Engaging first year science students through a multidisciplinary approach

Eilish McLoughlin, Odilla Finlayson

Eilish.McLoughlin@dcu.ie, Odilla. Finlayson@dcu.ie
Centre for the Advancement of Science and Mathematics Teaching and Learning,
Dublin City University,
Dublin 9.

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Abstract

First year undergraduate science students generally attend lecture and laboratory modules in introductory Chemistry, Physics, Biology and Mathematics, regardless of their ultimate degree programme. Students often do not see the links between these subject areas and in some cases, even question the relevance and importance of each discipline. In this initiative, students were engaged in all the disciplines through tackling multidisciplinary and interdisciplinary science problems, in small groups, facilitated by postgraduate tutors. Topical problems included nuclear energy, brewing, water treatment and environmental issues of oil pollution. As a result of this module, students gained an appreciation of the relevance of all science disciplines and of the importance of communication skills. Evidence obtained from analysis of student feedback, over a four year implementation period with over 600 students, indicates that while many students engage fully with the content, others find the open nature of the problems less appealing. A discussion of the challenges involved in student assessment and in devising suitable problems will be presented in this paper.

Keywords

Multidisciplinary, science, small-group, problems.

1. Introduction

Students in first year university science programmes generally must take modules or courses in all science disciplines to a basic level. The reason for this is that we, as curriculum and programme developers, see the relevance and interrelations of each of the disciplines to each other and the necessity for a student to have a good foundational knowledge in each one e.g. a chemistry student will usually also take basic courses in biology, physics and mathematics as well as chemistry. However, the students may often not see the necessity or relevance of the other subjects (Figure 1).

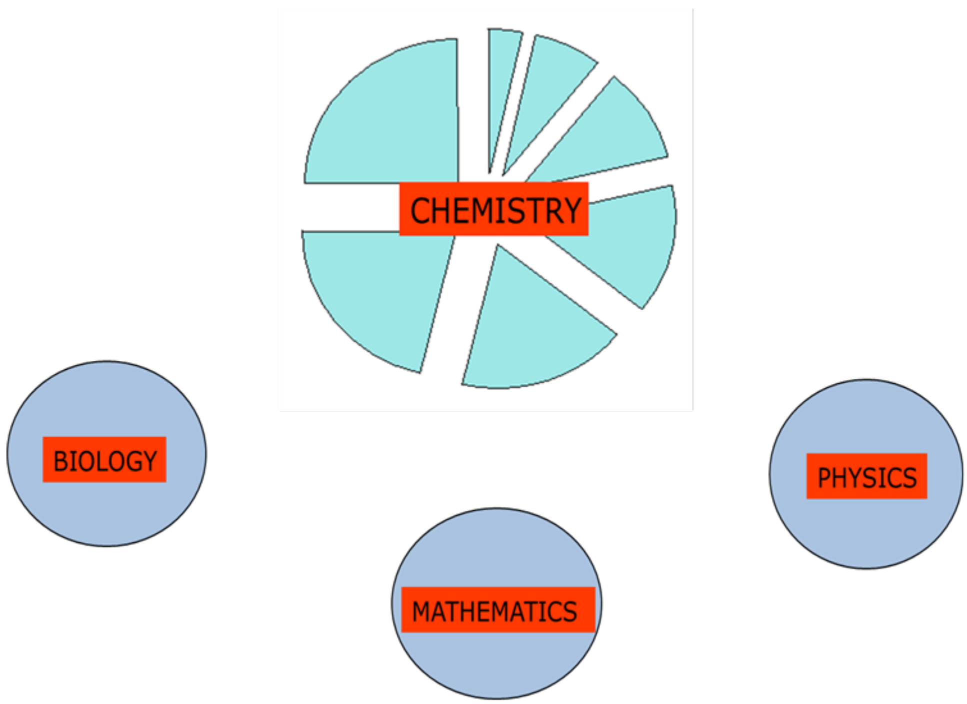

Figure 1: Diagramatic Representation of Fictional Individual Chemistry Student's Perspective of a First-year Programme: Size of the Disc Showing Relative Importance and the Segmented Disc Represents Individual Modules or Parts of Modules.

Recent employment/skills reports have identified the need for university graduates to have proven abilities in a range of skills, including communication, problem solving and group working / team working skills (Europe Needs More Scientists, 2004; Bennett, Dunne & Carre, 2000; Sunal, Wright & Bland 2004). In many science degree programmes, many of these skills are not addressed or are only addressed in the final year of study (Gray, Emerson & MacKay, 2005). The authors of this paper suggest that students should be involved in these activities from the very beginning of their study at third level.

A third distinct issue within university undergraduate programmes deals with the future careers of our students, i.e., the industries that our graduates will work in, the type of activities they will be involved in, the research activities, etc. Much of the scientific research in science now involves multidisciplinary teams of researchers, with knowledge in several different disciplines, or indeed interdisciplinary teams, where knowledge is cross-disciplinary. However, students in first year programmes are generally not exposed to these types of research problems.

These three issues then combine to raise the question as to what activities can we engage students in, so that we can:

- Expose them to the multidisciplinary and interdisciplinary areas of science, and the nature of science;
- Encourage realisation of the importance of each discipline to their central discipline of study;
- Provide opportunities to get first-year students involved in skills development such as communication skills, team and group working skills.

To address these issues, we devised a module of study that consisted of a range of problems that were multidisciplinary in nature, which students could tackle in a group work setting. Groups of students involved in this module were those who would ultimately specialise in Analytical Science, Biotechnology, Applied Chemistry, Environmental Science and Genetics and Cell Biology, all pursuing a common first-year programme involving introductory courses in Biology, Chemistry, Physics and Mathematics.

2. Problem Details

Zoller (1993) identified that students required problem-solving skills, so that they could become responsible and effective citizens. Cardellini (2006) stated that "problem solving is a process in which various reasoning patterns are combined, refined, extended and invented. It is much more that substituting numbers in well-known and practiced formulas; it deals with creativity, lateral thinking and formal knowledge". Therefore, a set of problems and problem scenarios were devised that:

- were based on their 1st year science modules i.e. students should have met the underlying science in their course work to be able to tackle the problems. The aim was not to teach new material through the problem but to reinforce student's own knowledge and skills. Students should see new applications for their knowledge or require to use their existing knowledge within new contexts.
- had an element of each of the disciplines, physics, chemistry and biology, included in each or at least most of the problems.
- were a mixture of open and closed problems.
- were relevant and interesting to the group of students.

Problems generally can be classified as either closed, which have an acceptable answer, or open, where there are numerous acceptable answers, and there may even be a variety of methods possible to reach that answer (Reid and Yang, 2002). Johnstone (1993) categorised problems into eight types, depending on the availability of data, the familiarity of the method and the clarity of the goal. These types ranged from Type 1, where the data provided was complete, the method familiar to the problem solver, and the goal clearly stated, to a Type 8 problem, where the date given was incomplete, the method unfamiliar, and the goal unclear. The categorisation from Type 1 to Type 8 was not designed as a hierarchical structure, but rather highlights the different areas of problem solving. Therefore, we felt that it was necessary to include different types of problems within this module.

Additionally, we wanted to have problems where there was not "only one-right answer", thereby to expose students to the true nature of science, where often the answer is unknown. Wood (2006) highlighted the problem that if our teaching does not include such problems, then our students can develop the view that all is already known in science, and that they can make no personal contribution. To this end it was important to raise ethical issues within the problems also. Table 1 summarizes some of the problem scenarios, and outlines the scope of each problem, the content and the output required. An example of a problem was Home Brewing. The scenario was set within the social context of student assessing if they could generate a profit from setting up an independent home brewing set up. Specifically, it covered the chemical synthesis of alcohol, possible impurities from the process, interpretation of workflow diagrams of the brewing process, discussion of asepsis and sterilization techniques, and energy and thermodynamic calculations on energy of heating and cooling, energy costs with a final estimation of the profit margin, based on equipment requirements and ingredient costs.

Table 1
Problem Scenarios Showing the Range of Scope, Content and Output of the Problems

Problem Title	**Scope**	**Content**	**Output**
Everyday Science	Explanation of everyday applications of chemistry, physics, biology.	Open	Poster presentation /Critique
Nuclear Energy	Process; reading of scientific articles; extracting arguments	Given number of reference papers	Letter to Minister
Shrinking Man	Cell structure and function, Immune response system, DNA, Electronic configuration, Reduction /enlargement.	Series of questions to solve	Scientific evaluation report
Genetic Screening	Genetic screening. Ethics arguments.	Representative of particular lobby group	Articulate stance Group debate
Home Brewing	Thermodynamics, Energy calculations, Organic synthesis of ethanol. Sterilization techniques.	Process and data re-scale	Report – profit
Caving	Energy generation, chemical formation, bat species, mechanical pulleys.	Series of questions to solve	Article
Contaminated Water	Tests for potable water, e.g. BOD, COD, chlorides, sulphates, algae, microbes.	Select 5 test results	Report for a lay audience

The problems devised would be considered to be Type 3 to 6 on Johnstone's classification. As these problems were designed as group activities, the dynamics of group work had to be considered. Within the module, we aimed also to have a broad range of assessments involved within the module, such as, from poster presentations, scientific evaluation report to debate, as indicated in Table 1.

3. Implementation

This module has been implemented over the last four years with approximately 180 first-year students each year. The group size was 4 – 5 students which were in the main self-selected. The duration of the module was 12 weeks with some problems running over 2 weeks, and each week, students were timetabled for 3 hours in groups to generate solutions to the problems.

In the first week, all students were given an introductory session outlining the aims of the module and why it had been developed. They then participated, within their small groups, in a workshop on group work and finally, within each group, they devised a 'modus operandi' of how each member should behave within their group, and also what they would do in the event of any difficulties within the group. This was done in order for each group to discuss between themselves the potential issues that could arise in their group, and to allow them to set the limits within the group on support provided by the group. As the assessment for this module was based totally on a group mark, then it was important for each member of the group to contribute to the working of the group.

Over the four years, there were some changes to implementation in the light of student feedback after each year. For instance, in the first year, the problem session was three hours and the students were given the following week's problem at the end of the three hour session. However, feedback from the group at the end of year 1 focussed on four key issues that the students encountered, as is summarised in Table 2. In year 1, namely, they wanted more time for their group to meet after being given the problem; they wanted more clarification on the more open-ended problems in terms of what was required; they wanted a detailed feedback on their problem solution; and they asked for some mechanism to show that each member of the group was contributing to the problem.

To address these issues, in subsequent years, the problem session was reduced to two hours and there was a one-hour slot with the whole group, where issues relating to the previous problem were discussed and the problem for the following week was presented. It was felt that this was required to clarify any ambiguity in the problem or to clarify any issues that the students had before they tackled the problem. It was also useful in spelling out the detail of the assessment criteria for that problem. The one-hour session was timetabled for the morning after the problem session, so the students received general feedback within 24 hours of them completing their problem. This was useful as the problem was still fresh in their minds and they could remember what they had done (as recommended by Race, 2003). Groups were not given an opportunity to resubmit. Finally from year 2 onwards, each individual had to submit a paragraph online, where they noted their own involvement within the group in solving the problem. This was also to alert the academic and tutor staff to any issues of group members not working together, etc. It should be noted that the paragraphs submitted by the individual students did not form part of the assessment; however, if a student did not submit a paragraph, then it was assumed that they were not involved in solving the problem and therefore were not awarded the group mark. This mechanism was introduced to try to move the groups to co-operative learning groups, in where each individual would feel accountable for the whole group to be successful (Johnson and Johnson, 1994).

Table 2
Key changes that were implemented after Year 1

Change	Year 1	Year 2 - Year 4
Timetabled problem solving time	One three-hour session per week	One one-hour session with whole group + one two-hour session in small groups per week
Introduction to the problem	Brief introduction at the end of three-hour session	Introduced in the one-hour session – time for students to seek clarification
Feedback	Feedback given to groups over several weeks	General feedback given within 24 hours
Individual contribution	None monitored	Each student submited a paragraph online

4. Results and Discussion

Similar problems were set over the four years and each year, students' opinions both on the problems themselves and the overall module as a learning experience were elicited though paper surveys. Students were presented with a series of questions to which they indicated their extent of agreement by indication on a 5-point Likert scale. Additionally, small groups of students volunteered to participate in focus group discussions, which were either facilitated by the individuals themselves or by an external person. The output of these surveys and focus group discussions formed the basis of our evaluation of the module.

The main aims of this module was to develop a module that would highlight the multidisciplinary and interdisciplinary nature of science, that would interconnect the three science disciplines, and that would allow students to develop additional skills as discussed earlier. The module content should encourage students to make decisions on the basis of evidence or limited data, to find relevant information, and to form opinions (based on scientific arguments) on a current scientific issue of direct interest to the public. We wanted to see all students actively participating in the groups and collectively using their scientific knowledge to solve the problems. In most problems, the students should already have covered the basic science required to solve the problem, so the aims of the module did not include teaching of new content knowledge through the problem; however if students learned new content knowledge, then this was an additional benefit.

The results of student surveys on the group work aspect of the module are given below. Table 3 shows the percentage of students who agree (either strongly agree or agree) and disagree (either disagree or strongly disagree) to a series of statements. The data is given for each of the four years and also the total over the four years is shown. It should be noted that the remainder of the students indicated 'somewhat/unsure' to each statement and these % can be determined from the data given.

Table 3
Student Opinions of Group Work

Statement	Total % (4 Years)		*Agree (%)				**Disagree (%)			
	*A	** D	Yr1	Yr2	Yr3	Yr4	Yr1	Yr2	Yr3	Yr4
I learn a lot of science working in my group	**61**	**14**	74	51	59	59	4	26	19	10
I make a large input into the work of my group	**89**	**1**	90	87	93	87	0	2	0	3
My group functions very well - everyone contributes and the work is shared evenly. Everyone makes a valuable input.	**74**	**11**	82	68	71	75	7	14	9	15
I like working in my group	**79**	**7**	88	69	81	79	4	10	6	8
The number of people in my group is just right for tackling the problems	**78**	**9**	87	68	71	85	5	17	11	5
I would prefer to work on my own to solve the problems	**16**	**62**	9	18	22	17	70	56	59	61

* Strongly agree + agree **Strongly disagree + disagree Balance is % somewhat/not sure

Students generally indicated that they felt that they liked working in their groups, they were making a large input into the work of the group and that they learned some science as part of their group. Also, they preferred tackling the problems as a group rather than individually. Focus group discussions highlighted problems with members of a group not pulling their weight, and this was particularly evident in groups that were 'amalgamated' or that were particularly big. In year 2, there was somewhat less satisfaction with working in the group and this also came out in the focus group discussions. In year 2 there had been several changes to group members over the first few weeks, and this may account for the lack of satisfaction with the groups. The number of people working on a problem, i.e. the group size, was usually 3-5 members but in Year 2 this ranged from 3-7 members and this may explain the slightly less positive agreement to the question on the group size. While some group problems were tackled by referring back to the rules that the group had agreed on at the beginning, some issues lingered to the end of the module and academic staff were reluctant to directly interfere with the workings of the groups before the group tried to tackle issues themselves.

With respect to the scientific content of each problem, students in year 1 were generally more favourable than in subsequent years (see Table 4, which indicates the % of student agreement to a series of statements relating to the scientific nature of the problem).

Table 4
Mean Student Opinions on the Scientific Content of the Problems

Statement	Total % (4 Years)	*Agree (%)	**Disagree (%)

	*A	**D	Yr 1	Yr2	Yr3	Yr4	Yr1	Yr2	Yr3	Yr4
There is enough time to complete the problem sets during the session if everyone has prepared beforehand.	**72**	**15**	88	59	63	73	2	26	21	14
I find the problems interesting and challenging	**54**	**17**	71	48	40	52	13	21	23	12
I like the mix of physics, chemistry and biology in the problems	**60**	**18**	74	57	46	60	11	19	31	13
I have the necessary Physics background required to solve the problems	**29**	**52**	34	23	25	31	44	56	58	51
I have the necessary Biology background required to solve the problems	**74**	**7**	73	70	73	80	4	12	8	5
I have the necessary Chemistry background required to solve the problems	**47**	**33**	58	44	44	40	26	32	35	39
I found all the calculations in the problems difficult	**45**	**21**	35	50	46	50	31	7	24	20
I feel that I am learning a lot by doing the problems	**52**	**17**	73	46	41	45	8	19	31	13
The problems help in revising / reinforcing the physics, chemistry and biology that I have covered in lectures	**46**	**26**	67	39	32	43	12	27	45	25
Overall I found the problems challenging but doable	**64**	**11**	82	60	53	56	6	13	17	10

* Strongly agree + agree **Strongly disagree + disagree Balance is % somewhat/not sure

There was very strong agreement in year 1 with the statement:

Overall I found the problems challenging but doable.

However, while the level of agreement has dropped over subsequent years, it is still above 50%. This indicates to us that we have set the problems at the right level. While generally, the feedback from year 1 is more favourable that in subsequent years, the level of agreement over the years is remarkably similar. Students felt that they had sufficient time in which to complete the problem but found the mathematics aspects of the problems challenging. While the students felt that they generally had the necessary biology background to tackle the problems, this was less positively stated for chemistry and even more so for physics. This may reflect the prior experience of the students before entering the university, where almost all have a background in Biology, while approximately 50% and only 30% had taken chemistry or physics respectively, at second-level. But, in spite of the varied backgrounds, the students were able to cope with the problems and they liked the integration of all the disciplines within the problem. From the focus group discussion, it was clear that the students found this approach more challenging than a traditional lecture type format. They also felt that they had to attend as they would be letting down their group if they did not. Interestingly, from the focus groups, it was clear that the students did not identify roles for members of the group (such as, leader, scribe, etc.). Instead, they identified the information required for the problem, or the separate tasks within the problem and divided them up between the members of the group in a collaborative manner. The group then came together to collate and compile their answer to the problem. No one individual took over the group. Also, it was clear that some groups met outside of the timetabled time to go through the problems.

Finally, the students were asked their opinion of each problem and if they felt they had learned from that particular problem. The responses are summarised in Table 5.

Table 5
Student learning from each Problem

Problem Title	I liked the problem (% Agree)				I learned from this problem (% Agree)			
	Yr1	Yr2	Yr3	Yr4	Yr1	Yr2	Yr3	Yr4
Introductory Problem	79	63	78	75	57	44	62	65
Science in the News		40 (1)				57		
Morning in the Life		69 (2)				66		
Nuclear Energy	72 (1)	70 (3)	76 (7)	72 (5)	87	80	79	88
Water Contamination	82 (4)	61 (4)	69 (2)	71 (3)	89	74	76	84
Shrinking Man	66 (3)	49 (5)		47 (7)	75	60		50
Genetic Screening		73 (6)	73 (6)	69 (6)		78	82	87
Moon Hoax		84 (7)				83		
Home Brewing		50 (8)	53 (8)	60 (2)		65	64	79
Industrial Oil Spill	74 (2)	43 (9)	52 (4)	62 (4)	84	54	63	77
Everyday Science			71 (1)	85 (1)			73	77
Caving Problem			53 (3)	67 (8)			67	71
Library Session			50 (5)				58	
Modern Industry			63 (9)				64	

*The number in brackets denotes the order of the problem in each Year.

Over the four years, it is clear that the majority of students both liked and learned from each problem. Interestingly, the % who learned from each problem was greater than or approximately equal to the % of those students who liked the problem, e.g. 70% of students in year 2 liked the Nuclear Energy problem, while 80% stated that they had learned from it. Therefore, as a learning experience, students have responded well over the four years. Interestingly, problems of topical interest such as nuclear energy, water contamination and genetic screening scored highly in all years for both engagement and effective learning. These issues are not addressed directly in lectures in the first year programme, so students had to do some additional literature research and compile their findings in arguments that could then be presented. This was the first introduction for students within the programme to develop these skills. Finally, it is clear that class groups are not 'reproducible' from one year to the next. The problem Shrinking Man (which involved the scenario of a man shrunk to a suitable size to be injected into the blood stream of a rabbit and students had to discuss various obstacles that the man met on his journey through the rabbits body – focussing on relative size and biochemistry) was an interesting problem for year 1 students but was not liked by year 2 and 4 students. The Industrial Oil spill problem scored more highly in year 4 – maybe due to its coincidence with the events in the Gulf of Mexico (Oil Spill in Gulf of Mexico, 2010). The Home Brewing problem shows increased popularity with students in latter years.

5. Conclusions and Future Work

In conclusion, we have developed a module to highlight the multidisciplinary and interdisciplinary nature of science, showing the relevance of each of the science disciplines and providing opportunities for first year students to develop a range of skills. We have implemented this module with a large cohort of students (approximately 180 students each year) over a four year period. The balance between open and closed problems was not an issue for the students. In general the students found the problems challenging but doable and they generally both liked and learned from each problem – the extent of the learning varied from problem to problem.

The problems used allowed the students a chance to develop a range of additional skills that would not normally be introduced in first year – such as developing arguments, finding scientific data and evidence (literature search and synthesis of the literature data), presentation skills, poster presentation, scientific writing, concise arguments, lack of 'right' answer. These skills are key to further development as successful science students and as potential researchers. In the focus group discussions, one group focussed on the development of these skills, and they discussed how necessary these skills were and how they felt more prepared to implement these skills in later years of their study. In contrast, the other focus group (consisting mainly of girls) were negative about development of these skills stating that they should only be tackled when required and later in the programme, e.g. finding literature only when relevant to a final year project, likewise with debates, or poster presentations.

In terms of the group work, students liked working in groups and preferred to tackle these problems as part of a group rather than as individuals and stated that they felt that they had contributed well to the working of their group. There was almost full attendance at this module.
In terms of assessment, students generally achieved higher marks in this module than in the other scientific modules. We did not expect to see a correlation in marks as in this module other skills were being assessed and it was all group assessment. Additionally, we did not determine the scientific knowledge of the students individually at the end of the module, so we cannot determine if their scientific knowledge increased. Certainly, they were exposed to more independent or cooperative learning than in lecture modules, and also they were given the chance to develop alternative skills, such as, finding information, generating arguments, etc. The social dynamic within the group should not be overlooked. Here were groups of first year students actually discussing science!

Future work will involve a more direct measurement of the particular skills and will involve detailed analysis of the nature of the discussion that the students engage in within their groups, the scientific language used in their discussions, and the process that the groups use in tackling the problems.

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