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A Practice-led Approach to Aligning Learning Theories with Learning and Teaching Strategies in Third Level Chemistry Education

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Abstract

Large class sizes and a diverse student cohort have resulted in challenges for academics in third level institutes both nationally and internationally. This is a result of widening of participation and the drive to create a knowledge-based society in Ireland for the future. The focus in this paper is on third level chemistry education and looking at the issues arising both in the class and laboratory and suggesting learning and teaching strategies in order to overcome them or to enhance efficiencies. The learning and teaching strategies suggested however may be applied across many disciplines. The learning theories that underpin these strategies are highlighted throughout the text to strengthen the pedagogical framework on which they are based. Behaviourism, constructivism, cognitivism and social constructivism are the four main learning theories that support the discussion. Exemplars from the literature and practice led, and all designed, developed and evaluated in the Dublin Institute of Technology (DIT). The role of learning technologies has been included where appropriate. There are many ways of addressing issues of teaching diverse groups at third level that are free and readily accessible, it is hoped that this paper will encourage academics to try a new educational approach in their practice.

Keywords: Behaviourism, Blended Approach, Cognitive Load, Learning Technologies, Learning Theories, Scaffolding, Social Constructivism, Student Centred

Introduction

The context of this paper is to give practice informed examples of a blended approach to learning and teaching strategies that may overcome some of the current issues arising in third level chemistry education whilst aligning learning theories that underpin them. There are commonalities in the issues arising in third level science education internationally such as: managing student diversity, engaging first year students, enhancing flexibility in the classroom and catering for mass education in a digital era to name but a few. The rationale for focusing on chemistry education at third level is to highlight examples of learning and teaching strategies that have been designed and developed in practice to overcome the aforementioned issues. Many of the examples are hoped to motivate educators to explore student centred approaches more than teacher focussed models in their practice. This paper also aims to familiarise third level educators in pedagogical frameworks and schemas that they may use in their practice. The alignment of learning and teaching strategies and the appropriate learning theory will reinforce examples for educators but may also cause some reflection on practice in terms of what is an optimum pedagogical approach for our students progressing through third level chemistry degree programmes.

The scope of this paper looks at the four main learning theories namely: behaviourism, constructivism, cognitivism and social constructivism in the context of chemistry education, but the examples discussed may be applied across many disciplines. Through discussion of the learning and teaching strategies it will be acknowledged that a mixing of the influencing theories is often the most suitable scenario. On moving from first year to final year a progression from a behaviourist model to a more constructivist/ social constructivist approach is recommended to encourage the creation of independent learners. Examples of the application of educational technology will be incorporated where appropriate. The role of

learning theories in primary and secondary education is very much to the forefront and does not receive the same emphasis when transitioning to third level education. This may be a circumstance of the lack of formalised educational training of third level academics where their training was emphasised in their research discipline i.e. Organic Chemist, Physical Chemist rather than what was traditionally known as teacher training. Nowadays however many third level academics are engaging with formalised training in third level higher education such as that offered by the Learning, Teaching and Technology Centre (LTTC) at the Dublin Institute of Technology (DIT) which is the postgraduate diploma in third level learning and teaching. Although many third level academics have been designing, developing and evaluating learning and teaching strategies in their disciplines, creating a blended learning and teaching model without formalised pedagogical training they would not necessarily be aware of the educational theoretical frameworks on which these developments can be structured.

The Influencing Learning Theories

Behaviourism, constructivism and cognitivism are the three most influential learning theories in western society as described by Carlile & Jordan (2005). For the purpose of this paper social constructivism is also included. These four learning theories are powerful educational frameworks which are not only used in schools but are employed in everyday life; from a babies learning development at home to multinational corporate training schemes each learning theory has its place. Formalised third level learning and teaching programmes give academics time and opportunity to reflect on the role of pedagogical literature in their practice and where learning theories are underpinning what they consciously or unconsciously do with their student groups. It is hoped that this paper demonstrates examples from the literature of a blended learning environment which look at the role of learning

theories in the development of students' abilities. Such student abilities are; (i) acquiring concepts, (ii) improving learning skills and (iii) integrated learning related attitudes, values and beliefs regardless of using chalk and talk or a global spanning MOOC (massive open on-line course) as described by Coppola (2013).

A blended approach to learning and teaching strategies that may overcome some of the current issues arising in third level chemistry education will be discussed for the purpose of this paper. The main issues arising are common for most third level institutes and are depicted in Table 1 accompanied by suggested learning and teaching strategies that may assist in addressing the issues and aligning them with the relevant learning theory. Where appropriate the role of e-learning in terms of technology enhanced learning as described by Smith & Killen (2013) to engage and empower learners will be suggested. Learning technologies will be incorporated in an effort to move from a teacher centred traditional behaviourist model of chemistry education in the classroom to a more student centred constructivist/ social constructivist mode.

Issue in Chemistry Education	Learning and Teaching Strategy	Relevant Learning Theory
Student diversity	Creating a VLE with a blend of support material	Constructivism
Variety in Maths & IT ability	Sample answers with accompanying podcasts	Cognitivism
Variety in prior knowledge	Peer to peer teaching, group work	Constructivism/ Cognitivism/ Social constructivism
Lack of preparation time	Pre-lab and pre-lecture work	Cognitivism/Behaviourism
Inconsistency in tutorials	Tutorial workbook/ sample answers for tutors	Behaviourism
Surface learning in lab practicals and in class	Context/ project based labs, workshop style classes (problem based driven)	Constructivism/ Social Constructivism
Student engagement/ motivation	Industry visits, debating, context based learning	Social constructivism

Table 1 Addressing third level chemistry education issues by aligning learning and teaching strategies with underlying learning theories

Educational issues such as those highlighted in Table 1 are now observed and suggested remediation strategies are put forward. In support of the discussion, each of the learning theories is referred to in terms of their overarching principles. The learning and teaching strategies aligned to each individual learning theory are then evidenced from practice-led examples from the literature in the context of chemistry education. The examples given, many of which have been developed and implemented in DIT are familiar to the author and are by no means suggested as being 'best practice', but are included to showcase examples of learning and teaching strategies and where they have been applied.

Scaffolding Learners

The implications of widening of participation in chemistry higher education have been acknowledged for the past decade (O'Connor, 2006). It has been recognised that mass science education in third level results in student diversity, variety in prior scientific knowledge and surface learning in the lab and in-class. One such learning and teaching strategy to address student diversity is to create a virtual learning environment (VLE) or learning management system (LMS) which will allow students to engage with learning materials and to construct their understanding at their own pace. By using a blended approach to the design and delivery of learning materials, this will cater for the diversity in learners needs. VLEs should be designed to make the most of the web 2.0 tools (wiki, discussion boards, quizzes) in order to create an engaging environment for the learner rather than using it to post class notes. The VLE can be reinforced in the classroom by creating opportunities for peer to peer teaching or group work activities. This allows room for the students to take control of their learning and the lecturer in turn takes a more facilitative role. An example of an on-line directed chemistry programme delivered in a constructivist environment using

Jonassen's constructivist learning environment model to design the online activities has been reported by Molphy & Pocknee (2005).

Context-based Learning and Teaching

Taking a context based approach to teaching chemistry has been a motivating factor for both staff and students (O'Connor & Hayden, 2008). The use of real life scientific societal problems as case studies gives the chemistry content more meaning and creates a student centred environment by moving from the more traditional structures of lectures and laboratories. McDonnell *et al.* (2007) designed project based contextualised undergraduate spectroscopy laboratories. The context based laboratories add an element of professionalism to the practical session as the students are given a real life industry problem to solve and they must work in pairs or small groups to plan, design, trouble shoot and conclude some sort of answer. The key is not about the answer but how they got there and the students' rationale on the route they chose to reach their conclusion. Such context based laboratories are challenging for the student and the facilitator but are a much richer and more rewarding learning experience for both parties than the traditional type practical's and create an environment for memorable and deep learning.

More recently McDonnell *et al.* (2012a) developed four context based module resources which can be internationally accessed through the Royal Society of Chemistry (RSC) website under Learn Chemistry. The four resources created at the DIT are a fraction of the off the shelf chemistry resources available for free on this open access website under the titles:

- Molecules against malaria (Medicinal Chemistry) - Class based;
- Small materials to solve big problems (Nanotechnology) - Class based;
- Faster Greener Chemistry (Catalysis and Green Chemistry) - Lab based;

- Pollutant Detection and Remediation (Physical and Environmental Chemistry) - Lab based.

The resources are a selection of laboratory based and workshop/class based context based learning activities as depicted above. The resources are produced with a student pack and an academic pack with resources to support both cohorts. It must be recognised that although the constructivist approach is preferable to allow an element of academic freedom and create space for learners to build their own knowledge. There also has to be much thought put into how the context based lab/ workshop may be facilitated in terms of induction to the activity, planning, guidelines, appropriate resources and assessment criteria so that the learning outcomes of the module are achieved. The constructivist/ social constructivist approach taken here is very much student centred. Much work has been published on the role of constructivism in chemistry education to date and a concise summary of this topic has been prepared by Seery (2010).

Preparing for Class and the Laboratory

The role of pre-lab/class preparation is paramount in order for the students to get the most out of a laboratory or class lecture session. Pre-class/ lab activities have been used at the DIT in an effort to engage learners with the learning material/ activity prior to the event whilst being aware of the cognitive load of the learner (McDonnell, O'Connor & Rawe, 2012; Seery & Donnelly, 2011; Seery, 2009). The students engage online with the pre-class activity and take a short quiz which is part of their module continuous assessment mark. The student must also do pre-lab activities in their lab workbook with the view of having read the procedure and being prepared for the lab work ahead. Again the students are awarded marks, although minor, as part of this work.

Use of pre-lab/pre-class activities prepares the learner for new material to be covered by introducing concepts (definitions, formulae, calculations, diagrams, units) to the learner to reduce their cognitive load in class time and allow for deep learning/ learning for understanding in their class or lab time (McDonnell *et al.*, 2012b; Seery, 2009; Childs & Sheehan, 2009; Reid, 2008).

Visualisation

Chemistry as a discipline is accepted internationally as being a conceptually difficult subject for a novice learner and requires building upon prior knowledge that the students have acquired in order to progress. This becomes an even greater problem when taking the diversity of the student cohort into consideration. There have been great advances in recent decades in appealing to visual learners for example chemistry simulations (Avramiotis & Tsapalis, 2013), student authored chemistry vignettes (Read & Lancaster, 2012) and taking a more context based approach as mentioned previously.

Roadruck (1993) applied Piaget's work to chemical demonstrations and argued that the demonstrations must be designed in such a way as to be at a correct cognitive level for the audience. He also believed that students should be allowed to be part of the demonstration, if not creating and presenting it themselves.

Acknowledging the Students' Cognitive Load

The cognitive load of the learner must be acknowledged when teaching in large class sizes with a diverse student body. Cognitive load by definition is defined as the total amount of mental effort being used in the working memory. Cognitive load theory was developed by Sweller (1988) when studying problem solving. Sweller (1988) argued that instructional

design can be employed to reduce the cognitive load of the learner. Cognitive load theory as applied to our working memory can be broken into three elements; extraneous load, intrinsic load and germane load as depicted in Figure 1.

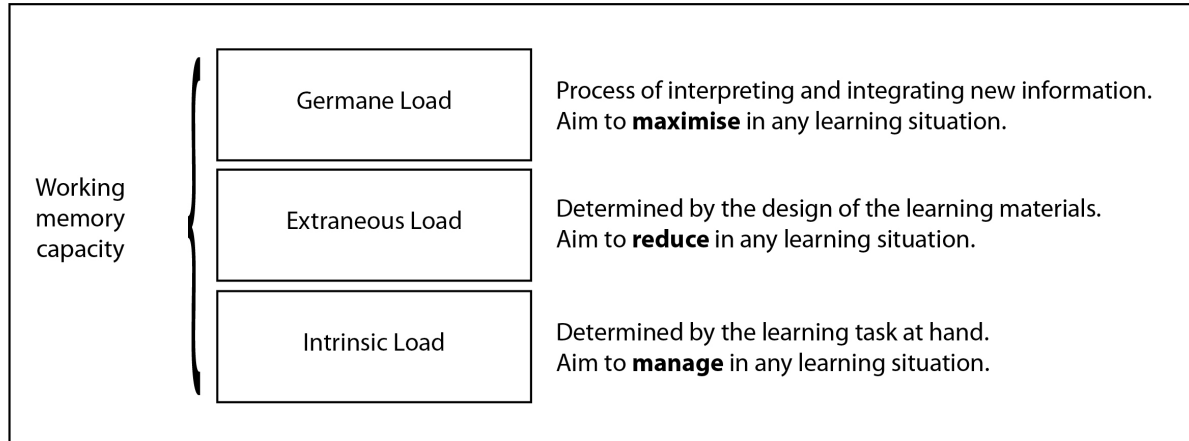


Figure 1 The three elements of cognitive load theory: extraneous, intrinsic and germane (Sweller, 2008)

There are many ways to assist the learner and reduce their cognitive load for example through their VLE or in the classroom. A cognitivist approach would be to introduce worked examples in class or sample answer handouts, podcasts or screencasts on the VLE and this can be very helpful to bridge gaps for the learner and scaffold the learner at their individual pace through challenging material. Learning through peer to peer fora such as:

- discussion boards
- learning technology platforms such as PeerWise
- face to face in groups

each of which can support the learners' needs as they may find new ways of interpreting the information from their peers in a social constructivist environment.

How individuals assimilate new information has been studied by educational psychologists for decades internationally and several reviews have been published on the topic (Ayres &

Paas, 2009; Artino, 2008; Baddeley, 2003; Sweller & Chandler, 1991). More recently Cook *et al.* (2013) have looked at the teaching of metacognitive skills as a learning strategy to enhance the students' performance in first year general chemistry. Mindmap's (concept maps), mnemonic's, a step by step approach to calculations are all examples of learning and teaching strategies that would align with the schemas of cognitivism which are useful learning and teaching strategies for scaffolding learners. An example of the use of mnemonics in redox chemistry is OIL RIG, oxidation is loss of electrons, reduction is gain of electrons. Many more examples of mnemonics in chemistry can be found online to support student learning.

Training in Chemistry Education

Behaviourism has a significant role in learning and teaching fundamental concepts in chemistry as the basic lab skills along with chemical health and safety regulation training for working in the laboratory must be clearly understood. Behaviourism evolved from behavioural psychology research and is based on conditioning theories such as Pavlov's classical conditioning, Thorndike's connectionism, Guthrie's contiguous conditioning and Skinner's operant conditioning (Belford, 2013). Essentially this is 'compliance training' at its best where there are right and wrong ways in which students must work in the laboratory. The international pharmaceutical sector, many of which are represented in Ireland and employ our graduates appreciate such regimented training as this is part of any induction of their employees into their tightly regulated industry. The role of an analytical chemist requires a very high level of accuracy and precision and this is prepared for in third level education from the introductory laboratory classes in use of pipettes and burettes, right through to the use of advanced instrumentation like LC-MS (liquid chromatography-mass spectroscopy) or ICP (inductively coupled plasma) for trace analysis in later years of degree

programmes. The behaviourist model is used to teach in most cases the analytical techniques/ skills required for this role.

In 2013 at the DIT, first year tutorial workbooks were prepared for the level 7 and level 8 chemistry students to replace their weekly tutorial sheets. The tutorials are supported by a variety of staff that facilitates tutorials on a weekly basis for the first year students. To ensure consistency across the large classes which are broken into small groups (circa 20) for tutorials, tutorial workbooks with accompanying sample answers for tutors were designed. The workbooks consisted of themed worked examples with a variety of calculations and other open ended questions for the students to answer and work through during tutorial time. This allows students time to reflect on class or lab work they have done during that week and to discuss with their peers any problems arising. This is a constructivist/ social constructivist approach to learning. The students are awarded marks as part of their continuous assessment (< 5 % of module mark) for their weekly participation at tutorials and for completing their workbooks which employs the behaviourist model or 'carrot and stick' approach.

Byers & Eilks (2009) acknowledged that behaviourism builds on aspects of practice that are known to be effective, such as the promotion of learning through repetition. Byers & Eilks (2009, p.12) argue that *"whilst behaviourism is helpful in understanding the simple issues associated with basic training processes, it has proved much less successful when it comes to understanding important issues in higher level learning, such as concept acquisition, problem solving and creativity"*. Hence the behaviourist approach may be appreciated in the areas of introductory first year chemistry modules and laboratories and in regulatory and compliance training.

Peer-led Learning, Teaching and Technology!

Creating communities of practice is one method underpinned by Vygotsky's sociocultural theories (1978) that allows the learners to construct their knowledge and learning materials. Some examples are: class room debates, industry visits for undergraduate students to give them insight into the professional practice and where they may contribute to society in the future. More recently the use of online free educational software has been engaged with, for example wiki's (Wells & Clougherty, 2008; Seery & McDonnell, 2012) and PeerWise (Bottomley & Denny, 2011; Ryan, 2012). Both the use of wiki's and PeerWise allow students to direct, create and evolve their learning, the depth and limit of which is depicted by the facilitators learning outcomes guidelines and assessment regulations. These are examples of innovative ways in which students can interact in a meaningful way on-line on or off the campus and more ways of harnessing technology in chemistry education are discussed by Seery (2013). In a recently published book chapter on eLearning and blended learning in chemistry education, Seery & O'Connor (2015) take a holistic look at the place of educational technology in a blended learning environment focusing on exemplars from the current literature and highlighting the added value of this approach.

Social media networks: Facebook, Twitter, LinkedIn as described by Ashley-Roberts (2012), all have their role to play in the blended learning environment and evidence of this may transpire in the chemistry education literature more frequently in the future. The Royal Society of Chemistry (RSC), American Chemical Society (ACS) and the Journal of the American Chemical Society (JACS) each have a presence on Facebook. Professional chemical associations have acknowledge students interest in social networking such as the RSC and ACS have designed web 2.0 initiatives for example RSC has Chemistry World and

Education in Chemistry blogs and the ACS Mobile App which is called molecule of the week (Martinez, 2010).

Twitter has been used for the promotion of questions and answers (more so than oral interaction) in large first year chemistry classrooms (Cole, 2013). Our 21st century students currently in third level chemistry education for the most part have a natural interest in technology platforms which motivates them to learn and share content. The use of clickers has been identified as a very useful diagnostic tool in large general chemistry classrooms (King, 2011) and now the clickers device is not as critical through the introduction of Socrative on mobile devices. This allows students to use their mobile phone as a polling device.

Conclusion

In conclusion there are common themed issues arising in third level chemistry and science education which may be addressed by employing learning and teaching strategies, some of which are around for decades others which embrace learning technologies to support our 21st century students. Each are underpinned by the four main learning theories behaviourism, constructivism, cognitivism and social constructivism in our practice. Examples of learning and teaching strategies from the chemistry education literature have been aligned to learning theories; however it must be acknowledge that no one learning theory solves all. In the first instance, third level academics should be aware of the pedagogical frameworks that they are incorporating into their practice and the underpinning learning theories that are involved. By familiarising themselves with the variety of models and schema presented, they may make more informed choices for their future practice and for sound pedagogical reasons.

Scaffolding the learners through a blended learning environment is recommended as they progress through their programme; however the learner should become less dependent and more self-directed in the later years of their studies. It is our role as educators to give them the tools or the building blocks to be proficient at what they do. The tools for organising, assimilating and discovering their own knowledge should be embedded into the programme in early years to promote effective learning in a more independent manner. An inclusive blended approach to the learning and teaching strategies underpinned by the learning theories, supported by relevant learning technologies where appropriate, could create a successful platform for a blended learning environment for third level chemistry education.

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