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Research Article

Investigating the Impact on Skill Development of an Undergraduate Scientific Research Skills Course

Kay H Yeoman and Barbara Zamorski

School of Biological Sciences, University of East Anglia, Norwich, Norfolk

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Abstract

This paper describes the design and subsequent impact of a scientific research skills course. Student understanding of the university research environment, their confidence in finding and using scientific literature and in scientific writing and presentation pre- and post-course was investigated. The findings suggested that understanding of the research environment and research process which was poor pre-course, improved after its completion. This increase in students' understanding and confidence was also observed in their understanding of the research literature, and their ability to write scientifically and present scientific material. The students gave the course a high evaluation rating, praising the teaching and the transferable skills that it offered. The research projects carried out by the students were successful, but during the process it was found that those projects which were less well defined at the start and offered the opportunity to design research questions were more successful in the development of higher cognitive skills than projects which were highly defined at the start. The research project allowed the students to become emotionally attached to their work and this substantially increased their motivation to succeed. This enquiry based learning course provided a platform for the meeting of teaching and research and demonstrated a mutualistic symbiosis.

Keywords: research-led teaching, enquiry based learning, transferable skills

Introduction

There has been a lot of interest in recent years in the links which are purported to exist between research and teaching in the academic environment and also the importance of these links. This wealth of literature has embedded new terminology in this area of educational research which includes descriptive terms of the supposed relationship, such as 'nexus' (Jenkins *et al*., 2003, Henkel, 2004, De Weert, 2004) and 'symbiosis' (Zamorski, 2000). The former term is used to describe the link between staff research and student learning. The latter is a scientific term used to describe an intimate biological relationship, which can be parasitic (generally harmful to one partner) or mutualistic (beneficial to both partners). Research in its broadest sense is the acquisition of new knowledge through investigative procedures. These procedures can, in the case of scientific research be done via wet-laboratory experimentation, but they can equally be done though the novel interpretation of existing literature, as in the disciplines of English, Law and History. When using this definition, Elton (2001) suggests that research and teaching are simply two different forms of learning and that any link between the two is mediated through scholarship. According to Deakin (2006), the scholarship model of teaching proposes that it should not be seen as an activity separated from research, but as pursuits which relate with each other through learning.

In trying to establish a mutualistic symbiosis, research-led teaching has become a philosophy driving many UK universities as illustrated by their mission statements. The UEA 2001 mission statement ('Principal Objective 4'), speaks of the "need to preserve the interaction of research and scholarship with teaching". There are however a growing number of academic studies which highlight the confusing and inconclusive relationship between the two (Brew and Boud, 1995, Elton, 2001, Hattie and Marsh, 1996). Despite this, the drive towards linking the two activities in academic institutions has been increasing over the last few years.

Scientific knowledge is grounded in research and there is a fundamental and substantial link existing between teaching and research. Indeed they are so intertwined at the root that one cannot survive without the other, forming a genuine mutualistic symbiosis. In the biological sciences discipline the link is simply not questioned, "We know it is true as part of our discipline culture" (Sears and Wood, 2005). Research ideas build upon peer teaching through primary scientific literature and conferences. The theories and paradigms which build up around this interaction are gradually disseminated into teaching to inspire future generations. Despite the literature suggesting only tenuous links between research and teaching, Hattie and Marsh (1996) and Jenkins *et al* (2003) suggest that this does not mean that it is not worth striving to identify, establish and strengthen the symbiosis, indeed they believe it is essential that institutions put into place within the curriculum areas where teaching and research can meet. It is interesting to note that Gibbs' (2002) examination of research-led teaching suggests that the environment which allows teaching and research to meet is lacking in UK universities and more opportunities need to be provided to allow stronger relationships to form. In order to address this issue case studies and projects are being established to advise on how it is possible to develop new links in teaching practices, for example the Linking Teaching and Research in the Disciplines project, funded by the former LTSN Generic Centre and now supported by the Higher Education Academy.

Brew and Boud (1995) argue that what learning and research have in common is the process of enquiry. An enquiry-based teaching approach motivates students by helping them to learn "about and through research" (Jenkins *et al*., 2003). In the education literature there have been a number of papers describing and analysing enquiry-based courses. Rasche (2004) and Stahelin *et al* (2003) report that these enquiry-based courses are being designed to enable students to obtain research experience while learning laboratory techniques and pursuing open-ended research questions. DebBurman (2002) suggests that the involvement of students in real research projects promotes interest and learning in complex scientific content, helps develop science experimental skills and enables students to gain familiarity with the science culture. Qualters (2001) showed that students viewed this type of learning as a "connecting mechanism" both with other course content and more interestingly in a personal way with faculty. Enquiry based learning also develops key transferable skills needed for lifelong learning and Kahn and O'Rourke (2005) suggest that the leadership skills in managing these types of complex projects for example are very important in future employability. There are several ways to incorporate enquiry based learning into the curriculum and these overlapping elements include problem-based learning, individual and group projects, research projects, field work, case studies and investigations (Kahn and O'Rourke, (2005). These elements provide ways in which research and teaching can meet and interact as suggested by Jenkins *et al* (2003).

Research is active, exciting and dynamic, but it does not need to be at the forefront of the field to be of value to teaching. Research capabilities include innovation, independence, setting and solving problems, analysing critically and being able to handle information in a variety of ways. These research capabilities require a wider body of knowledge and techniques within the discipline, and higher cognitive skills (Roach *et al*., 2000). We believe that the skills that make a good researcher are also those which are required for student centred learning, and any teaching which enables students to develop these skills would benefit not only their immediate studies, but lay a foundation for learning throughout their lives.

This paper describes the development and subsequent impact of a scientific research skills course for second year undergraduate students in the School of Biological Sciences, University of East Anglia (UEA). The aims of the pedagogic research described were two-fold. Firstly, to investigate the effectiveness of a new course in scientific research skills upon developing the understanding and confidence students have about the research environment and research skills respectively, and secondly, to investigate if the scientific research skills course developed a stronger relationship between teaching and research.

The participants

Twenty-one students took part in the course. Of these 18 were in their second year of study and 3 were in their final (third) year. The students registered on the course had completed extensive practical programs in their first year. They were conversant in laboratory maths skills and able to use basic laboratory equipment. They had a basic grounding in the theory behind microbiology, genetics, molecular biology, cell biology and biochemistry. Written permission from the students was obtained to reproduce their work and evaluations in this paper in accordance with local ethical rules.

Structure of the Scientific Research Skills Course

Prior to designing the research skills course, we considered the desired learning outcomes and decided on how they were to be achieved. The three-stranded pedagogy of the course, described in Table 1 aimed to impart sophisticated scientific and intellectual skills. The course had a variety of assessment methods, in order to test the students' acquired skills and to ensure the learning outcomes had been achieved. There was a mixture of individual and group assessed work and also a small element of peer assessment. The majority of the mark was awarded for the individual report of the project, written as a research paper.

***Table 1** A three stranded pedagogy of the research skills unit*

Seminars	Laboratory	Dissemination
The research environment	General Lab skills	Research paper
Safety	Laboratory safety	Oral Presentation
Ethics	Cell culture	Scientific poster
Data Analysis	Molecular techniques	
Scientific writing	Microbiology techniques	
Learning how to assess		

Research Methods

A questionnaire was used to assess understanding of the research environment and confidence in research skills pre- and post-course. For this assessment 31 statements were rated on the first day and last day of the course with a mix of Likert-type scale questions and yes/no answers. Using the modified Likert-type scale students selected one of seven choices, where 1 was strongly disagree, and 7 was strongly agree. The Likert scale was used to gauge strength of feeling. The statements were split into six sections: A–F. A: Scientific literature; B: Understanding the research environment; C: The research process; D: Scientific writing; E: Presentation of Scientific material; F: The future. Student anonymity was maintained during data collection.

An evaluation form was used to enable the students to assess their experience in undertaking the course and to comment on the effectiveness of the teaching method. The process of self reflection in the form of a personal diary maintained by the investigator was used to comment upon the effectiveness of the pedagogy.

Results

The students' responses to the statements in the questionnaire are presented in Table 2.

***Table 2** Student responses on a Likert Scale from 1–7, where 1 was strongly disagree, and 7 was strongly agree on statements in five sections; A: scientific literature; B: understanding the research environment; C: the research process; D: scientific writing and E: presentation of scientific material*

Section	Statement	Pre Course Response	Post Course Response
A Scientific literature	I know how to find research papers in Journals	3.8	6.5
	I know the purpose of a research paper	5.0	6.6
	I know the structure of a research paper	4.8	6.6
	I know where to look for relevant information in a research paper	3.7	6.4
	I know how to communicate the results of a research paper to my peers	3.4	5.6
	I know how to use research papers to inform my own research	4.0	6.1
	I know the different ways scientists communicate information to each other	3.0	6.0
	I know the different ways scientists communicate information to the public	3.8	5.8
B Understanding the research environment	I know the criteria by which my lecturers are judged by their peers	3.1	5.3
	I know what makes a successful research scientist	3.0	5.7
	I know the roles of the individuals in a research group	3.2	5.6
	I know what the RAE is	1.5	4.8
C The research process	I know how to ask my own research questions	2.6	5.4
	I know how to design experiments to test a research question	2.8	5.5
	I know how to collect data from experiments	4.1	6.0
	I know how to record experimental detail in a lab book	3.4	6.1
	I know how to analyse the data I collect	4.0	5.7
D Scientific writing	I know how to write scientifically	3.8	6.0
	I know what an abstract is in a scientific paper	4.5	6.2
	I know how to write an introduction to a paper	4.3	6.4
	I know the different systems of referencing	3.6	6.0
E Presentation of Scientific material	I understand how to present results	4.0	5.9
	I am capable of producing my own graphs	5.0	6.2
	I can discuss my results with confidence	4.2	5.7
	I can write a good oral presentation	4.0	5.4
	I understand the purpose of a scientific poster	4.3	6.4
	I know how to design a scientific poster	2.7	6.1

Understanding the Scientific Research Literature

The ability to access the primary literature and to find the right information within papers is a crucial skill, but the students seemed to have poor confidence in their ability to find research papers in journals.

The subject of finding papers was addressed within a workshop where they were shown different ways to try and obtain papers, and the use of Boolean operators to limit their search fields. This resulted in an increase in confidence post course. It is interesting to note, that despite a lack of confidence in finding papers, students seemed to understand the purpose of a research paper although they had a poorer conception of how to find relevant information within it. Levels of confidence in both these areas increased after completion of the course.

In the area of communication, there appeared to be limited understanding of the different ways scientists communicated with each other, which conflicted with their supposed understanding of the purpose of a research paper.

Understanding the research environment

The research environment is dynamic and exciting, although in our opinion it is virtually invisible to most undergraduate students. Students are never specifically informed on the research aspects of their lecturers' job and how they are assessed nationally. Any insight is gained through the students' own endeavour at trying to understand the research environment, for example through vacation work placements. There is no shared understanding of the process of how their university is assessed for the quality of its research, and how this subsequently translates into income. Perhaps not surprisingly, there was little understanding of what the research assessment exercise (RAE) is actually about prior to the course. Afterwards, students appeared to be more aware, with a three- point increase in the level of understanding. Interestingly, although there was little comprehension of the RAE the students seemed to have some perception of how lecturers are judged by their peers and what, in their opinion made a successful research scientist. After completion of the course there was a two-point increase in all these areas (see Table 2).

Students' Understanding of the Research Process

Understanding the actual research process is a fundamental skill of the research scientist, but also hones higher order thinking. Students had a reasonable level of understanding of how to collect, record and analyse data, prior to the start of the course. This understanding comes from undergraduate practical sessions. It is clear however, that students have very little understanding of how to ask research questions and subsequently design experiments to test those questions. This is not surprising considering the prescriptive nature of their previous practicals. After completion of the course, confidence in all areas had increased. This was most notable in the area of designing experiments to test research questions, although there is still more that could be achieved in this area to provide greater understanding. Surprisingly the students seemed quite confident in being able to analyse the data they collected, which indicated that the previous practical sessions were valuable in this respect. Although confidence increased post-course, by 1.7 points, more could have been achieved and this will be a key target for improvement of the course in future academic years.

Confidence in Scientific Writing

Scientific writing is a good training ground in the discipline of clear and concise writing. Students have had practice at writing from the start of their degree programme, but with varying levels of success. Scientific papers begin with the abstract and students seemed confident in understanding the purpose of the abstract and their confidence increased post-course. Students were encouraged to read the abstracts of papers whilst doing literature searching and this gave them experience in understanding how abstracts are a key part in distilling the essentials of a research paper. The introduction to research papers follow a general pattern: the four/five paragraphs in an introduction begin broad and gradually narrow in the subject matter, until the research aims of the paper are stated in the final paragraph. Students seemed confident in their ability to write an introduction but there was a substantial increase post-course. Students entering university from school come with a high level of information technology (IT) skills. They are able to produce good quality graphs, although they rarely annotate them properly so that the figure can be understood without reference to the text. Their skill in IT is reflected in the high degree of confidence shown in their ability to produce graphs prior to the course, however, confidence increased still further after completion.

Students were not as confident at presenting their data within the context of a Results section, for example: they could draw the graph, but seemed unclear how the graph fitted within the overall presentation of data. There was a 1.89 point increase in confidence post-course: this is not a substantial increase and reflects the difficulty students have in being able to construct a cohesive Results section.

Referencing scientific literature in the text and as part of a reference section is a crucial aspect of a credible piece of work. There was some understanding of the different ways to reference other literature prior to the course but there was a substantial improvement in confidence after the course, increasing 2.5 points. Understanding the correct way to reference is not a difficult concept to either teach or learn; the score prior to the course was lower than expected and probably reflects the fact that the referencing system was not explicitly stated in other courses the students had taken.

There was some understanding of how to discuss results, which improved after the course, but this is a difficult section to write in a scientific paper and in future more attention will need to be paid to this particular area.

Presentation of Scientific Material

The presentation of material, irrespective of its content, is a key transferable skill to acquire. People who are able to deliver a clear, precise and interesting oral presentation are at a competitive advantage in the work environment. Posters are a key way in which scientist's present information to each other at conferences and can provide an excellent visual demonstration of scientific discovery.

Throughout their degree programme students had several chances to participate in oral presentations of their work; this accounts for the higher degree of confidence in being able to write a good oral presentation compared to their confidence in designing a scientific poster. Interestingly, students seemed to understand the purpose of a scientific poster, but this understanding dramatically increased after finishing the course. Very few students will have been given the opportunity to actually design their own poster and this is reflected in the poor confidence level. This confidence level dramatically increased 3.4 points post-course.

Understanding of the value of Research Skills

Research skills are valued and transferable and the process of engaging with research leads to their acquisition. Students were asked if they agreed that the process of research helped with other skills and interestingly students were aware of the value of research and how it can lead to the development of other transferable skills.

Future research ambitions of the students

Part of the survey addressed the future for these students and questioned them on whether they would like to continue research after graduation. From the responses before the course 12 of the 21 students wanted to continue doing research and 9 didn't. Post-course, of those who completed the second survey, 9 out of 17 said they wanted to continue, but 8 didn't. The students were also asked if they felt capable of doing a further degree, pre-course 14 of the 21 students felt capable and 6 said no. Post-course, 15 out of the 17 students felt they could do a further degree, while only 2 said no. Information gathered in 2008 showed that 5 of the students have entered PhD programmes, 2 are currently doing MSc course and 3 have started PGCEs.

Students' Evaluation of the Scientific Research Skills Course

Evaluation by students is a crucial part of course development. The data presented in Table 3 represent their evaluation of the research skills course and are the responses obtained from open-ended questions. The comments provided by the students have been organised into three sections: general comments, practical comments and seminar comments.

***Table 3** Student evaluation of the research skills unit*

General Comments	Practical Comments	Seminar Comments
"The best unit ever! Enjoyed it so much"	"Learnt so much from the practicals"	"Seminars very interesting and informative"
"Very well planned, extremely interesting, learnt much as it was own ideas based."	"Fantastic, great skills and techniques acquired"	"seminars provided valid back-up to practical work and write-up."
"A really helpful unit and very interesting"	"I learnt so much more than in any of my other practicals."	"some seminars I found useful and interesting some maybe not so much."
"Very good an interesting unit, gave a feel of various aspects of research and reinforced choice to go into research career."	"Practicals very good for independent work."	"The seminars on the ins and outs of research were particularly interesting."
"Good range of assessment allowing for experiences of different aspects of research ie writing reports, poster etc."	"The practical work was well organised"	"For the first time ever I fully understand how to write a scientific paper. It feels more like the skills needed outside university"
"I have very much enjoyed this unit and think it will be very useful for next year."	"I feel more independent having to do my own repeats not just a class result and being able to do more science as it should be done."	"Not all the seminars were related to the practicals, I think some of the seminars were useless regarding the unit."
"The best unit by far so far. I feel that I understand what is being taught and so much better being shown one-to-one not just sat bored in a lecture."	"Although my friends complained I was never out of the lab I really enjoyed the work"	"Seminars were all useful. Maybe a few more than were actually needed"
"it is a relief to have a unit with no exam"	"Very informative about research projects, has taught me a lot about how to go about doing them and some of the things not to do."	"Seminars were helpful in understanding research methods."
"I though this unit was amazing. Very beneficial for any student especially before dissertation."	"Need improvements. There weren't enough materials to use, not enough help and explanation of what we were doing during practicals"	
"This unit helped me with the understanding of research very much"	"Interesting and gave good experience in doing research."	
"Very educational will definitely help for the third year"	"Very informative about research projects, has taught me a lot about how to go about doing them and some of the things not to do."	

Students were also asked to assess the course on a Likert Scale (1–5), where 1 was unsatisfactory and 5 was excellent. The average rating was 4.53, the highest rated course in the second year.

It was clear from the comments of the students that they felt it had been well organised and they had learnt many key skills. Some of them commented that it had been the best course they had taken so far and others that it would certainly help them cope with the final year research project. Some comments showed that they had gained insight into how to go about research by doing an actual project in the practical sessions. Others felt that their research projects needed more thought with regard to provision of equipment and also general support. The seminars were enjoyed and the majority of the students felt they had complemented the practical sessions, but there were several comments that some were not totally relevant to them. One of the key words used more than any other was “interesting”; in order to try and understand what the students meant by “interesting” they were asked to provide a more detailed response in an expanded questionnaire. The results from the questionnaire are summarised in Table 4. It can be seen that their responses were very individual. It is difficult to generalise from such a small sample, but the seminar which the students found the most interesting was the one on ethics, and this was mentioned five times.

Table 4 *Summary of responses from the expanded questionnaire*

Response	Frequency of occurrence
The most interesting seminars	
Ethics	5
Scientific writing	4
Presentation skills	3
Research environment	2
Which seminars were the least useful?	
Presentation skills	2
Health and Safety	1
Research Environment	1
List the most useful skills	
Team working	3
Communication	3
Writing skills	2
Planning	2
Patience	2
Interpretation	1
The most interesting things you learnt	
The research environment	4
Specific practical skills	3
The process of research	2
The most useful practical skills	
Laboratory techniques	9
Patience	2
Interpretation	2
Independence	2

Ethics currently receives little attention in the curriculum, although there are initiatives being instigated to change this.

This was followed by the series of seminars on scientific writing, which was mentioned four times. Interestingly the seminars on presentation and the research environment appeared on both the ‘most’ and ‘least’ interesting list, simply highlighting the individual nature of what students found the most engaging.

The skills the students seemed to value the most were team working and communication, classic transferable skills. Two of the students commented on the value of having patience, how science can take you in unforeseen directions and the importance of planning. The most “interesting” things they learnt were aspects of the research environment, such as the politics and pitfalls. Laboratory techniques featured as the most useful skills learnt during the practical sessions. Techniques, such as media preparation, cell and bacterial culturing and running enzyme assays are key technical skills which can be applied to a wide variety of research areas. Confidence and independence was also gained as a result of having designed and run an experiment, as well as knowing “what to do when things go wrong!”

Feeding Forward

One of the reasons for developing this scientific research skills course was to act as a bridge between prescriptive practicals in the first and second years and the final-year honours degree research project. The cohort of students who took part in this study was followed into their final year research project and a comparison of their component marks in their research project was compared against the course average (Table 5).

***Table 5** Marks for the final year research project of those students who did research skills compared against the research project course average*

Component of research project	Average for research skills students	Course Average
Conduct	72.36 ±10.04	69.47 ±11.50
Report	63.79 ±6.54	62.86 ±13.64
Oral Presentation	66.86 ±4.67	65.93 ±12.22
Overall	66.66 ±6.15	65.16 ±11.75

Interestingly, the marks for the report, the oral presentation and the overall mark were very similar. The conduct mark however was 3% higher for those students who had previously done the research skills course. This may reflect the added experience that these students brought to their final year research projects.

Discussion

Pedagogy can be defined as the strategies, techniques and approaches which are used in order to facilitate learning, perhaps put more succinctly it is the science of teaching. It is important to consider exactly how best to teach in order for the students to achieve the desired learning outcomes of a course, and thus pedagogy is essential in curriculum design.

In the scientific research skills course a three-stranded pedagogy was used. The first strand, the seminar and workshop sessions were designed to provide background information on the research environment; they also provided support for the attainment of writing and data analysis skills. The second strand, the practical programme, was designed to provide the students with an opportunity to develop higher order thinking and a sense of ownership. The final strand, dissemination, was developed to provide an understanding of communication. The common learning outcome from all three strands was the development of transferable skills. The seminar series was intended to provide support for the scientific research, they ranged from understanding statistics and experimental design to writing skills, presentation of information and ethics. The seminars on ethics were the ones that the students found the most interesting. Currently the students have very little exposure to ethics in the degree programmes in the Biological Sciences at UEA. In 2002 the Quality Assurance Agency for Higher Education (QAA) Benchmark Statement for Bioscience stated that “bioscience students should be confronted by ethical questions raised by their study discipline”. In 2002/3 a national survey was conducted by Willmott *et al* through the Higher Education Academy’s Centre for Bioscience. The rate of reply to the survey was 45% of the UK Higher Education institutes thought at the time to be delivering bioscience degree programmes. Of the reported 92 undergraduate programmes 69% offered some sort of ethical component which was either embedded within courses, offered as ‘stand alone’ modules or both.

The students used a workshop session to search for relevant scientific literature concerning their own research projects. They used brainstorming techniques to decide on suitable search terms. In this way the students felt an immediate connection with the scientific community and they were able to locate and access both primary research articles and review papers and it developed into a rewarding learning and teaching experience. As Willmott *et al.* (2003) suggest, the question of when students should be introduced to the primary research literature can be a dilemma; it is crucial for students to understand that this is the way in which scientists principally communicate with each other and keeping up to date with developments is essential for scholarship.

Research papers however, can be impenetrable and full of technical jargon. Providing the students with a strong motivation was the key to the success of this issue in this course, the students rapidly built an emotional attachment to their own project and this provided the impetus to read, assess, digest and in many cases use the information contained in research papers. Students were also asked to write their own scientific report in the format of a research paper. It was hoped that this would allow for further insight into the process of scientific writing and enable them to understand how their research fits with the wider body of scientific knowledge. The students were supported by writing seminars, which covered the critical analysis of scientific literature, how to structure a paper and most importantly how to write clearly and concisely. These were appreciated by the students who commented on them specifically in their evaluations.

The research project carried out by the students was the corner-stone of the pedagogy and provided the basis for improving higher order thinking and cognitive skills. As the research projects began, it rapidly emerged that the demands of these practical sessions on staff time were greater than anticipated. A single staff member could not cope alone with the demands of students, who had up until this time been used to following a set of instructions in a laboratory schedule; it became clear that this usual prescriptive method of learning meant they simply couldn’t think for themselves and an experienced postgraduate demonstrator was employed to help with the course. All of the projects were straightforward in the techniques being used and this was a major factor contributing to the ultimate success of the research projects. In a research driven advanced microbiology laboratory class Rasche (2004) also found simple techniques to be key in her enquiry based course and further recommended that the instructor prepared experimental resources to assist groups that may be unsuccessful during the course.

Students were taught how to disseminate their research findings through three different mechanisms, oral presentation, poster and research paper. This reflected the means of formal communication most commonly found in the research environment. The presentation of the work in both oral and poster formats requires a deep understanding of the material before it can be conveyed in a concise and visual manner and also requires an understanding of modern software technology. The oral presentations were prepared by each ‘research team’ and each member of the team had to present part of it. The assessment criteria were based on the quality of the slides, the information, the delivery and how well the questions were answered. The posters were assessed according to a set of criteria which the students themselves decided upon. This included visual impact, the quality of the information and the clarity of reading.

The writing of the scientific reports provides excellent training in the ordering of complex information and in its interpretation. It should also develop clear and concise writing. Ellis (2004) studied the student learning experience through writing and he argues that the direct object of learning through writing is understanding the meaning and written patterns of science. The act of learning is the writing process and the understanding which comes with it. The indirect object of learning through writing is written communication skills and the technological literacy skills learnt through the process.

According to Palmer (2003) enquiry based teaching inspires enquiry based learning and the students benefit enormously from this type of experience. From the findings presented in this paper the students clearly felt they had gained considerable practical and transferable skills from studying the course. They increased in confidence and skill in all of the assessed areas. These findings are similar to those reported by DebBurman (2002). Her paper assessed two groups of students on a cell biology enquiry based learning course, and found a similar degree in the increase in confidence in key skill areas.

There are some drawbacks to this type of enquiry based learning — it is an intense student experience as illustrated by the comment “Although my friends complained I was never out of the lab I really enjoyed the work”. There is considerable investment in the time of the lecturer, but as DebBurman (2002) suggests one can take advantage and offer research projects of professional interest. Finding and reading scientific papers meant an investment in both the student’s and one’s own scientific learning, an unexpected but rewarding consequence.

The type of project on offer enabled different learning outcomes to be achieved. The less well defined the project at the start, the greater the understanding of the scientific process appeared to be. As one student stated “I have understood exactly what I have done because I designed it.” The students who undertook an undefined project (such as investigating the microbial content of probiotics) first had to perform a literature search, not only to try to understand the area, but to find out what research had already been done. In this way they were able to decide the research angle they wished to pursue. These students then devised and ran simple pilot experiments to test their initial ideas and this enabled a research question to be defined. Generally, the techniques learnt in order to perform these experiments were simple and straightforward.

The students who undertook a defined research question from the start (such as the molecular based projects) had to first try to understand the terminology within the research question. They also performed literature searches to obtain background information. The molecular biology based projects built up from a series of steps and there was less room for a larger research question the students could devise themselves. These students however, did have the advantage of being exposed to modern molecular biology techniques. Interestingly, the emotional connection with the work appeared to be the same, regardless of whether the initial project was defined or undefined. This attachment to the work came from a sense of ‘ownership’ they were all doing research that no one else had done before, there was an investment of time, energy and thought and in the end there was pride in achievement.

Enquiry based learning develops critical thinking skills. Swartz (2004) describes five forms of critical thinking: complexity (interconnection between information), flexibility (adjusting to new knowledge), multiple perspectives (open to new ideas), self-reflection (examining experience) and insightfulness (to see or read into a situation). Evidence for the development of complexity of thinking came from reading the research reports. As part of their discussion students had to discuss their results in the context of the scientific literature, this meant that they had to make connections between their work and that of others. It is evident from two students that flexibility was being recognised "I was interested in the continuation of lab work, how one thing leads to another and how dynamic and easily changed it is from one odd or surprising result."
"I was interested in learning about the way experiments develop."

Self-reflection was part of the learning cycle as described by Kolb's experiential learning theory. As an example, students who performed pilot experiments, reflected upon the success of the experiment, made critical judgements about it and reviewed understanding and then fed this back into further experimentation and reflection. One would not have expected students at this stage to display signs of insightfulness or have multiple perspectives. These are arguably areas of critical thinking which in science only develop after a while in research. One needs to build up knowledge and expertise in a research area before one can be sceptical or penetrative.

This study has shown that the students perceive that they have benefited from the experience of undertaking the research skills course. It was rated highly for student satisfaction when compared to the more traditional taught courses and as Ryder (2004) suggests these types of research project have the potential to be the highlight of the degree programme. The skills this type of teaching allows them to acquire are important for life long learning, illustrated by one students comment, "it feels more like skills needed outside university".

In his research Deakin (2006) states that the student experience of research led teaching is that the learning is not passive, but an active process of 'learning by doing'. This is certainly the impression received through the student evaluation of the research skills course. However, one student stated that they 'learnt so much more than in any other practicals' suggesting that learning by doing is not enough in traditional practical sessions, but that the students have to be involved in the whole research process. Within the wider context on the discussion on linking teaching with research, Deakin (2006) suggests that it should not be the experts who decide on the value of linking teaching with research, but student experience. He ascertains that it is the experience of the students that gives the best evidence we have that linking teaching with research leads to learning.

The key to successful learning in research-led teaching is an emotional commitment to the learning experience which provides enhanced motivation. Ryder (2004) also describes this emotional attachment as a sense of ownership.

Conclusion

In an institutional context, universities who wish to promote strength in research-led teaching the opportunity must be provided for undergraduates to be made more aware of the multi-faceted aspects of research. They need to understand the research environment and the duality in the responsibilities of the lecturer. Students must be able to engage with more enquiry-based learning units in order to build their key transferable skills. Interestingly the findings presented in this study suggest that students are well aware of the value of research to transferable skills development even prior to completing the course. They know that time management, the ability to ask questions, to rationally organise material and to be able to present that material to an audience are important in any future career. The goal of any university is to enable their students to access and participate in lifelong learning and this can be achieved through the process of actively engaging students in specifically designed research courses during their undergraduate programmes. It is my opinion that this is the area where teaching and research can meet most effectively and have a genuine mutualistic symbiosis.

Communicating author: Dr Kay Yeoman, School of Biological Sciences, University of East Anglia, Norwich, Norfolk, NR4 7TJ. Tel: 01603 454234. Fax: 01603 592250 email: k.yeoman@uea.ac.uk

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