of Surrey, Guildford, Surrey, GU2 7XH, UK*
[b] *Department of Higher Education, University of Surrey, Guildford, Surrey, GU2 7XH, UK. E-mail: s.lygo-baker@surrey.ac.uk; Tel: +44 (0)1483 683350*

the context of the undergraduate chemistry curriculum'' (Hodgson and Bigger, 2001, p. 556). The Chemistry programmes at the University of Surrey have included Advanced Polymer Chemistry as an optional module for students in the third (FHEQ6) year or completing a Master in Chemistry (MChem, FHEQ7).† The module traditionally attracts approximately 30 undergraduate students (of whom 25% tend to be Masters level). The module itself had a 10 credit value and therefore nominally accounted for 100 learning hours. It was assessed by coursework (30%) and a 1.5 hour examination (70%). The lecturing staff working on the module had worked together for 4 years, taking responsibility for particular aspects of the module. The approach taken heretofore was the delivery of several one-hour weekly lectures followed by a tutorial. The concerns expressed by the lecturers were those commonly held across universities. The range of understanding varied, as did motivation and attendance. Although the overall success of students was not a concern the lecturers felt that a move away from a traditional transmission model of often complex conceptual knowledge towards an approach that allowed the students to determine what counted as valid knowledge would be of benefit. Rather than placing an emphasis upon learning how to learn, the lecturers believed it was important to acknowledge that the group were experienced in learning. The intention was therefore to move to an emphasis based on understanding how they had learned relevant information (Barnett and Coate, 2005). The lecturers explained that there was a tendency for students not to demonstrate the relational aspects of the knowledge or an ability to abstract information that are found within the SOLO taxonomy (Biggs and Collis, 1982).

On a broader picture, concerns have been expressed that the teaching of chemistry needs to embrace more innovative methods to encourage learners to study the subject and maintain motivation. For example, the European Chemistry Thematic Network in 2006 looked at innovative methods of Chemistry teaching. They suggested ten potential ways for innovating and by implication enhancing the quality of student learning. These included context and problem based learning, research-based teaching and learning and cooperative learning. Johnstone, in the 1996 Brasted Lecture, argued that teaching and research should have ''essentially the same structure'' (p. 262). It is clear that new pedagogical approaches are being applied, such as concept mapping (Burrows and Mooring, 2014), flipped classrooms (Fautch, 2014) and problem-based learning (Overton and Randles, 2015). It was partly in response to these and also using these as context, that a revised approach, looking to incorporate some of the suggestions above, was developed within this module.

1.2. The revised approach

Through a series of meetings with an academic developer the two lecturers devised an approach that aimed to shift the focus of the module away from a premise that content needs only to be transmitted or delivered. Instead it attempted to challenge the notion that little attention is paid to the curriculum (Barnett and Coate, 2005). During the discussions on the redesign it was apparent the two lecturers felt that they were providing 'voice overs' and delivering a set of 'facts' to an audience. This, it was believed, stifled interaction and limited the dialogue between teacher and student, and also between students. There was concern that many of the students had managed to get to final year and masters level study without needing to alter or develop their approach to learning significantly. It was felt that this may limit problem solving abilities and the ability to work collaboratively; aspects which have been increasingly cited as expected graduate outcomes (Andrews and Higson, 2008; Lowden *et al.*, 2011). The lecturers were concerned that this led to a situation that when faced with conceptually challenging material it was the lecturers who increased their effort to establish understanding, whereas there was a corresponding drop off by the students. The result, according to Eilks and Byers (2010, p. 234) is therefore a need ''not merely to teach better, but also to teach differently''. If, as constructivists argue, learning is an active process (Burke *et al.*, 2009), then to promote this activity there needs to be a shift from what we as teachers are doing and focus more upon what we expect our students to be doing. In addition, the lecturers shared Knight's view that a higher education should be ''about complex learning'' (Knight, 2001, p. 369), and that this needs to be undertaken by the students, rather than repeated annually by themselves as lecturers.

Rather than have one hour lectures followed later in the week by tutorials, the lectures were replaced by a series of problem based sessions that were set around small group interactions. The students were divided into groups to work on possible solutions to a range of related topics. The membership of the groups rotated each week, through the thirteen weeks so that during the module each student worked with every other member of the class. This was explained to the students to ensure that they had the opportunity to work with everyone so that strengths and weaknesses could be distributed. This was seen as particularly important when marks were being assigned and would respond to the complaint some students had over being in a 'weaker' group. In addition, the approach was justified as a way of reflecting that in employment they are likely to become members of different teams for different tasks and often unable to select with whom they work. The solutions produced were handed in at the end of each week and a mark assigned for each group. Preszler (2009), like Tien *et al.* (2002), found that small group working did enhance learning and in particular examination results in chemistry. In addition, it has been suggested that small group work in chemistry can ''promote a feeling of community among the students and the formation of mutual commitment and mutual goals among group members'' (Towns *et al.*, 2000, p. 112). There is also an important element of the development of trust between members of the group, which may be significant, although this can also be challenging within an environment which ultimately provides an individual assessment of progress. The principles underpinning these changes have been used in chemistry education and were drawn from both problem based

† Another optional module 'Introduction to Polymer Chemistry' was offered in second year (FHEQ5) and stipulated as a pre-requisite for this module.

learning (Overton and Randles, 2015) and the notion of the flipped classroom (Fautch, 2014).

Of fundamental important was to develop knowledge structures through discussion and to move towards notions embodied within curriculum as process (Stenhouse, 1975). To achieve this it was intended to shift the focus of the interactions between the students, the lecturers and the knowledge. It was hoped that through this shift in approach different learning opportunities would arise, with greater opportunity for peer learning through increased interaction that was not always directed through one of the two lecturers. This would not be at the expense of important concepts but, rather like the argument of Whitehead (1928), it would allow facts to be examined and different possibilities related to these to be explored.

There can be concerns with such an approach. The first is that there is a potential difficulty with consistency. It allows students to take different approaches and paths to arrive at different conclusions and the lecturers need to be able to respond to this. The model therefore relies upon the quality of a lecturer as a facilitator. The lecturer needs to allow the students to develop and articulate meaning and be comfortable that this can occur. Within this approach there is a concern that the traditional exam is unlikely to be able to deal with the complexity of the learning that has occurred. Cornbleth (1990) argues that when developing learning opportunities you need to consider what actually happens in classrooms, that is the, 'ongoing social process comprised of the interactions of students, teachers, knowledge and milieu' (1990, p. 5). In order to undertake effective learning however, Cornbleth argues that you need to pay attention to the particular setting or context you are to teach in. In this case, the changes that were made had to be undertaken within certain limitations and the particular context did not allow the flexibility to alter the final examination structure as this was part of a wider assessment strategy.

A major challenge was the fact that this revised approach presented a sizable change to the practice that the students were used to: given in particular that these students were third year and masters level students. It was therefore agreed that the first week should be used to explain the new approach and the rationale behind the change. The lecturers appreciated that the shift was significant and therefore there needed to be an opportunity to allow the students to discuss the approach and voice concerns. It was felt that another pedagogical approach, the introduction of concept mapping (Novak and Gowin, 1984), could be of benefit with this shift (Hay *et al.*, 2008).

Given the complexity of the knowledge within the polymer chemistry module it was felt that helping students to explore their knowledge structures using concept maps (Burrows and Mooring, 2014) could be useful. It was hoped that introducing the students to concept mapping at the start of the module would help the students visualise their understanding of polymer chemistry. Initially one part of the initial session was used to demonstrate how maps could be constructed and then the students were provided with post it notes and a large piece of A3 paper. Each constructed an initial map to show their appreciation of aspects of polymer chemistry. This was designed to enable the lecturers to gain an indication of how sophisticated the initial knowledge held was. Although the students were 'novices' in respect to the lecturers, they already possessed knowledge of a range of different concepts. An intention of the redesigned approach was to recognize that they were developing their own 'expert' frames of reference in the module. As such, an objective was to recognize what Anderson and Schonborn (2008) have suggested are the different stages towards the creative phase that helps to demonstrate expert understanding, which it was believed the mapping would help enhance. The first is 'mindful' memorization. This is the ability to take information with a view to making sense of it. Information is taken on with the express intention to discover its meaning. Once this has been achieved a second stage is to begin to put these pieces of memorized information together to begin to patch together a meaningful network. The final key stage is that the integration with other ideas and memorizations forms new conceptual frameworks. It was hoped that concept mapping would support this development, as the maps became more sophisticated networks (Hay *et al.*, 2008) that could be explained by each learner. The initial maps made were therefore revisited halfway through and at the end of the module, allowing students and lecturers to see how their understanding and meaning making were developing. It was hoped that mapping would allow the visualisation of student understanding showing how connections were being developed, so that there was greater evidence of a move from pre-structural understanding towards more relational and abstracted understanding (Biggs and Collis, 1982).

2. Methods

The intention of revising the approach for this module was to imagine how to draw together the processes, experiences and connections that help to make learning effective. It was acknowledged that the processes depended upon what was to be learned: in this case polymer chemistry.

The revised approach provided an opportunity to examine the impact shifting the emphasis of delivery from a more traditional approach (fairly didactic, lecture and tutorial) to a more student centred one (using principles drawn from problem based learning and the flipped classroom) had upon the learning process of the learners. Using the principles of action research this built on changes previously incorporated by the two lecturers and sought to more closely analyse the outcomes. The intention was therefore to consider the impact of the incremental changes in this particular cycle and adapt for the future, using an action research approach (McNiff and Whitehead, 2002). The intention was to examine a real iteration as it was undertaken, rather than a contrived one, and allow the practitioners to improve their understanding, adapting for future iterations. As the research was a practitioner led enquiry that aimed to improve practice it was felt that using the principles of action research would be a useful guide to adopt and would build on previous changes made.

Given the nature of the research, involving human subjects, discussions around the ethics of the approach were paramount.

Although the actions were within the institutional guidelines and there was no necessity to seek ethical approval it was felt important to hold open discussions with the students (in this situation the subjects) about the changes being implemented. It was through these open discussions that it was agreed that all the material generated by the participants in their maps would not be made public.

The data collected came from four main sources. The first were the concept maps constructed in the first, middle and last sessions. Students were asked if they were willing to share these each time so that change in knowledge structures over time could be identified. All the students involved agreed to this. The maps were analysed by the two chemistry lecturers to consider change in knowledge structures, additional concepts and those that were missing. After reviewing them they were returned. Secondly the observations of the two teaching staff were considered as they interacted over the module, including their experience of the quality of the interactions and the sophistication of the arguments being developed by students. These observations were considered in meetings between the three lecturers, with the academic developer noting the key observations made. Third, the students were invited to discuss the experience with the academic developer to feedback their experiences on a voluntary basis on three occasions, to which all agreed and engaged. These discussions happened at three stages during the process (the outset, half way through and at the conclusion). Finally, student performance was examined by consideration of the marks achieved. Whilst it is acknowledged that no generalisations can be drawn from the results it was intended to provide insight into the process and enable further refinement of the approach.

The intention therefore was to examine active and collaborative working that was to be encouraged to try and combat a situation that has been described where ''undergraduates have to create coherence out of curriculum disintegration'' (Knight, 2001, p. 371). There was an acknowledgment that the coherence that comes through sharing insights and practices makes use of both the explicit and learning that is less conscious and yet is drawn from what we do (Eraut, 2000). The research would examine an attempt to establish a learning environment which aimed to support a different approach within which it was expected that the students would interact within areas of similarity and present negotiated ideas to the 'experts'. The refinement of ideas using discussion may be powerful for not only bringing forward more considered and articulated understanding but also to allow the learners to develop additional knowledge that would otherwise remain hidden (Brookfield and Preskill, 1999). It may allow a clearer bridge to develop between the various 'novices' and the 'experts'. Student understanding therefore ''develops through the course of communicating ideas and interacting with others'' (Tien *et al.*, 2002, p. 608). It has also been suggested that small-group learning activities, such as those used in this module, can lead to positive outcomes, such as higher self-esteem, increased positive views of the subject matter and greater achievement (Towns *et al.*, 2000).

3. Results

During the three months over which the module was run‡ the students worked through a series of problems each week and had opportunities to feedback upon the experience so that revisions could be made to the approach. The questions developed were based around the key topics that had previously been taught, although these have been revised so that the emphasis is on the key principles involved. It was evident, particularly at the outset, that there was discomfort felt by the students. In discussion with the academic developer at the outset this appeared to come predominantly from concern over a need to adopt a different approach to learning. Interestingly when asked to reflect upon the experience afterwards the students noted that they believed that the approach required them to undertake more learning and that it took up greater amounts of time to work in this way. However, they believed that it was in their interests to adopt this approach and that it was a reasonable expectation. During this time the staff were always available to support the learning, to help offer suggestions and advice and provide additional information. In response to concerns expressed by some of the students relating to the need for additional support, a series of 30 minute videos and podcasts were made to supplement information available elsewhere.

It was clear from observing the class that there was a significant amount of conversation between students and also with the lecturers. A series of discussions would occur each week and the students were significantly more active in the learning environment than in the traditional lecture format. As has been found by studies looking at how social networks develop (Hommes *et al.*, 2012), it was evident that working in small groups led students to assist each other to learn and that as a consequence the learners did develop new relationships that were perceived by them as positive. Rather than storing up content knowledge gained exclusively from the lecturers, the students were negotiating and collaborating using the joint knowledge held within the group to offer solutions (Mazur, 1996). From observation it was clear that the students were using and applying knowledge, something that it has been argued is crucial to effective learning (Anderson and Schonborn, 2008).

It was interesting to note that, as Cornbleth (1990) had contended, the context was important. This was evident in two significant ways. First, the students noted that there were times when the requirements of other modules had a significant impact on their ability to organize the time required to undertake the amount of work necessary to complete the tasks for the module. It was evident that assessment, which is seen to drive learning (Boud, 1988), often occurred at similar times across modules and meant a dip in engagement. This was described by the students as encouraging a strategic response, which rather than being based upon a desire to engage with material, merely encouraged a deliberate approach based on doing 'enough' to be successful. Additionally, the change of location caused by timetabling challenges meant that the class

‡ The module is delivered and evaluated within a 15 week semester period.

moved away from a room where small group work was easier, to an old-style tiered lecture theatre. This certainly detracted from the ability to work in small groups and from observation had a corresponding effect upon levels of engagement.

From observation the lecturers reported that it was evident that the sophistication of understanding demonstrated by student interaction was developing through the module. Students were increasingly drawing upon a wider breadth of knowledge and this was also witnessed when the concept maps that students drew initially, during and at the end of the module were compared. These showed how isolated areas of knowledge were being drawn together, to demonstrate more integrated and sophisticated networks of understanding that could be described by students (Kinchin *et al.*, 2008).

These observations occurred through teaching the programme and reflected the events witnessed by the three lecturers involved. However, there was significant interest in whether the approach would have any significant impact – either positive or negative – upon the actual attainment of the group when they had completed the module assessments. Although it is acknowledged that direct comparison cannot be made as the group of students involved each year within the module was different, it was felt that comparing the in module marks, coursework and final marks from the examination over a four year period would at least allow indicative conclusions to be drawn.

Fig. 1 shows the results for students since the module has been run. The first line provides the overall combined cohort (FHEQ6 and FHEQ7), followed by the FHEQ6 and FHEQ7 cohorts. The next layer provides the module, exam and coursework scores. Error bars show 1 STD +/− within each sample. It appears that there is not a marked changed, suggesting that the shift in the delivery method has not significantly altered the immediate outcomes for the students.

Fig. 2 and 3 show the same results but are arranged differently: % of students within each class who passed the module/component (considering a 40% pass mark for FHEQ6 and a 50% pass mark for FHEQ7). Again, shown in overall module, exam and coursework and combined cohorts. Fig. 2 shows % pass of all components per year and Fig. 3 is the same data but grouped per component (to compare the year). When considered carefully differences begin to appear. First, the cohort from year 3 were a strong group, particularly the Masters students. The exam passes overall however are extremely high in comparison, particularly for the third year cohort who had engaged in the new approach.

4. Discussion

It is acknowledged that the results can only be indicative at this stage. However, it does appear that the shift from a more traditional transmission model of delivery to one oriented around problem solving with peers had no adverse effect. It appears, on the contrary, to have been beneficial. This is perhaps surprising given that this was an isolated occurrence and as the students noted, different from their previous experience. One area of concern for the lecturers had been whether, at this later stage of university experience, introducing a new approach would prove to be too uncomfortable. The evidence from this preliminary study

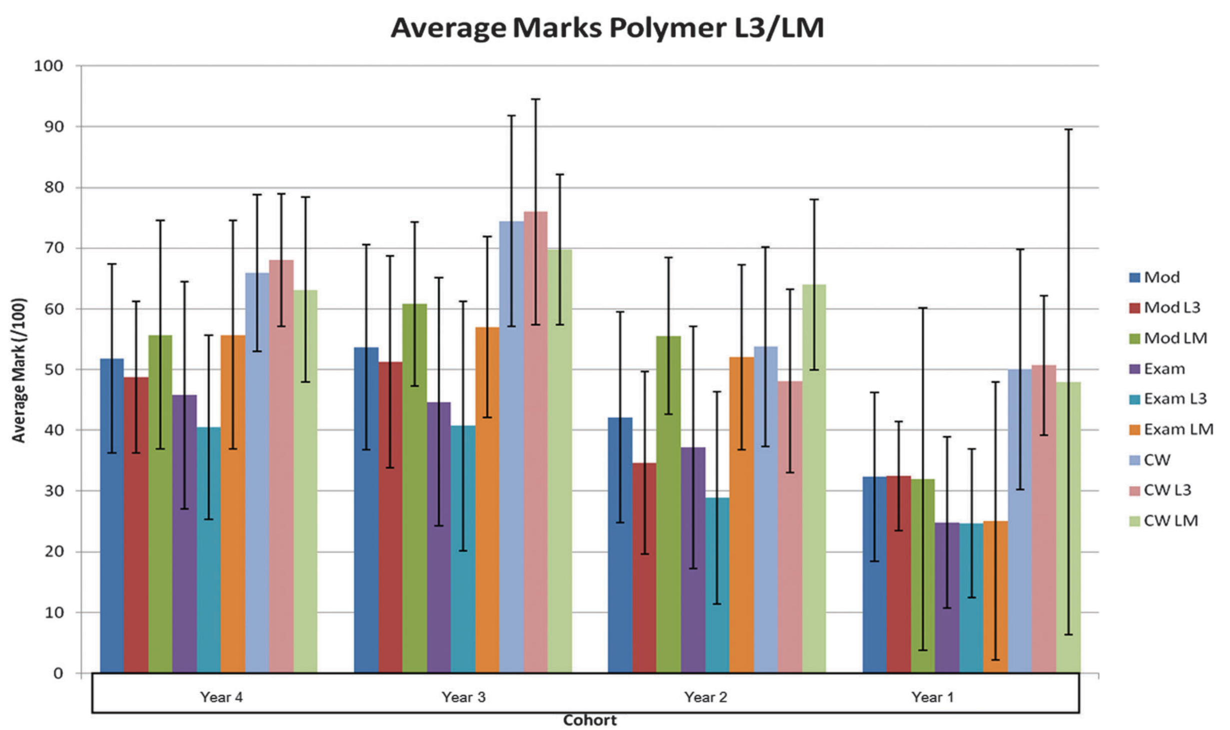

Fig. 1 Average marks polymer L3/LM.

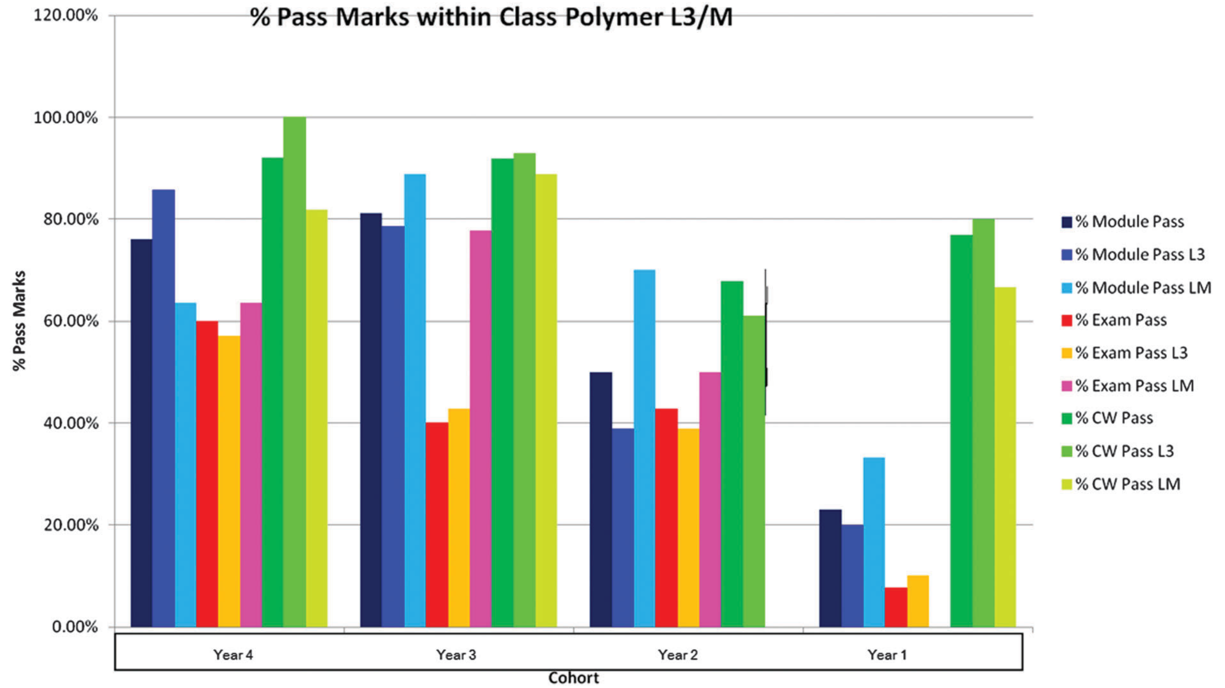

Fig. 2 % Possible marks within class.

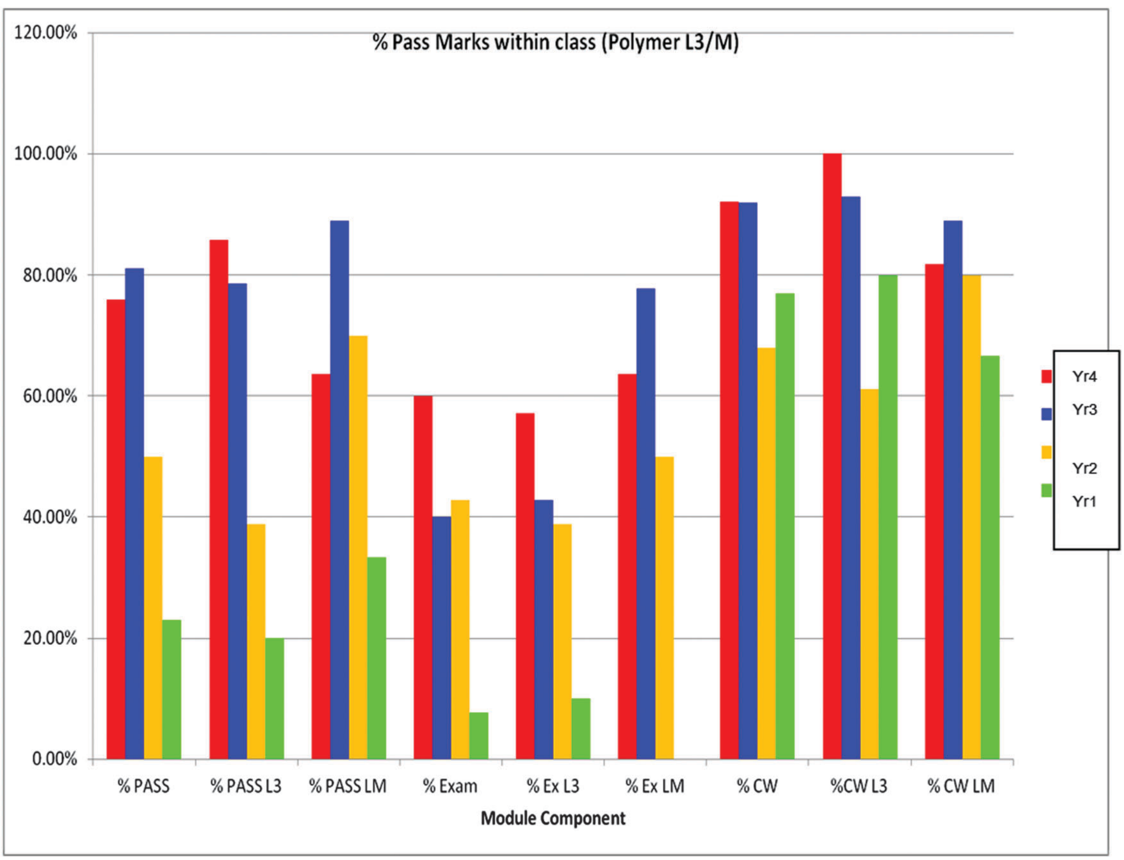

Fig. 3 % Pass marks within class.

suggests that it is not but that if this approach were to be utilised earlier within the curriculum then greater reward might occur.

The new design was put in place with an aim of ensuring that students would not merely reel off knowledge and information, but would be able to use this new or existing knowledge (Anderson and Schonborn, 2008). This is of particular importance because of the nature of science knowledge. Students studying sciences need to understand that the subject matter is dynamic and is constantly being refreshed and added to. As such, the cognitive skill needed for 'expert' knowledge develops over time. The basis for this module delivery redesign was to acknowledge this dynamism and therefore create a learning environment within which this was more authentic.

When we talk about experts we suggest that they possess the ability to make connections and use frameworks through which to conceive of knowledge in complex ways; novices struggle to do this. It has been suggested that experts have the capacity to do this with an understanding of core concepts and allow knowledge structures to be developed, whereas novices have far more fragmented knowledge (Anderson and Schonborn, 2008). It is in this regard that Novak (1998) has suggested that allowing experts to construct concept maps can be a useful tool for highlighting areas of tacit knowledge that may help explain to others how their sophisticated understandings develop. We also found that allowing novices to construct concept maps over time, also showed the potential for the students themselves, and the staff working with them, to demonstrate that the construction of meaning develops, not in uniform ways necessarily or following the same pattern or structure. As such, the movement from novice toward expert can be tracked and is not an either/or but a continuum that is multi-layered and constantly being developed and revised.

What the concept maps also indicated was a potential concern that many students may not possess the background knowledge required or anticipated. A key objective of the module was for the students to develop the capacity to go beyond remembering and recognizing information and become creative and articulate with this. It was intended that working together with peers might help to overcome the gaps in individual knowledge. Ausubel (1963) has argued that meaningful learning can only occur when a student has sufficient prior knowledge to be able to use additional information to attach this to. The intention was that by working with peers knowledge could be transformed by each student.

The maps also suggested what concepts that the students brought with them, which were retained, were added to and which ones were viewed as the most central. In the future these may be useful for the identification of threshold concepts, something distinct within the typical core material that goes beyond being a mere building block (Meyer and Land, 2003). It may therefore be useful to consider the notion of threshold concepts, where frameworks become the outcome of the expert knowledge demonstrated and without an understanding of a learner cannot progress effectively within a particular discipline. It has been suggested that a "deep understanding of the role of the (random) emergent processes in biology and chemistry is fundamental, and that once students understand these processes, their view of the discipline changes dramatically" (Loertscher, 2011, p. 56). The difficulty for this work may have been, as Loertscher argues, that more needs to be undertaken initially to assist students with understanding key threshold concepts so that the ability to then combine these and develop more complex and useable frameworks could be more easily developed and adapted. The suggestion is that, at present, this does not occur and although this study attempted to develop more sophisticated networks of knowledge, it is difficult to ascertain whether the approach was successful.

One of the significant shifts undertaken in the revised module delivery was away from a transmission mode using principles of the flipped classroom. This reduction in direction provided by the lecturer can be a concern. Kirschner *et al.* (2006) warn against moves towards minimal guidance. They argue that expecting individuals to solve problems and construct solutions from the knowledge that they have is unrealistic. The process is based on the assumption that knowledge can be gained through experience of the processes of the discipline, in this case polymer chemistry. Advocates of the constructivist approach suggest that learners can develop a way of learning that allows knowledge to be built up and yet this is challenged by Kirschner *et al.* The intention of the approach taken was to acknowledge that students were not expert in the discipline and yet have the ability to inquire and offer solutions, particularly by working collaboratively with peers (Mazur, 1996). It was reasoned that as third and masters year students they would already possess knowledge that could be used as well as experience of the process used within the discipline and would therefore not be the novice learner that first year undergraduates would be. It may therefore be reasonable not to expect students to learn effectively from the outset of their undergraduate careers with minimal guidance. However, with support from peers, lecturers and their own knowledge the move towards less transmission would appear to be sui given the evidence from this research.

Such a transition to student-led learning has to be handled carefully. Students' appreciation of their own levels of understanding can often be misleading (Brookfield, 2001). For example, when students are asked why they have not achieved as well as they anticipated in assessment tasks they are often unable to explain why. They believe that they understood the material in class and are therefore unable to explain why they are less capable of using this knowledge effectively on a later occasion. It may be that their own conception of their learning progress is flawed (Eilks and Byers, 2010). The knowledge held by the student, even if they believe that they have followed the information presented in the learning environment, may prove to be insufficient. This occurs particularly when presented with a problem that does not immediately mirror that outlined when the information was first encountered. Indeed, Meyer and Land (2003) suggest that the discourse within a discipline may render what is known less intelligible and therefore conceptually difficult. It makes teaching difficult in that one is also trying to help people master a language and thought process which of itself provides metaphors and concepts in various plays on ideas and thought. The approach in this module was to allow the voice of the teacher to be there to support and help build knowledge from the language provided by the students wherever possible. The challenge reported by the lecturers was to help support the development of conceptual understanding from the discourse used by the students, rather than the other way around.

5. Conclusion

The learning gained from this piece of work was initiated by a common concern raised by many including Johnstone (1997), who reflects the lecture as teaching method has not been used effectively. The concern was that the more information given to the students, the less efficiently this was being recorded and then used. The lesson, often cited in universities but seemingly not always acted upon, is that giving *less* to the students may actually mean they end up learning *more*. Although this was a small study and the results are only indicative, they have demonstrated a number of important areas for further consideration and future work. First, shifting an approach from traditional lecture based material to smaller problem-based group tasks appears to have increased the quality and depth of understanding; it certainly has not had a detrimental impact. Observing the sessions it was clear that the students engaged, were active and reflected that they believed it was an effective way for them to learn. In addition, the lecturers found the process more engaging for themselves, giving them the opportunity to observe and engage with learners in new ways that required greater flexibility but was developmental for them. As Tien *et al.* (2002, p. 627) have demonstrated given an opportunity ''students can provide a powerful new force in their own education''.

References

Anderson T. R. and Schonborn K. J., (2008), Bridging the educational research-teaching practice gap, *Biochem. Mol. Biol. Educ.*, **36**(4), 309–315.

Andrews J. and Higson H., (2008), Graduate Employability, 'Soft Skills' Versus 'Hard' Business Knowledge: A European Study, *High. Educ. Eur.*, **33**(4), 411–422.

Ausubel D., (1963), *The psychology of meaningful verbal learning*, New York: Grune & Stratton.

Barnett R. and Coate K., (2005), *Engaging the Curriculum in Higher Education*, Maidenhead: SRHE/OU Press.

Biggs J. and Collis K., (1982), *Evaluating the quality of learning: the SOLO taxonomy*, New York: Academic Press.

Boud D. (ed.), (1988) *Developing student autonomy in learning*, 2nd edn, London: Kogan Page.

Brookfield S., (2001), Through the Lens of Learning, in Paechter C., Edwards R., Harrison R. and Twining R. (ed.), *Learning, space and identity*, London: Chapman.

Brookfield S. and Preskill S., (1999), *Discussion as a way of teaching*, Buckingham: SRHE/OU Press.

Burke K., Lawrence B., El-Sayed M. and Apple D., (2009), Process Education – Past, Present and Future, *Int. J. Proc. Educ.*, **1**(1), 35–42.

Burrows N. L. and Mooring S. R., (2014), Using concept mapping to uncover students' knowledge structures of chemical bonding concepts, *Chem. Educ. Res. Pract.*, **16**, 53–66.

Cornbleth C., (1990), *Curriculum in Context*, Basingstoke: Falmer Press.

Eilks I. and Byers W., (2010), The need for innovative methods of teaching and learning chemistry in higher education – reflections from a project of the European Chemistry Thematic Network, *Chem. Educ. Res. Pract.*, **11**, 233–240.

Eraut M., (2000), Non-formal learning and tacit knowledge in professional work, *Br. J. Educ. Psychol.*, **70**, 113–136.

Fautch J. M., (2014), The flipped classroom for teaching organic chemistry in small classes: is it effective? *Chem. Educ. Res. Pract.*, **16**, 179–186.

Godemann J., (2006), Promotion of Interdisciplinarity Competence as a Challenge for Higher Education, *J. Soc. Sci. Educ.*, **4**, 51–61.

Hay D., Kinchin I. and Lygo-Baker S., (2008), Making learning visible: the role of concept mapping in higher education, *Stud. High. Educ.*, **33**(3), 295–311.

Hodgson S. C. and Bigger S. W., (2001), Studying synthetic polymers in the undergraduate chemistry curriculum, *J. Chem. Educ.*, **78**(4), 555–556.

Hommes J., Rienties B., de Grave W., Bos G., Schuwirth L. and Scherpbier (2012), Visualising the invisible: a network approach to reveal the informal social side of student learning, *Adv. Health Sci. Educ.*, **17**, 743–757.

Johnstone A. H., (1997), Chemistry Teaching – Science or Alchemy? *J. Chem. Educ.*, **74**(3), 262–268.

Kinchin I., Cabot L. and Hay D., (2008), Using concept mapping to locate the tacit dimension of clinical expertise: towards a theoretical framework to support critical reflection on teaching, *Learn. Health Soc. Care*, **7**(2), 93–104.

Kirschner P. A., Sweller J. and Clark R. E., (2006), Why minimal guidance during instruction does not work: an analysis of the failure of constructivist, discovery, problem-based, experiential and inquiry-based teaching, *Educ. Psychol.*, **4**(2), 75–86.

Knight P. T., (2001), Complexity and curriculum: a process approach to curriculum-making, *Teach. High. Educ.*, **6**(3), 369–381.

Loertscher J., (2011), Threshold Concepts in Biochemistry, *Biochem. Mol. Biol. Educ.*, **39**(1), 56–57.

Lowden K., Hall S., Elliot D. and Lewin J., (2011), *Employers' perceptions of the employability skills of new graduates*, London: Edge Foundation.

Mazur E., (1996), *Peer instruction: a user's manual*, Prentice Hall: Upper Saddle River.

McNiff J. and Whitehead J., (2002), *Action research: principles and practice*, 2nd edn, London: RoutledgeFalmer.

Meyer J. and Land R., (2003), Threshold Concepts and Troublesome Knowledge – Linkages to Ways of Thinking and Practising, in Rust C. (ed.), *Improving Student Learning – Ten Years On*, OCSLD: Oxford.

Novak J., (1998), Learning, creating and using knowledge: concept maps as facilitative tools in schools and corporations, Mahwah, N.J.: Lawrence Erlbaum.

Novak J. and Gowin D. B., (1984), *Learning How to Learn*, Cambridge: Cambridge University Press.

Overton T. L. and Randles C. A., (2015), Beyond problem-based learning: using dynamic PBL in chemistry, *Chem. Educ. Res. Pract.*, DOI: 10.1039/C4RP00248B.

Palmer P., (1998), *The Courage to Teach*, San Francisco: Jossey Bass.

Preszler R. W., (2009), Replacing lecture with peer-led workshops improves student learning, *Life Sci. Educ.*, **8**, 182–192.

Stenhouse L., (1975), *An introduction to Curriculum Research and Development*, London: Heineman.

Tien L. T., Roth V. and Kampmeier J. A., (2002), Implementation of a peer-led team learning instructional approach in an undergraduate organic chemistry course, *J. Res. Sci. Teach.*, **39**(7), 606–632.

Towns M. H., Kreke K. and Fields A., (2000), An action research project: student perspectives on small-group learning in chemistry, *J. Chem. Educ.*, **77**, 111–115.

Virtanen V. and Lindblom-Ylanne S., (2010), University students' and teachers' conceptions of teaching and learning in the biosciences, *Instruct. Sci.*, **38**, 355–370.

Whitehead A. N., (1928), Universities and Their Function, *Bull. Am. Assoc. Univ. Prof.*, **14**(6), 448–450.

Woods C., (2007), Researching and developing interdisciplinary teaching: towards a conceptual framework for classroom communication, *High. Educ.*, **54**(6), 853–866.