2019-07-01

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Recommended Citation

Ryan, B. J. (2019). Integration of technology in the chemistry classroom and laboratory. In (Seery, M. K. and Mc Donnell, C. (eds.)) *Teaching Chemistry in Higher Education: a Festschrift in Honour of Professor Tina Overton*, Dublin: Creathach Press, pp. 39-54.

Teaching Chemistry in Higher Education

A *Festschrift* in Honour of Professor Tina Overton

Edited by

Michael K. Seery and Claire Mc Donnell

Published by Creathach Press

Cover image by Christopher Armstrong

Back cover image (Courtesy of Tina Overton/University of Leeds)

ISBN: 978-0-9928233-1-3

overtonfestschrift.wordpress.com

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Integration of technology in the chemistry classroom and laboratory

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The role of technology in the chemistry classroom and laboratory continues to evolve, with mainstream applications such as pre-lecture/laboratory resources being supplemented by technological innovations such as immersive reality. Although the range is vast, care must be taken to select appropriate and pedagogically aligned technologies to enable learning.

In this chapter a model for the appropriate selection and application of technology enabled learning in chemistry is developed and explored in the context of two case-studies. This model, LEAPTech, is based on ten years of personal experience, informed by evidence and underpinned by the scholarly literature. This model will serve as a starting point for new educators and a useful checkpoint for more experienced educators.

Although the chapter is written from a chemistry education stance; the technologies, case studies and model examined are applicable to all practical STEM subjects. The LEAPTech model is central to the two case-studies detailed and provides context and capacity for readers to adopt a tried and tested framework and set of technologies from two chemistry education settings:

1. The use of augmented reality learning supports in the lab.
2. Collaborative online peer instruction in lectures.

Technology is ubiquitous; however, support is needed for educators around how to select appropriate technologies for their students. The LEAPTech Framework provides a sensible tool to map learning activity to an aligned and supportive technology, and to measure the impact of technology integration in a chemistry/science classroom or laboratory. An easy adoption of the LEAPTech Framework is enabled by the noted recommendations.

To cite: Ryan, B. J. (2019), "Integration of technology in the chemistry classroom and laboratory", in Seery, M. K. and Mc Donnell, C. (Eds.), *Teaching Chemistry in Higher Education: A Festschrift in Honour of Professor Tina Overton*, Creathach Press, Dublin, pp. 39-54.

Introduction

Technology has been used the classroom since the nineteenth century. Initially devices such as the overhead projector (1930) were considered significant advances on more traditional technologies such as the chalkboard (1890), the pencil (1900) and the ball point pen (1940; Anon, 2018). More recently, rapid advances in computing have revolutionised how technology is implemented to enable learning. With the advent of the Internet and smart devices, access to information is now easier than ever before (Siwawetkul and Koraneekij, 2018). For example, mobile phone technology has a 70% penetration and the majority of worldwide internet traffic is funnelled through smartphones (Boxer, 2018). The ever-present nature of technology in our daily lives facilitates rapid information access and permits alternative approaches to technology enhanced teaching to be adopted during (synchronous) and outside (asynchronous) class contact time (Pricahyo *et al*., 2018).

Technology integration has been rapid and continues to expand in all aspects of education (Maya *et al*., 2017). Science, and chemistry education specifically, is no different (Table 1). However, selection of the appropriate technology and the level to pitch it at for a given student cohort can be challenging. The LEAPTech (Learning through Engaged and Active Pedagogies with Technology) Framework (see Figure 1) was developed in order to provide a pragmatic approach to technology selection and integration. It evolved based on ten years experience and is informed by the scholarly literature. The underlying concept of LEAPTech is that technology integration should enhance the learning experience.

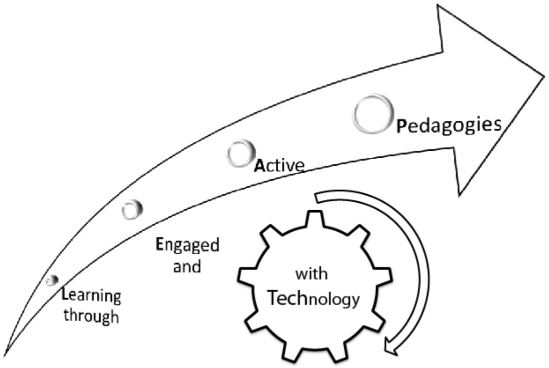


Figure 1: An overview of the LEAPTech framework. Learning is student centred and is driven by technology-enhanced pedagogy that engages and activates the students and itself is evaluated for appropriateness

Two concepts underpin the development of LEAPTech. Watson coined the mantra *pedagogy before technology* (2001, p251), and this informed the key first step in LEAPTech; a synergistic underpinning pedagogy that supports technology integration and use in both the lecture and laboratory environment. For LEAPTech, Beauchamp and Kennewells' (2009) interactive teaching with technology paradigm provided an adaptable approach to modify, map, and quantify the level of technology enabled interactivity (See Table 2 for examples). The use of a framework provides structure for both the academic and student cohort. The final step in LEAPTech is a detailed and rigorous evaluation of the technologies that complete this framework, as applied to the cases at hand. This ensures the appropriateness of the technology and the validity of the impact on the student learning experience. This approach chimes with Taber's (adapted by author) recommendation of *pedagogy before novelty* (2017, p398), using research to inform practice and offer evidence as to effectiveness.

Table 1: Some technologies used in chemistry education, both theoretical and practical, showing type of technology, the setting in which it was used and a primary reference

Type of Technology	Use of Technology	Reference
Augmented reality	Detailed organic chemistry reaction mechanisms and the use of laboratory equipment through trigger-induced augmented reality.	Plunkett (2018)
Animations	Developed students understanding of atomic structure though student generated animations.	Akaygun (2016)
Electronic laboratory notebooks	ELNs were used in a biochemistry laboratory leading to enhanced peer-to-peer collaboration and communication with instructors.	Van Dyke and Smith-Carpenter (2017)
Immersive virtual reality	Aided students to visualise chemical concepts, such as symmetry, chirality and solid-state structures, in three dimensions.	Lancaster (2018)
Modelling	3-D models were used to promote a deeper understanding of biomolecule function from a chemical perspective.	Barak and Hussein-Farraj (2013)
Online tutorials	Assisted students to develop problem solving skills based on automated responses in an online setting.	O'Sullivan and Hargaden (2014)
Pre-laboratory resources	Provision of pre laboratory question sets and instructional videos resulted in students displaying a better theoretical understanding and a higher confidence in their technique.	Teo *et al*., (2014)
Pre-lecture resources	Online lectures were provided in advance of class, and class time used for problem-solving resulted in a statistically significant increase in both emotional satisfaction and intellectual accessibility.	Mooring *et al*., (2016)
Simulations	Assisted students problem solving capacity by introducing simulations to the learning environment	Avramiotis and Tsaparlis (2013)
Student response systems	Promotes active learning through interactive questions that foster in-class discussion and can allow the instructor to identify student misconceptions quickly in a large class setting.	Shea (2016)
Video	Point of view demonstration of practical laboratory techniques that resulted in enhanced student laboratory performance.	Fung (2015)
Virtual laboratories	A virtual laboratory was used to assist students in their conceptual understanding of sub-microscopic chemistry.	Herga, Čagran and Dinevski (2016)
Wiki	Documenting collaborative learning and aligning theoretical knowledge with soft and technical skills.	Kristian (2015)

In this chapter, two aligned case studies (one in a laboratory setting, the other as part of a lecture course) are presented to contextualise and highlight the appropriateness of the LEAPTech framework. Abridged mixed method evaluation findings are also briefly presented to complete the stages of the LEAPTech framework. Over time, and through an iterative process informed by the LEAPTech framework, a deliberate transition towards dialogic and synergistic modes of technology use to enable teaching and learning can be achieved. This evolution is also unpacked and explored through recommendations for practice.

Table 2: Classification, and comparison, of the different levels of teaching enabled by technology with relevant technologies and example technologies provided. The technologies that underpin the case studies in this chapter are in bold. Adapted from Beauchamp and Kennewell (2010)

Classification	Characteristics	Sample Technology	Example Technology
Authoritative	The primary opinion supporting student understanding is that of the academic; there is little or no student discussion or contribution.	Slideshow presentation	PowerPoint notes
Dialectic	Student contribution is encouraged; however, the interactions are focussed on resolving student misconception and is academic facilitated.	Personal Response System	Clicker technology (such as Socrative)
Dialogic	Sustained and in-depth use of discursive interactions between students and academic resulting in purposeful outputs, from different perspectives, that develop student understanding.	Communication software	Nearpod, **Augmented Reality Scenario Based Learning**
Synergistic	Contextualised, open ended problems act as triggers that allow students and the academic of develop new knowledge.	Content creation software	**PeerWise**, Video

Rationale, Methods, and Case Study Design

Rationale

The case studies presented here are divided into two topics; laboratory and lecture associated technology enhanced learning. The rationale for integrating technology in these settings, informed by the LEAPTech framework, differs depending on the setting. In the laboratory, the adaption and adoption of augmented reality, combined with scenario based learning, assisted students in developing good pre-laboratory preparation habits and enabled a more student centred, research-orientated approach to laboratory teaching. In the lecture associated use of technology, students were empowered to curate significant user generated learning resources that were used to construct a student centred, peer instructed active learning environment (Santoso *et al*., 2018).

Implementation — Laboratory case study

In the laboratory case study, and as part of a final year dissertation research project, a final year student developed a pre-laboratory resource for a single problem-based laboratory session based on the extensive use of augmented reality for first year introductory chemistry students. Augmented reality overlays "*virtual information on top of the real world, with continuous and implicit user control of the point* *of view and interactivity*" (Kesim and Ozarslan, 2012, p297). To enhance student preparation before — and independence during — a thin layer chromatography (TLC) laboratory, an augmented reality smartphone application, HP Reveal, was used to make simple augmented reality based scenarios.

Chemistry behind the augmented reality implementation
A simple TLC laboratory was used as a test bed for the feasibility of augmented reality in the chemistry laboratory. A contextualised problem-based approach was implemented to allow the students to work their way through the laboratory-based problem, using augmented reality to support their laboratory technique development in a structured way. The context of the TLC laboratory was a crime scene, whereby clues were distributed around the laboratory, accompanied by augmented reality triggers. These triggers initiated an augmented reality experience for the students once they were viewed through the smartphone app. These augmented reality experiences focussed on supporting students in executing accurate and safe laboratory techniques in a just-in-time approach. The scenario the students were immersed in asked them to solve a crime based on the TLC analysis of the pen ink used during the crime (Mc Donnell *et al*., 2007). The students were not provided with a manual for the lab; instead they were given access to the laboratory technique videos before the laboratory, through the institutional virtual learning environment. The students were prompted, if needed, during the scenario by the augmented reality experiences, additional clues and by the author. Each student group used their own smart device, with the augmented reality application HP Reveal pre-installed. This permitted the students to engage with the augmented reality content through previously created triggers.

Setting up the HP Reveal augmented reality
HP Reveal was used as a mobile device application that allowed the students to experience augmented reality through their smart phone in the laboratory. HP Reveal recognises images from the physical world as triggers to initiate the augmented reality, over the trigger image, on the smartphone. This layered media can include audio, video, animatronics, or a webpage and gives the user an augmented reality experience. The augmented reality experience was created before the laboratory and comprised six steps:

1. Register with HP Reveal Studio (www.studio.hpreveal.com) and create a free account.
2. Upload your desired trigger image (see Figure 2 for examples) that the mobile device will recognise. This image can be uploaded as either a PNG or JPEG file type.
3. Upload your chosen overlay. This overlay can be an audio file, a picture, a video, or a 3D image or scene. HP Reveal Studio compatible file types include; JPEG, PNG, FLV, MP4, or TAR (for 3D overlays).
4. The trigger and the overlay are combined to create an *aura* (an augmented reality experience) and you can chose what will happen when the trigger is recognised. At this point you also have the option to add extra commands including pausing the overlay upon a user command, moving to additional content after user engagement with the overlay, making the overlay full screen, and initiating the camera on the smart device.
5. Save your aura to the *My Auras* space. At this point you can assign searchable hashtags to allow your aura to be easily found or you can share via hyperlink. The aura can be made public or private and a cover image, that is visible when the aura is displayed, can also be inserted.
6. Experiencing the augmented reality requires students to download the free HP Reveal application to their smartphone, search for the relevant aura and use the applications viewfinder to locate the trigger image to initiate the aura.

Implementation — Lecture-based case study
In the second case study, technology enabled peer instruction was used to allow students to co-construct

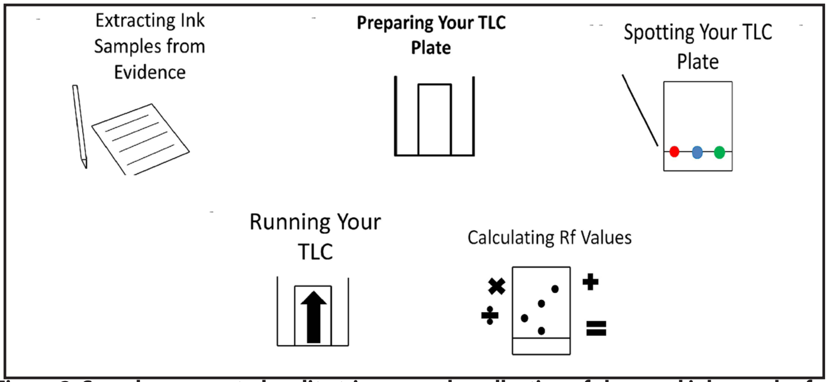


Figure 2: Sample augmented reality triggers and a collection of clues and ink samples from the contextualised problem scenario

knowledge and understanding in an enabling online environment. Peer instruction is "*an interactive teaching technique that promotes classroom interaction to engage students and address difficult aspects of the material*" (Mazur and Watkins, 2010, p39). In this case study, PeerWise (www.peerwise.cs.auckland.ac.nz) enabled peer instruction to move beyond traditional face-to-face peer interactions and permitted peer instruction to take place anonymously, and asynchronously, through a secure online space.

Chemistry behind PeerWise implementation

In this case study, students in three collaborating institutions were encouraged to engage in an online peer instruction space, PeerWise, with the aim of developing their chemistry understanding through question writing and answering. The focus of the question writing was topics covered in their Year 1 general chemistry modules, with a specific emphasis on introductory organic chemistry. The curricula in the three institutions converged on nomenclature, functional group applications and basic organic reactions informed by electron pushing/curly arrows. Students were asked, at a minimum, to:

1. Generate four questions over the course of a 12-week semester.
2. Ensure they completed the relevant study to confirm the answers were accurate and the feedback they provided was supportive.
3. Answer four questions and leave four positive and meaningful comments.

Student authored questions were categorised based on academic selected, pre-defined tags so as to allow the students to search the question database effectively. There was no academic moderation of the question/answer/feedback standard, and a small credit (4% of the module grade) was awarded on a sliding scale for student engagement, in line with the minimum expected participation.

Setting up PeerWise

PeerWise is a free, online space where students create multiple-choice questions, with accompanying feedback, that are shared with their peers. Peers then answer these questions, receive feedback and are awarded engagement badges and points that accumulate over time. Academic preparation is key to enabling students to peer instruct through PeerWise, and primarily involves creating the PeerWise space and subsequently providing training for students on appropriate question/feedback/comment authoring.

A PeerWise space is created by following these five steps:

1. Register for free, and request an instructor account (https://peerwise.cs.auckland.ac.nz/#join).

2. Once registration is complete, enter the your institutional PeerWise space with your username and password.
3. Create a new course (the secure online space where your students will peer instruct each other) and give the course an appropriate name; for example the module code and year.
4. The course will be assigned a unique course ID and you can upload the students to this course manually or via a spreadsheet, using a unique identifier (such as student number).
5. Students can be invited to enter the PeerWise space once they know the course ID number and their unique identifier. They complete a separate registration process, defining their own password etc.

Participants

In both case studies, appropriate technology was woven into an introductory Year 1 chemistry module and underpinned by an aligned social constructivist pedagogy. A social constructivist approach to teaching centralises individual student learning through social, group-based learning activities. It focuses on building individual understanding from existing knowledge within the group. The students in both case studies were non-chemistry majors, from multidisciplinary degree courses focussing on two core areas (Food and Pharmaceutical), across two levels, aligned with the Irish National Framework of Qualifications, where Level 8 is an undergraduate honours degree (see www.qqi.ie for details). These courses were at Level 6, a two-year certificate course, and Level 8, a four year honours degree course. The majority (> 75%) of students did not have prior chemistry background from secondary school. In the lecture-based case study, the population comprised students from three different higher education institutions in Ireland with a specific emphasis on fundamental organic chemistry theory.

Evaluation

The effect of introducing technology into the learning environment, based on the LEAPTech framework, was evaluated. Those who participated in the evaluation were protected following typical ethical guidelines that included; voluntarily participation, fully informed consent, ability to withdraw, anonymity, ensuring no harm to the participant or researcher, privacy, confidentiality and data storage. A case study methodology, combined with simple additional steps (for example the researcher did not conduct the interviews, surveys were completed anonymously and after the assessment for the module was complete), minimized bias and enhanced data conformity as part of a coordinated approach to data validity, reliability and research rigour. The data collected took several forms over the two case studies, but converged on three types:

- an anonymous evaluation form (either an online multiple choice questionnaire or a standard institute module review)
- an independent academic facilitated discussion forum
- a personal reflective researcher diary

All data were collected once the students had completed their modules, with the exception of the reflective diary, which was recorded by the researcher on an on-going basis. The reflective diary documented informal discussions with students, personal researcher observations, and comments. Students were asked for consent to allow the researcher to record any interesting or relevant points raised during an informal discussion. Data triangulation was utilised to ensure only valid themes were investigated and that the examples and findings are based on feedback from as broad a student base as possible (Jick, 1979). Quantitative data were examined using basic mathematical functions in Microsoft Excel to produce graphical representations of data. Qualitative data were coded onto several key themes informed by data saturation and based on researcher interpretation influenced by Strauss and Corbins' (1990) *Method of Constant Comparison* and Braun and Clarkes' (2006) *Six Step Approach to Data Analysis*.

Presentation and Discussion of Findings

Case study 1: Augmented reality laboratories

The research question that underpinned this case study was:

> *Can an augmented reality smartphone based application assist students in developing scientific laboratory skills and enhance their self-reported laboratory confidence in a problem-based learning environment?*

After completing the augmented reality enhanced laboratory, participants were surveyed to gauge their perceived enhanced understanding and skill development. A discussion forum provided rich data that was analysed and thematically coded (Braun and Clarke, 2006) and with further sources of data included a researcher reflective diary and undergraduate project supervisory meeting logbook. Iterative coding and thematic analysis were carried out until data saturation was achieved and convergence on three key themes emerged; (i) student laboratory preparation, (ii) visual aids to learning, and (iii) student confidence.

Theme 1: Student laboratory preparation

Many (75%, $n = 13$) students noted that they typically reviewed, at a shallow level, the laboratory manual before a laboratory. A low percentage (< 15%, $n = 2$) of students commented that they routinely carried out in-depth preparation before laboratories. Barriers to preparation included time pressure (these students had four laboratory sessions per week), poor self-regulation and responsibility for learning as a hangover from their learning experience at second level and the laboratory manual was considered too detailed and dense; all common barriers noted to pre-laboratory preparation (Pogacnik and Cigic, 2006). In this case study, the inclusion of the augmented reality triggers within the online preparative space significantly altered the student preparation. Approximately 95% ($n = 16$) of students noted they prepared for longer, took more notes and engaged the augmented content a number of times. Repeat engagement with augmented content included students repeat playing, as well as playing with pausing, the augmented content. Enhanced engagement with pre-laboratory activities, when they are technology based, echoes past studies by O'Brien and Cameron (2012) and Chaytor and colleagues (2017); although engagement does not always result in improved laboratory performance (Jolley *et al*., 2016).

Theme 2: Visual aids for learning

The use of visual aids to support pre-laboratory and in-laboratory practical work was considered very important by the student cohort. Students commented on how they liked to see the technique in action, carried out by someone skilled in the technique, before they then attempted the technique. All the respondents to the online survey ($n = 17$) cited that would seek out visual aids to help them prepare for all their laboratories, not just chemistry. In this study, the provision of the visual aids as preparatory guides allows the students to pause, consider, rewind and replay; thereby allowing the students to self-pace their learning and to connect the laboratory to corresponding lecture content (Schmidt-McCormack *et al*., 2017). The use of an expert in the video (shot in point of view, over the shoulder, or head on) allows for the inclusion of tips appropriate for novices as well as important and timely health and safety reminders (Agustian and Seery, 2017). The key element of just-in-time learning allows the students to prepare efficiently for the laboratory, but also re-use the resources in the laboratory at key points in the laboratory (for example setting up an instrument) through embedded augmented reality triggers.

Theme 3: Confidence

Undergraduate students, particularly Year 1 students, can lack confidence in their laboratory skills — mainly due to the lack of laboratory time in second level schools. In this study, students reported self-confidence in relation to their laboratory technique increased by 50% with the use of augmented reality, with past research indicating that increased confidence leads to enhanced learning (Chesser-Smyth, 2013 and Rasul *et al*., 2011). When probed, the students that participated in the discussion group cited making mistakes as their biggest fear in the laboratory, often resulting in procrastination in the laboratory. The provision of both pre-/post- and in-laboratory support and guidance, via augmented reality, was seen to help the students on multiple levels; including, reducing the in-laboratory cognitive load and making optimal use of face-to-face laboratory time (Supasorn *et al*., 2008).

Considerations for using augmented reality

Augmented reality experiences can be easily and inexpensively incorporated into the chemistry laboratory, using the LEAPTech Framework as a guide for appropriate integration. Providing access to the augmented reality experiences before, during and after the laboratory allows time for dialogic conversations to naturally take place. The augmented reality experiences replace the need for the academic to repeat procedural instruction; it empowers students through confidence in their technique and promotes meaningful discursive interactions in the laboratory. However, caution is required so that the augmented reality experiences do not distract the students in the laboratory. This can be achieved by enhancing just the key techniques through augmented reality. Additionally, actively engaging the students in purposeful dialogue at the key points of the laboratory procedure will further support student practical and theoretical knowledge development.

Case Study 2: Inter-institutional PeerWise implementation

The research question that structured this pilot case study was:

> *How does a shared, anonymous online learning space affect student perceived learning achievement?*

Three emergent themes, following thematic analysis, were noted and chime with recent research in this area (Kay *et al*., 2018); (i) student generated question quality, (ii) student motivation, and (iii) a shared online community.

Theme 1: Quality control

Of those that responded to the pilot survey, a quarter of the students (n = 3) struggled with the lack of question (and answer) quality control within PeerWise and resulted in PeerWise having a negative effect on their perceived learning. An example comment was "*I was unsure if material was correct*".

The quality of the student-produced question can be problematic when introducing PeerWise to a cohort. Indeed, this lack of question standard regulation by the academic has previously been observed as a barrier to use (Seery, 2014); however, research by Galloway and Burns (2015) suggests that with the correct support, guidance and facilitation, chemistry students can create higher order questions, with matched correct answers and learn in the process. Alternatively, this negative perceived effect on learning could be reversed if the roles are switched within PeerWise with each student taking on board the role of question quality controller. Utilising this flipped approach, the standard of learning deepens further for both the student reviewer and also those engaging with the questions.

> *There was some bad information as question answers were not always right. So [you had to do] your own research [to check if the] wrong answer is correct.*

This peer-reviewer role could be formalised within the comments section of each PeerWise question (Fergus, 2014), with a scaffold provided to assist students in both constructing and reviewing questions (Bates and Galloway, 2013).

Theme 2: Empowerment and motivation

All those that responded (*n* = 12) to the survey noted that they felt empowered by PeerWise and were encouraged to take responsibility for their learning within PeerWise. PeerWise was used in this pilot case study as a mechanism to support student transition from a typically teacher centric second level system to a student centred higher education (Purchase *et al*., 2010); this was noted in student responses to the effect of PeerWise on their perceived learning:

> *[We] had to do independent research and study to create valid questions.*
> *[PeerWise] helps you take charge of your own learning and revision.*

Additional motivators exist in PeerWise and these include badges and a leaderboard and these can be used to induce engagement initially and sustain motivation throughout the semester. In this pilot case study students that engaged more than the suggested minimum (write four questions, answer four questions and comment on four questions over a 12-week semester) cited they did so to gain more PeerWise badges and to enhance their position on the PeerWise leader board. This chimes with previous positive correlation between the gamification of PeerWise and perceived learning gains (Howe *et al*., 2018).

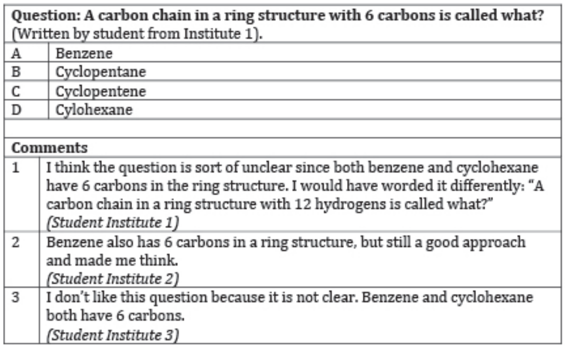
Theme 3: Community of practice

Over 90% (*n* = 11) of the survey participant responses noted that being part of a larger community (the three higher education institutions in one online space) was beneficial to their learning. Being able to connect and engage with peers within PeerWise has been shown to have benefits for those that engage (for example Duret *et al*., 2018); however, in this pilot case study the benefit of engagement with peers in other institutes undertaking similar courses of study was explored. The benefits of an inter-institutional collaborative PeerWise space included students sharing alternative perspectives on common theory, based on they way they were taught at their host institution:

> *It allowed me to learn how [the peers from the other institutions] approached certain topics and give me a greater understating.*

This concept was also evidenced throughout the analysis of the student generated questions and subsequent discussion within the comments sections (Figure 3). Furthermore, from a logistical perspective, combining three student groups increased the database of questions significantly. Once the questions were tagged appropriately within PeerWise, students could use the question database as a revision mechanism throughout the academic year.

> *The questions created were also relevant to our physical chemistry module; the volume of questions available would probably not be as large if it was just [one institute].*



Question: A carbon chain in a ring structure with 6 carbons is called what? (Written by student from Institute 1).	
A	Benzene
B	Cyclopentane
C	Cyclopentene
D	Cylohexane
Comments	
1	I think the question is sort of unclear since both benzene and cyclohexane have 6 carbons in the ring structure. I would have worded it differently: "A carbon chain in a ring structure with 12 hydrogens is called what?" *(Student Institute 1)*
2	Benzene also has 6 carbons in a ring structure, but still a good approach and made me think. *(Student Institute 2)*
3	I don't like this question because it is not clear. Benzene and cyclohexane both have 6 carbons. *(Student Institute 3)*

Figure 3: An example of peer-to-peer learning through the comments section in a typical PeerWise question. All three student higher education institutions are noted; either in question generation or the commentary. The comments are accurate, constructive and helpful to both the question author and also other students that attempt the question

The use of PeerWise in higher education is increasing, including the sciences in general (Hancock *et al*., 2018 and Kay *et al*., 2018) and chemistry specifically (Hudson *et al*., 2018). In this pilot case study the benefits of inter-institutional peer-to-peer learning were explored and found to be a positive influence on perceived learning. However, concerns regarding the quality of the students contributions remain; flipping the role of the student to one of critical reviewer as well as question producer may assist in addressing this shortfall in perceived learning.

Considerations for using PeerWise

Students authoring and answering peer-authored questions is an exercise that can be easily carried out using printed worksheets, following a social constructivist paradigm; however, the use of PeerWise enhances this approach. Within PeerWise all students have access to all questions, comments and feedback and can engage whenever they want. Additional motivators such as badges and a leader board are integrated in to PeerWise with minimal academic input required. As the online space is not viewed as academic controlled, students can develop a community of practice whereby the questions are generated, answered and commented on by the students, for the students. PeerWise, therefore, aligns to the LEAPTech framework, social constructivism supports learning and multiple studies have reported positive outcomes from its integration. It also pushes students to the highest level of Beauchamp and Kennewell (2010) classification matrix; synergistic learning through technology integration and allows students to develop new knowledge.

Implications and Adaptability

The LEAPTech framework provides a sensible tool to measure the impact of technology integration into a chemistry/science classroom or laboratory. Keeping the key tenets (pedagogy before technology and novelty) of the framework in mind during technology integration into a course will allow the framework to guide appropriate technology selection. Pitching the selected technologies at the right level of the framework will provide the greatest range of adaptability for your students. Additionally, from a practical viewpoint it is also important to consider the following in your context.

Accessibility

Will students be encouraged to use their own devices in class/laboratory and if so what is the bring your own device (BYOD) policy within your institution? If you plan on using devices within a laboratory environment, will your BYOD policy cover such use? Are your students willing to use their personal devices for learning; what about their personal data plans (see *Connectivity* below)? Will a BYOD policy place additional pressure on students who may not have smartphones/tablets/laptops, and if so, can a rental scheme be but in place so as not to disadvantage these students?

Inclusiveness

How will students with learning difficulties be enabled in a technology-enhanced classroom/laboratory? Adoption of universal design principles into your technology-enhanced environment can ensure inclusivity is central for all learners (Dinmore, 2014). Inclusive learning technologies can also be considered; for example, text to speech software integration for PeerWise questions/answers/feedback or closed caption annotations for augmented reality video-based resources.

Connectivity

Technology enhanced learning is synonymous with cloud computing and connection to the internet. Consider the teaching environment that you wish to enhance through technology integration; is this space suitably connected, via WiFi, so as to remove the need for students to use their own personal data plans? Does the wireless server have the capacity to deal with several hundred (in the case of large classes) near-simultaneous log-ons? Consider liaising with the local IT support to assess the capacity of the teaching space as additional requirements may be needed to support your classes connectivity.

To blend

How is the topic/module that you are considering for integrating technology currently delivered? What would be the perceived benefits of integrating technology into your class/laboratory? What are the disadvantages? Perhaps a blend, or hybrid, approach may achieve the best of both technology enabled and traditional approaches to teaching and learning (Pimmer *et al*., 2016). Start by integrating a technology in a small way into a class; for example, when you ask a question to the class, collect student responses through an appropriate technology such as Nearpod and marry it to an online homework task within PeerWise. Consult with your student group to evaluate their experience of this technology integration; if it is positive you can build further technology based enhancements into your teaching and assessment.

Assessment

Will you use technology as part of your assessment strategy? If so, it is worth considering familiarising the students with the technology in non-assessed settings. For example, if you plan to use PeerWise as part of your assessment strategy, you may allow students non-assessed practice time. Furthermore, the approach to teaching and assessment can be constructively aligned embracing technology. Constructive alignment is the process of configuring teaching and learning methods, assessment, and the learning outcomes so that they are aligned and symbiotic. An example would be the use of student response systems to capture student answers, and therefore evidence on learning outcome attainment, to multiple choice questions (MCQ) in class. Thus the teaching and learning method would involve answering MCQs. PeerWise could be used to promote this teaching and learning method outside class contact time by encouraging students to design and answer MCQs. The corresponding assessment could use the institutional VLE to assess more formally student attainment of the learning outcomes via MCQs (Ryan, 2013).

Evaluation

If you adapt the LEAPTech framework to select and map technology integration into your class or laboratory, you should also consider evaluating the impact of the innovation. In the augmented reality case study, the inclusion of augmented reality had a positive impact on students developing their self-reported laboratory skills. However, caution is needed here as this key finding suggests the students prepared more and felt more confident in their technique, but the accuracy of their technique was not explored as part of this study. A drift in perceived ability, whereby the novelty factor of the inclusion of augmented reality may have clouded the students personal judgment on their own technical abilities and this needs further exploration.

Conclusions

In this chapter the LEAPTech framework was introduced and used as a lens to showcase two case studies focussing on the adoption, integration and evaluation of technology into both the chemistry classroom and laboratory. In both examples it was found that, with judicious technology selection and integration, the learning experience of students in both the lecture and laboratory setting could be enhanced. However, the use of technology needs to be integrated, seamless and justified; technology needs to be built in, not bolted on. Common themes of student empowerment, responsibility for learning, and confidence are noted in the case studies explored in this chapter. Nevertheless, care must be taken when evaluating new technologies in any learning environment. Student positivity does not always correlate with enhanced student learning; careful consideration of research bias and data validation, through triangulation for example, can assist in the credibility and transferability of an investigation into the benefit, or otherwise, of a technology enabled learning environment.

Looking to the future, the annual reports from New Media Consortium (Becker *et al*., 2017) and The Open University (Sharples *et al*., 2016) are excellent, timely sources for those seeking to keep their finger on the pulse of emerging technologies and innovating pedagogies. For the case studies in this chapter, new avenues can be explored to further integrate technology and evaluate its impact on student learning. For example, augmented reality could be used to create interactive journal articles. In this example the interactive element (for example an audio summary) could be created by each student in a class, thus creating a suite of digitally enabled resources for their peers. This concept of student content creation, enabled through suitable technology, could be expanded to visual standard operating procedures for laboratory instruments and augmented poster presentations; the possibilities abound and are only limited by your creativity with the technology! Whatever direction taken with technology in the classroom/laboratory, the guiding principles of a suitable framework (for example LEAPTech) will help ensure the learning experience, for staff and student, is a positive one.

Acknowledgements

The contributions of Ms. Alice Lynskey (augmented reality) and Drs. Eileen O'Leary, Elaine O'Keefe, Gary Stack and Laura Crowe (PeerWise) are gratefully acknowledged.

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