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Learning in the Science Lab: a New Approach

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Abstract

This project aimed to improve the laboratory learning experience for undergraduate science students, focusing initially on first and third year cohorts, through specific objectives. Firstly, to incorporate novel teaching and assessment methods, including student led laboratories, in-house produced instructional videos, ‘Clickers’ audience response devices, and pre-practical on-line MCQ assessments. Secondly, to develop timely feedback mechanisms, including peer review, tutor face to face and audio feedback, online automatic feedback, and report checklists. Finally, to imbed transferable skills into the laboratory including group work, communication skills (written and oral), organisation & project planning, health & safety, and preparedness for laboratories, final year projects & placement. Pedagogical evaluation was through anonymous multiple choice questionnaires and independent academic facilitated discussion forums. The main benefits are students who are better prepared, both for basic undergraduate laboratories and for independent research-based final year projects; continuity in the development of transferable skills; improved assessment quality though constructive alignment and appropriate feedback; and improved student satisfaction through engagement and feedback. The key recommendations arising from this study are; to encourage preparedness for practical sessions, harnessing technology to engage students through interesting pre-practical activities; to encourage an improved culture of feedback, including mechanisms such as podcasts, which also ‘feed-forward’; and to encourage a culture where value is added to modules by actively incorporating transferable skills into all student activities and assessments, rather than a ‘bolt on’ approach.

Key Words: Assessment, transferable skills, feedback, laboratories.

Introduction, aims and objectives:

Traditional or *expository* laboratory teaching methods, where students follow a given procedure to obtain a pre-determined outcome will allow students to manipulate equipment, learn standard techniques, collect and interpret data, and communicate the finding in a written report (Bennett and O'Neale, 1998). However recently there has been debate on the merits of these methods. The level of critical thinking required to perform the experiment, and the consequent deep learning achieved is low, and there is no opportunity for creativity or contextualisation (McDonnell et al., 2007). Furthermore, the environment required for co-operative learning, which requires students learning together with peer tutoring, towards a common goal, is not facilitated by traditional laboratories (Eilks et al., 2009). A more ideal approach integrates application of knowledge to solve problems, group work, and an opportunity to design experiments, including consideration of the safety aspects (Bennett et al., 2009). The group work element is particularly important not only in relation to the socio-constructivist perspective on learning, but also because group work probably comes closer to any other single activity in preparing students for employment, and has been highlighted by the IBEC Education and Skills survey (Mc Gann, 2010) as a skill which needs to be developed further in third level graduates.

With regards to the first year cohort, the practical component of two related laboratory technique modules was redesigned to develop the students' technical skills, scientific observation and report writing. To prepare the students for their laboratory sessions each student was given the complete laboratory manual at the start of each semester. The manual linked to additional resources, including lab instructional videos which were produced in-house, and available through *Webcourses*, the institutes' virtual learning environment (VLE). The students were also required to complete short, graded multiple choice quizzes targeting the important theory behind the upcoming laboratory. The MCQ was automatically graded and provided instant feedback to the student on each question. To support the development of their communication skills, the students initially reported individually on short distinct sections of a typical scientific report and received one-to-one feedback. Following on from this, students worked in small groups to produce four group reports over the course of a twelve week semester. Each report was graded by the lecturer and one-to-group feedback was given. The students also anonymously peer assessed (APA) each others contribution to the group report. The students did not see individual anonymous peer scores; however, they were given the average peer assessment score and this was used to calculate the peer assigned contribution to the overall report mark. The peer contribution was worth 25% of the total report mark. Upon completion of the APA process, the lecturer facilitated a discussion which was used to suggest improvements for future reports. To align learning outcomes and the assessment of lab skills the students practical, problem solving and report writing skills were assessed by an end of year laboratory-based exam which incorporated both technical and communication components.

The third year component of this joint project involved the re-structuring of Food Chemistry laboratory practicals associated with two related modules, with the aim of adding to the learning outcomes of traditional laboratory teaching methods through redesigning learning activities, implementing appropriate and timely feedback processes, and integrating transferable skills including group work and presentation skills. In the first module students worked in groups to 'run' the practical for the rest of the class. The experimental method was provided to the group from the bank of 'tried and tested' experiments which had traditionally been used for food chemistry laboratory teaching. The students then researched the necessary theory to provide the pre-practical presentation. The group was responsible for liaising with the technician to requisition the necessary chemicals and equipment for the experiment. They were also accountable for the safety aspects. On the day, they were in charge of organizing the lab, and explaining the theory, the method, and afterwards, the calculations. The process was repeated in the second module; however the group were also required to devise their own experiment, and were guided through suitable literature to aid this process. In both modules, anonymous peer marking of group members was a component of the assessment.

Group laboratory report submissions were a feature of these modules. Weekly face to face feedback sessions allowed representatives from each group to peer review and discuss the written reports of all groups, and to get expert feedback from the teacher. At the end of the first module a generic scripted summary of this feedback was recorded by the teacher using *Audacity* software, and the audio podcasts made available to listen directly or download from the

Institutes' VLE. This was used in preparation of a final individual lab report. The assessment also included a group scientific poster. A two hour feedback session incorporating peer and teacher feedback on draft posters was organised ahead of final submissions. Pedagogical evaluation took the form of an anonymous multiple choice questionnaire (n=32) and an independent academic facilitated discussion forum (n=8).

In summary, the aim of this joint project was to maximise the learning associated with undergraduate laboratories for First and Third year students by redesigning and aligning assessment and teaching strategies, devising and implementing appropriate and timely feedback processes, and integrating transferable skills at key stages in the curriculum. The student groups were selected based on their participation in suitable modules lectured at Dublin Institute of Technology, School of Food Science and Environmental Health. The first year cohort consisted of students taking the following modules: Laboratory Techniques and Computer Applications, DIT Module Code: TFCH1007 and Foundation Organic Chemistry, DIT Module Code: TFCH1003. The third year group comprised of students talking Food Chemistry I and II, DIT Module Code: TFCH3011/12.

The objectives of this project were as follows:

Objective One: Incorporation of Transferable Skills	
First Year	Third Year
laboratory preparation (video & MCQ)	team work
scientific observation	communication
technical manipulation	project planning
scientific reporting / writing	preparedness for final year project
laboratory safety	employment preparation

Objective Two: Redesigning assessment practices	
First Year	Third Year
Pre-practical on-line assessment	Student led laboratory practicals

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Objective Three: Focus on Feedback	
First Year	Third Year
Peer feedback	peer feedback
tutor feedback	tutor feedback
on-line, instantaneous feedback	audio feedback

Summary of main findings.

The following discussion focuses initially on the first year laboratory redesign project, followed by the third year project. It provides a brief overview of each project, and summarises the results of student evaluation, including key student comments. It also provides the authors reflections on the project and the student reaction in the context of seminal and recent literature in this area, and indicates where improvements may be made in the future. Finally it outlines the key recommendations and conclusions from the research findings.

First Year Group.

Overview:

A redesigned assessment strategy was implemented for a basic lab skills module to specifically target the problem areas of scientific observation and report writing over the course of an academic year. To support this approach the module content, both lecture and laboratory, was redesigned to better align to each other and also to help the student to '*construct'* their own learning. This redesign placed a higher emphasis on continual assessment of lab preparedness, improved the students report writing skills through a reduced number of reports accompanied by formative, constructive feedback and focussed on the correct laboratory technique within the laboratory environment.

Laboratory Preparation.

The main purpose of the on-line multiple choice quizzes was to prepare the students for the up coming laboratory session. Content of the quizzes included safety issues, lab theory, lab technique and simple calculations. The students participated fully with the on-line quizzes (100% completed at least 8 out of the 10 quizzes; students were not required to participate in quizzes in cases where they were absent from the lab due to certified personal reasons, e.g. sick, medical appointments etc.). The vast majority of the students, 94% and 91% respectively, felt the quizzes were user friendly and gave them enough time to complete. Seventy-seven percent of those surveyed felt better prepared for the upcoming laboratory after completing the quiz; noting that they felt more familiar with the lab (equipment, concepts, aims etc.) after competing the MCQ and this helped remove anxiety from coming into the lab, one student commented "*The MCQ prepares and informs you of what's going on in the upcoming lab".*

Student opinion from the evaluation forum gave further insight into the possible reason behind why almost one quarter of students, after engaging with the lab manual and quiz, did not feel better prepared for the lab. The main problem evidenced was scientific calculation; the general student consensus being "*we feel like we were thrown in at the deep end*". The sample calculations available to the students in the lab manual were not sufficient for the students and some student suggestions included: *"Allocate more time when there are calculations involved"* and *"Do* [the MCQ] *before the lab, then do it after the lab to see can you improve* [your score]*"* or *"Do an MCQ before the lab with no calculations, then do one after with calculations"*. However the students did see the benefit of the calculations as part of the MCQ, but their timing would be better following the laboratory, stating "*I do think that the calculations are good, because once you do them in class it would give you time to recap on them to understand them when you are on your own doing them*". Indeed, after the lab the students understood the calculations: "*I did badly in that MCQ, but I understand* [the calculations] *now*".
Students felt motivated to read the manual before going into the lab: "*Sometimes when you read it* [the lab manual]*, its just words on a page, but when it's in a question you have to think about it*". Indeed, if there was no MCQ associated with the lab manual the students "*would have just skimmed over the lab manual*" as with other lab based modules. Students noted that the alternative assessment strategy was a viable substitute for the traditional one report per lab model currently pursued within many other lab based modules: "*For every other lab we would have to do a report, this* [the MCQ] *was an easier way...it only took an hour, but you were still preparing yourself for the lab*". Additionally, students commented: "*This* [assessment strategy] *gave you a break, where you could actually enjoy the lab, because you have done the MCQ, you've done the work...when you had to do a report, you could spend longer on it*". One student noted that "*its sounds like we are lazy, but its actually not!*" and that fewer reports mean that

"*lecturers have more time to go through it* [the lab report] *with you*". Following on this feedback theme, ninety percent of those polled stated that the MCQ feedback was helpful even if they got the question wrong. Students also engaged more with the in-house produced laboratory videos than with the lab manual as a method of preparation for the upcoming lab session (76% compared to 53%).

Skills Development.

The student responses were very clear that the content of the module, and the skills they learnt, were appropriate to their course. For example, 91% of those surveyed could see the relevance of the techniques they learnt in this module to other modules in their course. Furthermore, 96% and 92% respectively felt more confident in the application of the skills learnt and collection data during a typical lab. Here the critical technical skills are highlighted (e.g. instrument calibration and usage), in conjunction with transferable skills such as data recording and observation. However students noted the difficulties in calculation and analysis of laboratory data as a continued problem area. Only sixty-five percent of students felt more confident in carrying out calculations on collected laboratory data after completing the redesigned module. This is in direct comparison to the confidence levels of students (96% and 91%) using the instrumentation and collecting the data in a typical lab. It appears the students are confident in using the instruments and collecting data, but struggle with the analysis of this data and the subsequent higher order thinking skill of evaluation. The basis of this problem may be other areas of the students learning, typically the areas of maths and logic. In the discussion forum a student noted: "*I struggle with maths...so when you are given calculations....and you haven't studied them before I found that very difficult*".

The aligned nature of the module (lectures aligned to labs and subsequently the real world connection) was observed by eighty three percent of the students. Students commented that "*the lab work helped me to understand the lectures and visa versa*" and "*I could see the application of some of the labs in the real world*". Students worked individually for one semester and in small groups (four or less) for the second semester. The students were comfortable working individually or in groups, although initially group work was resisted by the students; "*we did not know what to do, we had never worked in groups this size before...we were out of our comfort* *zone*". However, over the course of the semester the students settled into group work (seventy one percent felt the lab work in groups became easier with time). The anonymous evaluation highlighted the division of the lab work as a potential problem, one student noted: "*I was bored sometimes because my part of the experiment was not interesting or challenging"*. The fair division of lab duties is crucial for engaging and motivating all members of the group. Students appreciated the importance of group work, noting that "*we will be working in groups after college, so it's important we learn how to deal with it now*".

Report writing.

In the module redesign the number of reports was reduced from twelve to four per semester. The assessment redesign incorporated additional short weekly MCQs and an end of year laboratory skills exam. Overall the module scores improved modestly (5% for semester one and 9% for semester two) compared to the year previous to the module redesign. Students observed the benefit of peer involvement (86% perceived benefit of working with peers) which almost matched the confidence of the student in producing a good quality scientific report (79%). During the evaluation forum, students noted the lecturer facilitated feedback session as important; as "*you could see what other group members had done well in the report*" and "*I learnt what I had to do to improve my section of report from discussing reports written by my groupmates*".

Feedback.

Feedback was formally given to students on two major areas; the MCQ and scientific reports. Feedback for the MCQ took the form of on-line comments, based on the student responses to the quiz questions. Invariably the students were encouraged by receiving feedback. If the student selected the wrong answer, (s)he was given the correct answer and an explanation why their choice was incorrect. The vast majority of students (91% and 90%) felt that the MCQ on-line feedback was helpful, and improved their understanding even if they got the answer wrong. Student comments included: *"*[Feedback was] *really good, if you didn't get the question, it explained it...it didn't just say, 'incorrect'...it gave you a reason why you were incorrect*" and "*feedback was really helpful, it was the best part*".

Feedback for lab reports took the form of one-to-one discussions in semester one and one-to-group discussions in semester two. Almost all students (96%) felt that the lab report feedback was beneficial, with 98% of students commenting that one-to-one or small groups were the best way to give feedback. One student commented: "*If I don't get any feedback I don't know if am doing it right or wrong!"* however, "*with feedback you know you are improving, you know you are going in the right direction*". The student further expanded on this point; "*no feedback is not going to help, just getting a mark means nothing*". It is clear that the students appreciate that a higher level of reporting is required in third level, but they need guidance and help to achieve this standard. Indeed, the students taking part in the discussion forum were very motivated and were eager to improve their report writing skills, stating that one-to-one feedback was "*very helpful*, [the lecturer] *points out what I need to include in my report, what would improve my report*". Many students were motivated not only by the feedback, but also by their perceived improvement in their report writing skill: "*you see your marks rise every week...your aiming for 10/10 in your last one* [report]". The students did not find the feedback sessions intimidating, but instead very beneficial as the module drew to an end: *"I thought the last report was the easiest one* [to write], *you had all your previous reports, all your previous mistakes; I found it the easiest but it was supposed to be the longest! Because you knew what you were doing because of the feedback.*"

In semester two lab report feedback took a one-to-group constructivist feedback approach (Askew & Lodge, 2000). In this arrangement the group (typically 4 students) report was initially graded and then discussed, both by the group and also the lecturer, linking previous feedback sessions to the current report and, ultimately, towards future submissions. The group leader was given a copy of the written feedback discussed and (s)he disseminated this to the group after class. Ninety-six percent of students noted that they tried to implement the feedback points in subsequent reports and consequently eighty-two percent of students noted that their scores improved over the course of the year. Furthermore, the majority (84%) of students noted that their reports improved in other lab based modules also and eighty-one percent of students felt more engaged by the alternative assessment strategy and module redesign.

During pedagogical evaluation students commented that their understanding of the course content improved over the study; citing that the formative feedback, both on-line and face-to-face, and assessment strategy redesign proved critical for their engagement and motivation. The role of one-to-one and one-to-group feedback was also noted as crucial to student learning and subsequent development of key skills such as scientific report writing. However, formal and informal module evaluation highlighted areas which require improvement, and many of the students' suggestions have been implemented in further improvements to the module. For example, several students struggled with sections incorporating scientific calculations; particularly if they could not follow the examples in the preparatory manual. The evolved version of this module redesign attempts to improve understanding, to foster continual development and to promote independent learning, by giving the students the option of repeating the MCQ after they complete the associated lab. In this approach, akin to Bruner's' Spiral Curriculum (Bruner, 1966), the students could attempt the MCQ before the laboratory, identify which problematic areas/concepts/calculations, and seek clarification during the laboratory session from the academic team. An additional area further developed was the much praised peer-review and feedback. Peer reviewing academically annotated scientific reports allowed the students to develop an understanding of what a "*good scientific report*" should include; an enhancement of this was to collate and anonymise examples of differing standards of student produced reports and publish them on the institutes VLE (virtual learning environment). Students could then peer review at any time and as the repository of student produced reports increases, so should the students' understanding and access to this important reusable learning resource.

Third Year Group.

Overview

The practical element of a pair of associated Food Chemistry modules was redesigned to add value to the traditional laboratory experience, and to bridge the gap between traditional laboratory practicals ordinarily in the first three years of undergraduate study, and the supervised semi-independent research normal in final year projects. The redesign retained the development of skills which traditional 'recipe style' labs achieve, including allowing students to manipulate equipment and learn required laboratory techniques. Indeed many of the experiments particularly in first Food Chemistry module were the same 'tried and tested' methods used in the preceding traditionally taught laboratories. Importantly, as discussed by Carnduff & Reid (2003), in order to alter and improve the laboratory experience for students, it is not necessary to to change the experiment, just what is done with it.

Transferable skills and preparedness for work placement and final year projects:

The reform aimed to improve the student experience by providing students with the opportunity of putting the literature into context, in a supported setting, thus applying their knowledge to design their own experiment. This approach has been successful, with all students agreeing that choosing their own experiment had made the literature more relevant and meaningful, while almost all (94%) considered that designing their own experiment motivated them to engage with the literature. Students realised the difference between the methodology available in the literature, and how this is adapted for class experiments, with one claiming '*you don't realise when you've always been given the method [in a lab manual], but when you go to the literature, it's like 'this is not in English!' and you have to look up three papers to get a single method*' This realisation will be critical for student's preparedness for final year projects, where adapting the literature and experimental design will be the norm. Further preparedness for final year projects included safety risk assessments, requisition of laboratory consumables and organising all other equipment and glassware ahead of commencing any experiment. This type of planning, which becomes natural during research, is new to undergraduates. Final year project students can feel pressure to produce results, and therefore not spend sufficient time planning their methodology. An aim of this third year module was to demonstrate the importance of good planning ahead of laboratory work.

Overall, almost all students (94%) believed they were better prepared for final year projects, with one suggesting the experience was '*like a stepping stone towards final year projects'*. Furthermore, the majority of students believed that the project has increased their employability skills, including teamwork, organisation, communication and research. Interesting, one student commented that '*we looked at running the lab like it was a job'* while another described how she '*talked about this module in my interview for work placement. It made me feel like more of a grown up person, not just a student'*. When asked if they found the new approach to learning stressful one claimed '*it was a bit stressful, 5 on a scale of 1-10, more stressful than a traditional* *lab, but we gained a lot more from it'* while another believed it to be '*a healthy stress'*. Clearly, the students consider the experience to be more authentic, relevant, and perhaps similar, to the workplace.

Feedback:

Perhaps the most welcome aspect of these modules from the student perspective was the provision of varied, timely and relevant feedback, with frequent comments that it was the best feature of the modules. Petty (2009) discusses the meta-analyses of Hattie and Marzano, which claim that feedback is the single most powerful moderator to enhance student achievement. All students agreed that reflecting on their own reports, reading the reports of peers and discussing them with the lecturer at weekly feedback sessions was a useful way to learn. According to Higgins (2001), rather than a list of assessment criteria, '*feedback may need to be more dialogical and ongoing. Discussion, clarification and negotiation between student and tutor can equip students with a better appreciation of what is expected of them*'. On reading peer reports, one student remarked that *'you look at it [peer report] and think 'now I can see where I'm going wrong''.* This is consistent with the belief that effective assessment should allow students to become confident in making judgements about their own work, which ultimately takes account of the long term purpose of learning, and is considered an essential graduate attribute (Nicol, 2010). Particularly successful was the podcasted feedback. The students in this study mostly agreed (89%) that it was useful in preparing their final report with one commenting '*It's such a simple thing, but it's so effective. I still use it for different subjects'*. Together with the report checklist, which students also mostly believed (94%) to be useful for this module's written report, there appears to be a form of 'feed-forward' or remediation feedback which, as discussed by Hattie & Timperley (2007), allows students' self-regulation, and to develop greater skills in self-evaluation. All students agreed that the feedback provided would help with the assessments and reports in other modules, with one stating that *'I have put the checklist on my wall. If you follow it, you can't forget anything'*.

Assessment:

Overall the students were satisfied with the assessment of the modules under review. The poster assessment was generally well received (78%) with students commenting that '*the poster made looking at someone else's group work more interesting than a set of ordinary lab reports'*. Some students however felt that the poster may not be relevant as they may never have to produce a poster in the future. Students particularly welcomed the opportunity to re-submit the group poster following the poster session within two weeks. This is in line with best practice in assessment and feedback according to Nicol & Macfarlane-Dick (2006) and Black & Williams (1998), both suggesting that students should be able to engage in activities which help to close the gap between current and desired performance. Students felt '*looking at other's posters helped me to see where we went wrong, and what we did well and it was great that we got a chance to resubmit it*' and '*it was good that she* [the lecturer] *didn't just say 'yeah, you should have put that in', but instead said 'right, off you go and make the changes'*.

Room for improvement;

Feedback sessions

While many students (73%) did believe the whole group benefitted from a member attending a feedback session, there is room for improvement here. There was some breakdown with passing on the information from the session to the group as a whole, and this would need to be addressed in future, perhaps by students recording the feedback to a group Wiki.

Presentations

Surprisingly, only about half the group (54%) thought that the project had improved their presentation skills, but on further examination, this was because they either felt they were already good at presenting, or because they had not actually been part of the presenting team. In future, the latter could be improved by suggesting that all students must present at least a small part of the presentation.

Management of group projects

In the recent model, groups sent resources such as a laboratory method and pre-practical presentation to the tutor ahead of the peer teaching laboratory. In future, a group Wiki could be used to gather these resources. This would allow more convenient tutor feedback, and also could be used as part of a group assessment strategy.

Peer review

While most students (88%) agreed that the peer review was a useful way to assess aspects of group work, it would be improved by introducing an electronic peer assessment. This would simplify the logistics of organising and recording peer review compared to a paper system, and therefore allow a more comprehensive insight into the group, and according, a fairer individual assessment mark.

Summary of Research Outcomes.

Research outcomes from this project will be applicable to all practical based modules. The benefits of this approach to teaching are evident for both the student and the academic. Students are better prepared, both for basic undergraduate laboratories and for independent research-based final year projects (Dunne, 2011). Based on the aligned teaching approach adopted in both first and third year, there is continuity in the development of transferable skills resulting in increased employability (Mc Gann, 2010). An improved assessment quality is supported by constructive alignment and appropriate feedback which simultaneously resulted in improved student satisfaction and engagement (Petty, 2009). The key recommendations arising from the project evaluation include the absolute need to encourage student preparedness for practical sessions. To achieve this academics can harness technology to engage students through interesting pre-practical activities suited to level and stage (Swanson & Lynch, 2003). Furthermore, an improved culture of feedback, including innovative feedback mechanisms such as podcasts which also ‘feedforward’, should be promoted at both local and institutional levels (Hattie & Timperley, 2007). Finally, an ethos of adding value to modules by actively incorporating transferable skills into student activities and assessments, rather than a ‘bolt on’ approach, should be adopted (Carnduff & Reid, 2003).

Conclusion:

The project focused on First and Third year students in individual modules, however this approach is self-sustaining and can be rolled out across all years and all practically based modules without significant resource requirements. It will be particularly effective if there is a critical mass of engaged staff.

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