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# ARTICLE
# A Case Study in the Use of Primary Literature in the Context of Authentic Learning Pedagogy in the Undergraduate Neuroscience Classroom

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Providing opportunities for undergraduate science students to develop causal reasoning skills and the ability to think like research scientists is a crucial part of their preparation for professional practice as a scientist and/or a clinician. This has led many to question whether the traditional academic in-class lecture still has a functional role in today's undergraduate science education. Here, we performed a case study to attempt to maximize the use of in-class time to create a more authentic learning opportunity for undergraduate neuroscience students in our institution, the majority of whom go on to be research active scientists. We hypothesised that using seminal research papers as a teaching tool in a flipped classroom setting would model for neuroscience students what it means to think like a research scientist, would provide an opportunity for them to develop their causal reasoning skills and allow them to become more comfortable with the nature of professional practice (i.e., research) in the context of the discipline. We describe the design and implementation of this teaching approach to undergraduate final year neuroscience students, and evaluate their perception of it. We provide evidence that this approach models for the students what it means to reason like a research scientist, and discuss the implications of these findings for future practice. We propose that these findings will help add to the educational experience of all Neuroscience students whether they are on pre-med or on a research track.

*Key words: University; Undergraduate; Neuroscience; Education; Pedagogy; Lecture; Engagement; Flipped classroom; Causal reasoning; Authentic learning*

How do we design teaching to ensure our students are competent disciplinarians at the end of any course? This is the primary objective of authentic learning pedagogy which aims to mirror the real-world of a disciplinarian navigating in their field by situating learning tasks in the context of future use (Lombardi, 2007; Herrington et al., 2014). Such an approach provides an opportunity for students to develop their professional identity during the knowledge acquisition phase of learning, and to cultivate their reasoning skills as they relate to professional practice (Yardley et al., 2013). While this is easy to imagine when one considers a medical or engineering student, what of neuroscience students? How do we create authentic learning opportunities for students, the majority of whom go on to be research active scientists? In many European institutions, there are dedicated Bachelors of Science (BSc) courses where students graduate with a BSc in Neuroscience (similar to majoring in Neuroscience). After graduating, many students go on to pursue higher research degrees in the subject, while some enroll in what is called graduate entry to medicine, in a similar way to pre-med students enroll in medical school in North America. Regardless of the university system or their future career path, it is important that all Neuroscience students, whether on a pre-med or a research track, can think critically and understand the scientific process.

Arguably the best way of training students in the scientific process is to teach science through practical classes. However what purpose then does in-class lecture time serve other than for information delivery? We propose that by adopting a well-designed pedagogical framework, lectures provide an opportunity for science students to be encultured into the discipline (Lave and Wenger, 1991), and to learn the 'genres' of the discipline. These as defined by Brown are the ways a disciplinarian recognizes whether a problem is an important problem, or a solution, an elegant solution, or even what constitutes a solution in the first place (Brown, 1999). We propose that using seminal research papers as a teaching tool in a flipped classroom setting (Lage et al., 2000) can model for science students what it means to think like a research scientist, and allow them to become comfortable with the complexities of ill-defined real-world problems in the context of the discipline (Lombardi, 2007). This proposal is supported by excellent work from Hoskins and others on the C.R.E.A.T.E method (Consider, Read, Elucidate hypotheses, Analyze and interpret data, Think of the next Experiment), which has used primary literature as a portal into the scientific research process (Hoskins, 2008; Hoskins et al., 2011; Bodnar et al., 2016; Sato et al., 2014). Others have used successful variations of this approach where students read and interpret research papers in advance of a class (Round and Cambell, 2013). Building on this work, here we propose that the use of primary neuroscience literature as the primary teaching tool in the neuroscience classroom aligns with several pillars of authentic learning pedagogy (Lombardi, 2007; Harden, 2015) for the following reasons.

The thought processes that underpin scientific research can be broken down into at least four general stages that model the thought processes and conduct of a disciplinarian. 1. Problem identification (hypothesis generating): What is it that I am going to study, and why is this an important question in my field; 2. Experimental design: What approaches am I going to use to answer this question; 3. Data collection and analysis: What are the results of the experimental design; 4. Dissemination and interpretation: What do these results mean for my original question and in the wider context of the field. By their very nature, research papers in any discipline begin with challenges that cannot easily be solved, and generate results that are open to multiple interpretations. Two other pillars of authentic learning state that it should have real-world relevance and be open to multiple interpretations and outcomes, all features of research papers.

The majority of neuroscience students in the BSc Neuroscience program at our institution go on to pursue higher masters or doctoral degrees or enroll in medical school. Both professions that require them to be able to think critically and understand the scientific process. We hypothesize that working through a real-life problem in class through the break-down of a research paper, would expose the students to the types of real world tasks and thought processes undertaken by neuroscientists. Equally the interpretation of scientific results is often open to diverse opinions thereby modeling for the students the complexities of ill-defined, real-world problems in the discipline (Lombardi, 2007). Moreover, given that authentic learning pedagogy also proposes that students should reflect on their learning (Lombardi, 2007), we hypothesize that reflecting on the implications of the data in research papers may allow for a metacognitive experience that allows students to reflect on how they know and why they know, which is important for conceptual understanding in science (Schraw et al., 2006; Zepeda et al., 2015). Furthermore, the ability to recognise, interpret and conclude based on the results of scientific experimentation can be defined as *causal reasoning* or the ability to recognise the relationship between cause and effect (Grotzer, 2003). Grotzer and colleagues propose that in order for students to learn how scientists understand their research questions, lessons should invite students to analyse the modes of inquiry that scientists engage in and then reflect on what this means for their own scientific thinking (Wong et al., 2009). When considering this in the context of the proposed use of research papers as a teaching tool in the classroom, we hypothesize that this approach may allow students to analyse the modes of inquiry that scientists in the discipline use to generate new knowledge, and make explicit for students the nature of causal reasoning within the discipline. We describe the design and implementation of this teaching approach to undergraduate final year neuroscience students and their perception of it. We provide evidence that this approach models for the students what it means to think like a research scientist and discuss the implications of these findings for future practice. We propose that this applied approach will add to the educational experience of all neuroscience students regardless of whether they are on a pre-med or research track.

## MATERIALS AND METHODS

### The environment and course

This work focuses on implementing a new teaching design in a subset of lectures in a Developmental Neurobiology (www.ucc.ie/modules/descriptions/AN.html#AN4008) course given to 20 undergraduates in final year in the BSc Neuroscience program at University College Cork, Cork, Ireland. These students were in their fourth year of university and would have written a literature review on a topic in Neuroscience in their third year, meaning that they had some experience in navigating the general structure of a research paper, and some experience in reading them. The Developmental Neurobiology course, a required core component of this BSc degree, consists of 30 one-hour lectures that are supported by the University web-based learning portal (Blackboard™), which is used to post PowerPoint™ -based lectures presentations in advance of the lecture. Our new teaching approach was trialed in a subset of six one-hour lectures on target innervation and synapse formation, which had previously been taught using a traditional didactic approach.

### The teaching approach

The revised teaching approach was designed around the activity of using in-class time to study a research paper that discovered a core concept about the topic under study. This use of research papers in this way as a teaching and learning tool was chosen based around the Scholarship of Teaching and Learning concepts of authentic learning and causal reasoning in order to model for the students what it means to act and think like a researcher in the discipline. Causal reasoning is defined as the ability to recognise, interpret and conclude based on the results of scientific experimentation or the ability to recognise relationships between cause and effect (Grotzer, 2003). We aimed to scaffold our approach based on the work of Grotzer and colleagues at Harvard Project Zero who have focused on how causal understanding interacts with science learning to develop curricula that support deep understanding (Grotzer, 2003). We sought to use research papers as a teaching tool in the classroom to make explicit for students what causal reasoning in neuroscience looks like in practice and to allow for a metacognitive experience through reflection (Schraw et al., 2006; Zepeda et al., 2015). Grotzer and colleagues propose that a lesson plan designed to do this has six steps (Wong et al., 2009) (Table 1).

| | |
|---|---|
| *Step 1: Reveal current thinking.* | *Step 2: Think how scientists come to discoveries.* |
| *Step 3: Analyzing scientific case studies.* | *Step 4: Discussing the case studies.* |
| *Step 5: Researching a Scientist.* | *Step 6: Make connections to one's own thinking.* |

*Table 1. Six steps of a lesson plan designed to develop causal reasoning skills.*

To reveal students current thinking (step 1), the class began with a 10-minute lecture to ensure students grasped the main points in lecture material that was posted in advance of the class prior to studying the research paper. This was followed by a 45-minute systematic breakdown of key experiments in the research paper, which covered steps 2 to 5. This was based around a question and answer style session with the focus on identifying and breaking down crucial experiments in the paper that described core and fundamental concepts in the discipline. The instructor continually posed the following four questions to the students throughout each lecture. Students responded to the group as a whole which created a positive and engaging group dynamic:

1. *Why is this a significant question in developmental neurobiology?*
2. *What information or knowledge is known and what are authors trying to do?*
3. *What is the process through which they generate this new knowledge?*
4. *How do they combine multiple lines of evidence to reach their conclusions?*

In order to provide an opportunity for students to make connections to their own thinking (Step 6), and to provide an opportunity for them to reflect on the material, we incorporated a simple, anonymous "Clearest/Muddiest Point" Classroom Assessment Technique (CAT) (Angelo, and Cross, 1993). This CAT was a simple, non-graded, anonymous, in-class activity in which all students were asked to write brief answers on individual slips of paper to the questions; "*What was the clearest point from today's lecture?"* and *"What is the muddiest point or the point that you least understood?"* This CAT is a well-validated approach to gather useful feedback on the teaching and learning process as it is happening. Anonymous student responses to the muddiest point were collated and answers to their questions were posted on-line through the Blackboard site within 24 hours of the lecture. The goal was to create an opportunity for students to reflect, to make connections to their own thinking, and to receive feedback to clarify any misconceptions.

**Gathering student feedback**

We used a 10-item feedback questionnaire to collect quantitative information with multiple choice questions or 5-point Likert scales on students' views on the new teaching approach. For questions asking their views on lectures, students were also given the opportunity to comment on their answer. Although the questions included a mix of categorical and scalar responses for most items, given the low numbers of students in this class (n=20), the use of an alpha co-efficient and Kendall Tau b to support reliability and validity were not appropriate. As such we do not claim that this survey is a psychometrically valid and reliable tool, but is rather a tool for collecting descriptive data pertaining to student views on learning resources and their opinions on this teaching approach. A departmental colleague checked the survey for ease of understanding and a pilot survey was first issued to three students in our research team. No problems were detected with the questionnaire.

**Data analysis**

To carry out statistical analysis, all data from Likert scale questions were converted to ordinal data (1=strongly disagree; 2=disagree; 3=neutral; 4=agree; 5=strongly agree). These data were entered into Excel, version 14.0 (Microsoft Corp., Redmond, WA) or GraphPad Prism 6 (GraphPad Software, Inc., San Diego, CA) or exported to the Statistical Package for Social Scientists (SPSS), version 22 (IBM Corp., Armonk, NY). Pearson's chi-squared tests (X2) tests were carried out to assess significant deviations in preferences from chance expectations. Preference for a particular choice was assessed relative to the total number of expressed preferences in a given question. Data were considered to be statistically different from chance expectations at $p < 0.05$. Specific student comments were entered into Word, version 14.0 (Microsoft Corp., Redmond, WA) and a thematic analysis was performed manually.

**The primary research articles used in the teaching**

The following six papers where used with the titles and the links to the primary source shown below. These papers were chosen to illustrate a number of important key developmental processes in the formation and elimination of synapses, they also highlight the evolution of the methodology used to study them, and how a complementary methodology using both *in vitro* and *in vivo* approaches can be used to study a particular research question. We do not claim they are the optimal papers as it is up to individual faculty to decide on the most suitable ones for their own particular courses.

1. Genetic analysis of ephrin-A2 and ephrin-A5 shows their requirement in multiple aspects of retinocollicular mapping (Feldheim et al., 2000). http://www.ncbi.nlm.nih.gov/pubmed/10774725
2. Agrin promotes synaptic differentiation by counteracting an inhibitory effect of neurotransmitter (Misgeld et al., 2005). http://www.ncbi.nlm.nih.gov/pubmed/16043708
3. LRP4 Is Critical for Neuromuscular Junction Maintenance (Barik et al., 2014). http://www.ncbi.nlm.nih.gov/pubmed/25319686
4. Spike timing plays a key role in synapse elimination at the neuromuscular junction (Favero et al., 2012). http://www.ncbi.nlm.nih.gov/pubmed/22619332
5. Role of pro-brain derived neurotrophic factor (proBDNF) to mature BDNF conversion in activity dependent competition at developing neuromuscular synapses (Je et al., 2012). http://www.ncbi.nlm.nih.gov/pubmed/23019376
6. ProBDNF and Mature BDNF as Punishment and Reward Signals for Synapse Elimination at Mouse Neuromuscular Junctions (Je et al., 2013). http://www.ncbi.nlm.nih.gov/pubmed/23761891

## RESULTS

**Quantitative and Qualitative analysis of student views on the revised teaching**

Having completed the assignment, students were invited to voluntarily complete a feedback questionnaire designed to gather quantitative and qualitative information regarding their views on the teaching and their experience of it. Firstly, students were asked to rate their level of agreement on a five-point Likert scale (1=strongly disagree, 5=strongly agree) with the following six statements. Students were also asked to comment on their answer to provide further insight. Selected examples of individual student responses are shown below each statement that are grouped by their level of agreement with the statement which is shown in parentheses (1=strongly disagree to 5 = strongly agree). Where a student response in a particular category of the Likert scale is not shown, no student selected that option.

***Statement 1. The abbreviated lectures on synapse formation and elimination are more beneficial to my learning than traditional 50-minute lectures***

90% of students had a positive response (agree or strongly agree) when asked if lectures were beneficial to their learning. This was supported by the $\chi^2$ tests on the overall distribution of preferences, which was highlight significant ($X^2 = 29.5$, df = 4, p <0.0001). Of all five choices, "Strongly Agree" showed the largest number of expressed preferences (65%). The mean Likert score was 4.55. For a graphical representation of the mean Likert score for all six of the following statements see (Fig. 1).

- *"The lectures are clear and well explained. I leave understanding the information already instead of spending ages at home on my own trying to understand it. This lecture style is far more beneficial than rushing through slides and reading directly from them." (5)*
- *"It is more interactive, one can freely question/think about the topic without feeling like you are interrupting 'the flow' of the lecture." (5)*
- *"I have found from day one that grappling real world examples have a way of "clicking". While initially more difficult than traditional lectures, I find they fall into place by the end." (5)*
- *"Made the class interactive and taught driven towards the use of information given." (5)*
- *"They were more engaging- question based learning better solidifies learning I find." (4)*
- *"Very detailed explanations, and can see the benefits of real life experiments." (4)*
- *"Applying theory to experiments allows me to fully understand." (4)*
- *"Sometimes hard to understand." (3)*

***Statement 2. The lectures on synapse formation and elimination have improved my confidence in my ability to read research papers***

Similarly, 90% of students had a positive response ($X^2 = 21.5$, df = 4, p<0.0001). "Strongly agree" and "Agree" showed an equal largest number of expressed preferences (45% of the responses were n each category). The positive feedback was also reflected in the student's responses.

- *"It reinforced the idea that I can take key facts and examine them and not get bogged down in often laborious and stuffy texts." (5)*
- *"Allows me to interpret what I have previously struggled to." (5)*
- *"Engaging in current papers and looking at figures shapes how I interpret papers." (5)*
- *"Using papers along with the lecture notes made it easier to apply knowledge to relevant topics." (5)*
- *"Practicing to explain diagrams has helped a lot." (4)*
- *"Going through the papers gave me a better idea of what to look for when reading papers." (4)*
- *"You become adjusted to the language the paper uses (i.e. difficult scientific terms) and lecturer explains everything in detail at an appropriate pace." (4)*
- *"Improved my ability to pick apart word-heavy publications that once made me nervous." (4)*
- *"I found that careful and slow reading really helps and that difficult words don't necessarily mean something different." (4)*

***Statement 3. The lectures on synapse formation and elimination have improved my understanding of experimental methods and their purpose in neuroscience research***

Perhaps most strikingly, 100% of students had a positive response (agree or strongly) ($X^2 = 34.5$, df = 4, p<0.0001). 60% of students selected "Strongly agree" with the remaining 40% of student choosing the "Agree" category.

- *"Most lecturers don't reference the applicability of the information learned." (5)*
- *"Explains different techniques with their benefits and limitations. Also, discussion of the other techniques that could prove the same thing." (5)*
- *"What would you do next & how could we refine it" questions made me think about design." (4)*
- *"Showing how techniques are used in real-life studies highlight their relevance." (4)*
- *"I like learning new techniques and thinking about what situation you could apply them to answer a question. I learned the photocaging technique." (4)*
- *"Going through the methods and different procedures in actual experiments makes it more clear." (4)*
- *"Sometimes several controls need to be used to prove your hypothesis and not just one." (4)*

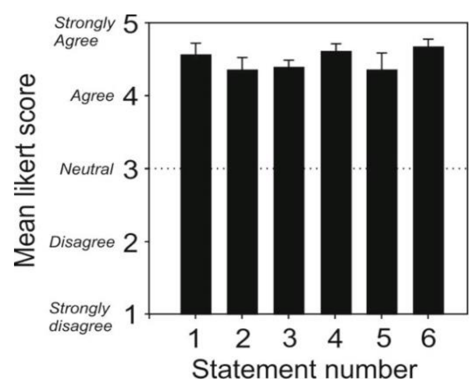


*Figure 1.* Student views on the alternative teaching approach. *Students were asked their views on the new teaching on a five-point Likert scale from 1 (strongly disagree) to 5 (strongly agree). The graphs represent Likert score data as the mean ± S.E.M.*

***The use of a CAT as a tool for reflection***

Students reflecting on what and how they know is proposed to be important for conceptual understanding of science (Schraw et al., 2006; Zepeda et al., 2015). Therefore, in the present study, we used the last five minutes of in-class time to carry out the simple, anonymous "*Clearest/Muddiest Point*" Classroom Assessment Technique (CAT) (Angelo and Cross, 1993). While we used it to check for student understanding of the core concepts, we also sought to provide an opportunity for them to reflect on what they had just learned (metacognition). Students were asked for their views on the use of the CAT in this manner.

***Statement 4. Providing us with written feedback based on our questions at the end of class improves our understanding***

This statement was referring specifically to the CAT and the written answers that were posted online to student questions. 100% of students had a positive response to this statement ($X^2 = 32$, df = 4, $p<0.0001$). 60% of students strongly agreed, while 40% agreed with this statement.

- *"Allows for answers to questions that some may not now they even had leading to an overall understanding." (5)*
- *"By doing this one must really think about the lecture again." 5)*
- *"Not only for asking questions, but also forcing yourself to ask "ok what was key here and what was not as important" – also immediately shows what you didn't get." (5)*
- *"Really liked this, helped with understanding." (5)*
- *"Anything we didn't understand was answered and it also made us think about what we just learned and question it." (5)*
- *"Forces you to think about what you understood and put it into words as well as clarifying what you didn't understand by challenging you to write a question about it." (4)*
- *"If there is a section you don't understand it gives you a chance to go over it in next lecture. Feedback also allows you to recap what you learned in class that day." (4)*

Finally, students were also asked whether in their view, the alternative teaching approach kept them engaged, and whether this format should be implemented in other courses.

***Statement 5. This lecture format has kept you engaged throughout each lecture***

85% of students had a positive response (mean Likert score = 4.35). This was supported by $\chi^2$ tests ($X^2 = 21.5$, df = 4, $p<0.001$). "Strongly Agree" was chosen by 60% of students while 25% of students selected "Agree". Only two students commented on this statement.

- *"I am prone to distraction when a lecture is dictated so it is great to feel part of the process." (5)*
- *"Not always but most of the time." (3)*

***Statement 6. This lecture format should be implemented in other courses***

All students gave a positive response (mean Likert score = 4.60). This was also supported by an overall significant difference in $\chi^2$ testing ($X^2 = 34.5$, df = 4, $p<0.0001$). Two-thirds of students selected strongly agree, with the remainder agreeing with this statement. Students were not asked to provide a written comment on this statement.

**Preliminary assessment of student exam performance**

While the primary purpose of this paper was to focus on the implementation of the teaching approach, and the student's reaction to it, we also carried out an initial assessment of whether this teaching approach may improve the quality of student learning. We assessed the percentage of students achieving the highest grade in the final course exam on material taught in the traditional manner compared to material taught using the revised teaching approach. Interestingly, 22% of students achieved the highest grade when examined on material that was taught in the traditional manner. In contrast, 31% of student achieved the highest grade when examined on material taught using the new approach. This suggests that this revised teaching approach does benefit students but this requires a more detailed investigation in a future study.

**Looking forwards: a qualitative analysis of student views on ways to improve the approach**

Having determined that students liked the new approach, we next sought to better understand what it was about the approach that they liked most, liked least, and how it could be improved in the future. Students were asked to comment on the following three questions, and their answers were grouped according to specific themes that emerged:

**Question 1: What did you like MOST about the lectures on synapse formation/ elimination (format, delivery, and/or style etc.)?** Please comment.

When we analysed the student's responses to this question, two main themes emerged:

<u>Theme 1: The format of the lecture</u>

- *"Delivery. Asking questions to students keeps them engaged when compared to listening to lecturers just reading form their slides."*
- *"Delivery – looking at real research papers going to actual papers that discovered these things & how they did it, not just learning off what they discovered. Questions."*
- *"Delivery of the lecture was very clear. I found using research papers along with lectures notes was very helpful. Also, points were clarified numerous times so I never felt lost in the information."*
- *"The process of delivery: "Here is a problem. Why is this a problem? How do you go about this experiment?" It gave a real insight into the process and more essentially, understanding."*
- *"Delivery and style, all information was relevant and in context while still providing proof of applicability."*
- *"I liked that we went through it step by step first with a bit of background on the topic."*
- *"I like the way each step was reviewed as we went along because it helped me to remember the information. It was clear what was the important take-home information compared to having 30 slides to read and memorise. I also very much liked that the papers were given to us with the important parts highlighted."*
- *"The use of actual papers and the lecture style where there was more interaction with the class."*

- *“The use of papers to help with understanding and the same with use of a practical model.”*
- *“A lot of information was given on the topic but lecturer highlights the main points and discusses it with the class, making sure everyone understands.”*
- *“The lectures were well presented ad being asked questions makes you think about the topic. The summaries are also very helpful.”*
- *“Loved the style of lectures, really applies to my method of learning.”*
- *“The interaction in the lecture stopped me from losing interest/concentration halfway through.”*

Theme 2: Improved understanding of difficult concepts

- *“The papers provided helped with my understanding of the mechanisms – seeing the results versus just Learning about what may happen. I like the recap at the end of the lectures.”*
- *“Research papers used to both teach a concept and show how it can be used. Logical progression from one to the next.”*
- *“How difficult articles are made more understandable. Also, all the questions during the lecture on the articles helped to fully understand and remember all of the information.”*
- *“Clear and deliberate breakdown at difficult and possible contradicting processes.”*
- *“How elimination works was interesting. How the explanation was slow so everyone understood.”*
- *“Looking at papers which dealt with the concepts in class made it easier to understand how the concepts worked in vitro and in vivo.”*
- *“Relevant to current research.”*

**Question 2: What did you like LEAST about the lectures on synapse formation /elimination (format, delivery, and/or style etc.)?** Please comment.

When we analysed the student’s responses to this question, three main themes emerged:

Theme 1: The time/pace of the lecture

- *“Worried that it may be too slow a delivery? Understanding has definitely improved though.”*
- *“No real critique in this regard. It may require a 1h 30 minute time slot.”*
- *“Sometimes felt that we were going quite sow and could have progressed through basics quicker allowing us to focus on the more difficult/advanced aspects to the topic.”*

Theme 2: Different teaching style

- *“Unsure how answering a long essay question on the subject would be possible from what is covered in the lecture.”*
- *“Everything was clear and thoroughly explained. The teaching style is very similar to how I study so it works for well for me. Overall I didn’t dislike anything.”*
- *“Different to the usual style of lecture we have had for the last 4 years and was difficult to get the head around initially. This is not necessarily a bad thing.”*
- *“Sometimes you feel you know the material well due to engaging with 90%, only later to realise you have not understood a key component.”*
- *“Having to read papers, flick through pages back and forth while trying to look at slides on the board if there were any and trying to take notes at the same time.”*
- *“Occasionally the relevance of the information to the exams was cloudy in the first two lectures but improved as time went.”*
- *“I found that going through the different experiments where there were knockouts and different proteins involved was confusing!”*
- *“A lack of traditional notes may make studying harder.”*

**Question 3: How could lectures on synapse formation/elimination be improved?**

Students responses were grouped into those that suggested improvements or those that did not.

Suggested improvements

- *“Sometimes speed is a bit too slow and repetitive – could cover more ground.”*
- *“Maybe to let student try to find and underline the most important parts of the article themselves, like in one of the first lectures.”*
- *“If the class spoke up more. Animations!”*
- *“Give us /post a summary question sheet of a few questions we should be able to answer after the lecture so we can try them and clarify what we understand well and don’t. More questions inviting us to design an experiment to test a hypothesis.”*
- *“Continue to engage with the class and keep going over important points made.”*
- *“Maybe if at the end we could recap on what the lecture was about it would be helpful."*
- *“These topics are quite heavy and lectures are linked therefore perhaps 2x2-hour lectures a week would be more beneficial as could really progress through the topic.”*
- *“Include a set of lecture notes explaining the topics covered – I find that sometimes I miss something.”*
- *“A brief 2-3 line at the opening or closing giving a sum up of the learning objectives”*

No improvements suggested

- *“It would be very difficult to.”*
- *“N/A. I like this style better overall.”*
- *“I felt it was well done and explained nice and slow, which for me was beneficial.”*

## DISCUSSION

In this study, we used an alternative teaching approach in which we based each lecture around an important research paper that discovered a fundamental aspect using a varied methodological approach in the field. This teaching intervention was designed to maximise the use of in class time to make explicit for students not just course content (information), but also the elements of disciplinary practice. Our quantitative analysis of student’s feedback through the use of Likert rating scales and X2 tests show that a statistically significant majority of students found this approach more beneficial than traditional lectures, and that the approach improved their confidence in reading research papers, which suggests that this may improve their understanding of experimental methods and their purpose in Neuroscience, but this requires detailed examination.

***Content coverage: The depth versus breath debate***

It is important to point out that by focusing on essentially discrete case studies through the use of research papers, this lessened the time available for content coverage, while allowing us to explore the topic under study in more detail. This is not a new problem, and the debate around the optimal degree of content coverage in science courses is one of the most long-lived and contentious conflicts in science education (Schwartz et al., 2009). Some argue that students are best served by encountering as great a number of topics relevant to a particular discipline. Others suggest that focusing on fundamental concepts that are the most important from a disciplinary stand point at the expense of covering many topics in the discipline is a far more productive strategy for student learning. For example, Goforth and Dunbar carried out an 8-year study of an introductory geology course at university level that they taught by focusing on one or two areas, or a broad range of topics. Through an analysis of student responses, the authors concluded that exploration of a relatively narrow subject in depth offers many opportunities for discovery-based learning (Goforth and Dunbar, 2000). Moreover, Schwartz et al. (2009) reported that students who covered at least one major topic in depth (defined as studying it for a month or longer) in high school earned higher grades in college science than students who reported no in-depth coverage (Schwartz et al., 2009). Interestingly, in the same study, those students that reported "breadth" in that they covered all major topics actually had a significant disadvantage in college courses in biology (Schwartz et al., 2009). We propose that the in-depth approach better serves the needs of students. This is reflected in the students' comments who stated that the class was taught in a way that was driven to the use of information and that applying theory to experiments allowed them me to fully understand. These findings all suggest that this approach allows students to appreciate the usefulness and the relevance of information, and how it relates to the disciplinary practice.

Though in this report we have not formally focused on students' performances of understanding, 40% more students obtained the highest grade in the end of course exam on material that was taught using the new approach when compared to material taught in the traditional way. Furthermore, there was a formative element of assessment built into the question and answer style format of each lecture that required students to answer questions raised by the paper. It is interesting therefore to consider these findings in the context of the dimensions of disciplinary understanding – *knowledge, method, purpose, form* (Stone Wiske, 1998). Historically, courses like this tend to teach more to knowledge, or rather what we treat as knowledge (Schön, 1995), by placing a significant emphasis on the information that we have to get through, as if disciplinary knowledge was somehow a thing to be given rather than constructed. This is reflected in a student comment stating that most lecturers do not reference the applicability of the information learned. Essentially there has been a traditional focus on content coverage or knowledge what has also been described as the mile wide, inch deep approach. However, by emphasising the knowledge domain, students are not encultured into disciplinary practice. As highlighted by McCarthy, without the methods (how we learn to build knowledge in the discipline), disciplinary purposes (why this knowledge has significance for us and how we own and make sense of it) and disciplinary forms (the various representations we give to knowledge in making it our own and sharing it), knowledge becomes inert and without context (McCarthy, 2008). We suggest that this revised teaching approach makes explicit for students how knowledge is relevant by making explicit the methods, purpose and forms dimensions of disciplinary practice. This is supported by student feedback stating, *"showing how techniques are used in real-life studies highlight their relevance"* and that "*I like learning new techniques and thinking about what situation you could apply them to answer a question."* These comments all support the idea that this approach makes explicit for students the other elements of disciplinary practice and introduces them to what it means to think like a researcher. This is reflected in comments that it made them think about design, while giving a real insight into process of research. This is essentially an insight into the elements of disciplinary practice.

***The use of a CAT as a tool for reflection***

In this study, we also used a CAT at the end of each lecture. Specifically, the goal was to use it to check for student understanding of the core concepts, and to provide an opportunity for them to reflect on what they had just learned (metacognition). All students found this to be beneficial. Moreover, the students' comments support the proposal that a CAT used in this way can be a vehicle for reflection. As the feedback shows, students stated that the CAT it made them think about the lecture again and that it made them think about and question what they had just learned. These findings support the use of a CAT as a reflective tool that allows students to reflect on in-class teaching and to reflect on what this means for their own scientific thinking (Wong et al., 2009).

***Overall successes and limitations of the approach***

When we asked students what it is about the approach that they liked most, two main themes emerged based on their feedback: 1. the format of the lecture and 2. Improved understanding of difficult concepts. When we explored these in more detail the majority of students liked the question and answer style format of the lecture, which maintained their engagement, and created more interaction in the class. This is interesting, as we have previously shown that Neuroscience students are likely to attend lectures if there is a good standard of teaching, and equate such good teaching with active engagement (O'Keeffe et al., 2017). This has also the added benefit of maintaining student engagement. The students' comments on why they liked the overall approach, suggest that they liked *"looking at real research papers* [and] *going to actual papers that discovered these things and how they did it, not just learning off what they discovered."* Students comments that this approach gave a real insight into the process are important, as this supports the hypothesis that this approach models for students the nature of disciplinary practice.

However, despite the fact that the majority of students liked the approach and suggested that it should be implemented in other courses, this approach is not without its limitations. The teaching is quite different, and as pointed out by the students, this can take some getting used to. A number of students also commented that the approach may be a little slow. This is interesting considering that in our previous work asking students what a good lecture consists of, time emerged as a central theme from their feedback. Specifically, they would like more time in lectures and that lecturers should not rush through them (O'Keeffe et al., 2017). While this approach may have slowed things down too much, in future perhaps a balance can be struck. It is worth pointing out however that some students suggested that these sessions might be too short. Extending these sessions and incorporating more formal performances of understanding during in class time would be ideal. Adding in experimental design questions and answer sheets would be a perfect addition as a performance of understanding during in-class time in the future. This also raises the point as to how this type of teaching is assessed. Presently this course is assessed using a mid-course best of five MCQ and a written essay exam at the end of the course. In future work it will be important to develop the assessment in tandem with the teaching. It may be also interesting to explore assessment as a tool for learning through the development of performances of understanding linked to the course material (Weurlander et al., 2012).

In summary, we suggest that using in-class time to undertake a systematic breakdown of a research paper may make explicit for neuroscience students the nature of disciplinary practice. We suggest this teaching and learning style will support approaches to enculture students in the genres of the discipline and can be effectively used to transform the classroom from a transmittal model of teaching to a place of active learning. We propose that this may be of benefits for all neuroscience students, whether they are on a pre-med or research track.

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