A project-based learning approach to protein biochemistry suitable for both face-to-face and distance education students

R.J. Prior, School of Health Studies, University of Canberra, Australia
J.K. Forwood, School of Biomedical Sciences, Charles Sturt University, Australia
Robyn.Prior@canberra.edu.au

Abstract: *Flexible learning approaches are being increasingly adopted within Universities to improve the learning outcomes for students. Online, distance and project-based learning are examples of teaching and learning methods that have gained popularity due to their ability to deliver course outcomes in a flexible manner. At Charles Sturt University, students undertaking the degree of Bachelor of Biotechnology can study all subjects in either the face-to-face or distance education modes. Prior to 2006, one core second year subject within the course, Protein Biochemistry, was delivered in a more 'traditional' style to both cohorts of students. Face-to-face students were given didactic lectures on protein structure, function and analysis techniques, while distance education students were provided with a study guide, lecture notes, and a prescribed text. Laboratory practicals were also a component of the subject, completed by distance education students at an on-campus residential school. Both cohorts of students had access to an online subject page where they could discuss subject material on a forum and access learning resources such as tutorial worksheets. Students evaluated in 2003-2005 felt that the subject was difficult, were not able to see connections between different subject topics and frequently performed poorly in the subject examinations. As the assessment was predominantly exam based, students were particularly focused on 'what will be in the exam' rather than the subject material. In response to both staff and student feedback, alternative learning and teaching approaches were considered. In 2006, the project-based learning (PrBL) pedagogy was implemented into both face-to-face and distance education modes, fully replacing traditional lectures, study guides and examinations with a project-based curriculum. Here, we present a paper that describes the PrBL approach used simultaneously in both face-to-face and distance education modes to teach Protein Biochemistry. A preliminary evaluation of the implementation of this approach is also included.*

Introduction

Project-based learning (PrBL) is an instructional strategy based on constructivism, where learning is accomplished through completion of a complex task or project. It is related to but distinct from problem-based learning, in that there is a defined pathway or set of questions to answer through the completion of a project (Savery and Duffy 1995; Thomas 2000). Typically, projects central to the curriculum are focused on problems that 'drive' students to encounter important concepts and principles and involve students in a constructive investigation. Projects are student-driven to some significant degree and there is often an additional emphasis on cooperative learning between students and teachers in a 'learning community' (McGrath 2003; Petrosino 2005).

The advantages of the PrBL pedagogy and the degree to which PrBL could address the problems associated with traditional subject delivery inspired teaching staff to re-design a Protein Biochemistry subject around the basic principles of PrBL. Since 2003, Protein Biochemistry has been included in the Bachelor of Biotechnology course at Charles Sturt University. The subject provides an overview of protein structure, function, purification and analysis techniques. Like all subjects in the course, students have the option of studying Protein Biochemistry either on campus or externally through the distance education (DE) mode. In 2003-2005, on-campus students were given didactic lectures on protein structure, function and analysis techniques, while distance education students were provided with a study guide written by teaching staff to support their self-directed learning. All students were prescribed the same readings and had access to a common online subject page. Through this website, all students could access lecture notes, revision worksheets and an online discussion board where subject material and assessment could be discussed with other students and teaching staff. Laboratory practicals were also a component of the subject, completed by distance education students at an on-campus residential school. The assessment strategy included a laboratory report (20%), mid-semester examination (30%) and a final examination (50%).

Subject evaluations in 2003-2005 revealed a general dissatisfaction within the subject. Generally, students lacked enthusiasm for the subject, felt the subject matter was too complex, and could not see the relevance of subject matter to their course. Furthermore, a review of the teaching methodologies used by teaching staff in 2005 identified the following problems in the subject design:

- Subject topics were presented as distinct topics, and taught separately by different lecturers. Students frequently did not see connections between topics and viewed the subject as ‘hard’ or ‘boring’, which was often reflected in final examination results.
- Knowledge acquisition was limited to what was presented in the core readings and texts. While teaching staff often tried to impart new knowledge or current research, students responded with ‘will this be in the examination?’ The educational design of the subject did not easily accommodate new knowledge, with the exception of altering prescribed readings on a yearly basis.
- The subject was limited to studying key examples where protein structure was examined, rather than imparting the core skills necessary to study proteins.

These issues were consistent with problems frequently observed when more traditional approaches to learning and teaching are used (Merrill, Li and Jones 1991). Having reviewed the subject design, it was apparent that students could benefit from changes to the learning and teaching approaches used in both on-campus and DE modes, such as teaching the subject with a common theme or project throughout the subject, and replacing ‘required knowledge’, with a core ‘scaffolding’ of material which could be used during a semester-long project. Through such a project, new knowledge could be acquired by the student.

A revised curriculum

In 2006, a PrBL-design entirely replaced the traditional didactic lectures and DE study guide. While the laboratory component of the subject item remained unchanged, the examination-based assessment items were replaced with more authentic assessment items, designed to both assist students to develop protein analysis skills and promote independent, life long learning (Lee 2004; Blumenfeld, Soloway, Marx, Krajcik, Guzdial and Palinscar 1991). The subject curriculum was structured around the completion of these assessment items (2 assignments, A1 and A2), and inspired by the success of PrBL projects used for on-campus students in related subjects both in Australia and overseas (Lee 2004). The challenge faced by teaching staff in this subject was the design and delivery of a PrBL curriculum suitable for both on-campus and DE students. While there are increasing examples of PrBL being used in a distance environment, there is little literature addressing the implementation of a flexible PrBL approach to biochemistry suitable for both a class of both on-campus and off-campus-students (Murphy and Gazi 2001).

Inspired by a single protein structure assignment described by Lee in 2004, at the commencement of the subject students were each allocated a unique protein, in the form of a Protein Data Bank (PDB) file. Students then completed Assignment 1 (A1), a report on protein structure, the generation of structural images using PDB structure coordinates and the protein modelling program *RasMol* (Martz 1995). Results were presented as both a written report and an oral presentation, during a class ‘structure and function conference’. Finally, students completed assignment 2 (A2), an essay reviewing experimental methods used to study protein function, concluding in the design of an original experiment. Assignments 1 and 2 (as described in the Appendix) were designed to cover the subject material with the 5 basic principles of project-based learning in mind (Thomas 2000):

- projects are central to the curriculum;
- projects focused on problems that ‘drive’ students to encounter the central concepts and principles of a discipline;
- projects involve students in a constructive investigation;

- projects are student-driven to some significant degree; and
- projects are realistic.

Projects are central to the curriculum
In Protein Biochemistry, there are no examinations, nor are there traditional lectures given to on-campus students. Assessment items *are* the curriculum in this subject, with student learning occurring in the process of completing the assessment items.

Projects focused on problems that 'drive' students to encounter the central concepts and principles of a discipline
A primary feature of A1 is to generate structural images of a protein, which highlight features of primary, secondary, tertiary, and quaternary protein structure. In order to generate appropriate images, students need to understand levels of protein structure and how proteins fold. They also need to identify important aspects of the protein structure such as active site clefts, binding sites for metal ions and other metabolites, and flexible regions that may contribute to regulation. A primary feature of A2 is the design of an experiment which could be used to study the function of an engineered or mutated protein. This exercise requires students firstly to study what methods can be used to investigate the function of a protein. There needs to be an understanding of how the function is related to the structure (reviewed in A1), so that students can identify amino acids which they would like to engineer. Students then need to identify and design an experiment which could test the effect of the amino acid substitution on function, and explain the principles of this experiment. The compulsory attendance and discussion during oral presentations, in addition to the critique of experiments during assessment 2, ensure students are exposed to a wide range of protein structure, function, and technologies.

Projects involve students in a constructive investigation
Students need to perform literature searches and read the prescribed texts in order to understand what is required in the assigned tasks. New images of the studied protein are generated using *RasMol* (A1), and an original experiment is designed (A2). Success in the assignments is dependent on understanding the basic concepts of the discipline. Completing each assignment involves the 'discovery' of information present in both prescribed textbooks and in current scientific literature. 'knowledge building' of concepts assists in the construction of graphical images of protein structure (A1), and understanding of experiments which can be used to investigate protein function (A2). In a 'learning community' with other students in the class, skills in experimental design can be developed.

Projects are student-driven to some significant degree
Students are assigned a unique protein for investigation in this subject. Subsequently, the study schedule covers the general steps which are necessary in order to complete the assignments, but are not specifically scripted. Each protein will have a unique structure and function, and students will have the flexibility to choose which features of structure and function they wish to explore, discuss and present in each assignment. The last task of the session, the design of an experiment, is the most challenging. While students continue to investigate their own allocated protein, students are required to pair up with a 'research partner' when designing their experiment. They are required to submit evidence of how each partner assisted the other, and how a partner's comments were incorporated into their own experiment. The acquisition of additional skills such as effective teamwork, communication and problem solving, in addition to the synthesis of subject content has been identified as a major strength for incorporating constructivist approaches to learning and teaching such as PrBL into science-based subjects (Wright and Boggs 2002).

Projects are realistic

Assignments 1 and 2 have a general theme, whereby the student is a graduate protein biochemist and is required to perform background research on a protein (structure in A1, function in A2) before designing an experiment (A2). Just as in the 'real world' of biochemical research, students prepare a review article on a single protein (A1), present their findings in an oral presentation (A1), and design a new experiment to further investigate how structure effects function (A2). Importantly, students study the one single protein throughout the session, so new concepts and ideas discovered in A1 can be built upon in A2. Currently, different proteins are being allocated to students each year, with a view to 'rotate' proteins after a 5 year gap. With only 30 students each year, and a growing Protein Data Bank, this is maintainable by staff.

Integrating opportunities to motivate and guide students through the completion of these assignments is reported to be a common challenge to educators adopting both project- and problem-based learning (Blumenfeld, Soloway, Marx, Krajcik, Guzdial, M. and Palinscar 1991; Mergandoller and Thomas 2002). As both on-campus and DE students were given the same assessment tasks, a wide range of both face-to-face and online support mechanisms were included in the curriculum. To support student learning for on-campus students, traditional lecture time was replaced with class 'meetings', where students and staff could meet, and class discussions were driven by students' needs and questions. For example, in 2006, class meetings ranged from 'how are proteins expressed?' to 'can we discuss a DNA-binding assay described in a journal article I have identified?' The online discussion board was used more frequently for class discussions between DE students, and between on-campus and DE students. Discussion was promoted by requiring (but not assessing) students to make regular contributions to online discussions and topics. Structure and Function Conferences were held for both on-campus students, during class meeting times, and DE students, at residential school. The residential school provided essential face-to-face time for DE students to also discuss their progress in the assignments and to choose research partners for the second assignment. Finally, teaching staff provided email support for all students who required additional assistance.

Preliminary evaluation and conclusions

Due to the small numbers of students studying Protein Biochemistry (combined on-campus and DE class sizes: 2003, n = 30; 2004, n = 42, 2005, n = 20, 2006, n = 25), analysis of student evaluations has been primarily qualitative. When asked for comments on aspects of the subject students found helpful to their learning, students commented favourably on the amount of time available to complete assessment tasks, on the assessment tasks themselves, and on the design of the subject. A DE student commented that they '*found the assessment tasks very helpful in respect we had to think for ourselves (sic) and discuss with others and it was more about what we would do in the real world of science*'. Another commented that '*For the first time with any subject studied to date I was learning principles and applying them, rather than learning facts/figures + regurgitating them without really understand what was going on*'. By allocating students a unique protein to study, students frequently demonstrated their enthusiasm and excitement for the assignments investigating 'their' protein. For example, a student commented that they '*found being responsible for my one protein that no one knew anything about, encouraged me to learn as much about it as possible. This provided some enthusiasm to do varying background research, thereby I learnt more by researching it myself rather than being lectured on it*'. This degree of ownership and personal involvement in the project is an additional strength for PrBL activities, where authentic tasks often result in increased interest in a discipline on the part of the student, resulting in higher motivation to work towards a goal (Blumenfeld et al. 1991). Student evaluations also identified areas where more support could be provided (e.g. levels of protein structure and protein folding) and requested that guidelines be more flexible for proteins where there is minimal literature available. These suggestions are being incorporated into the 2007 offering of Protein Biochemistry.

Overall, teaching staff were impressed at the level of effort and depth that both on-campus and DE students went to in the completion of their assignments. Learning was completely student driven, with lecture time used for cooperative, student-centred discussions. It was felt that while student learning was still driven by the subject assessment tasks, the nature of the assignments allowed students to better demonstrate their learning and knowledge of subject matter. This was demonstrated by the higher average marks obtained for the two assignments in 2006 (mean= 66%), compared to the average marks obtained in the exam-based assessments in 2003-2006 (2003 57%; 2004 63%; 2005 52%). However, the 2006 cohort of students also obtained higher marks in the laboratory-based assessment. Thus while the PrBL approach improved student enthusiasm and motivation, it is unclear at this early stage whether there is any correlation between the new learning and teaching strategy and student performance.

In conclusion, this paper reports the design and implementation of a flexible, PrBL approach to learning in both on-campus and DE modes of a Protein Biochemistry subject. Preliminary evaluations of the first offering of a PrBL Protein Biochemistry subject from both on- and off-campus students have been very positive, and may inspire other biochemistry academics, or academics teaching DE students, to consider the advantages of the flexible, PrBL approach.

Acknowledgements
The authors would like to acknowledge Robert Parkes, Wouter Kalle, Phillip Kerr and Roger Murphy for their assistance and guidance in the design, teaching and implementation of this subject in 2006.

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Appendix:

The details of the two, authentic assessment items are presented here. A study schedule and assessment criteria were also provided to students, to guide them in their learning journeys and assist in the completion of the assignments.

Assignment 1: Protein Structure Review

Length: five A4 pages (not including figures, figure legends and references) and 5 minute summary oral presentation.

Rationale:
Rapid improvements in structural determination methods, and the large number of DNA and protein sequences currently available online, now allow protein biochemists and biotechnologists to investigate the structure of any protein they choose. The primary goals of a structural biochemist are to:

- purify large quantities of a protein of interest;
- use structural determination methods to generate a structural model of the purified protein, with or without cofactors or other ligand;
- determine what features of a protein structure contribute to the function of a protein; and
- present their findings in both a written form (article) and oral form (presentation).

This assignment provides you with the opportunity to learn about the different levels of protein structure, and observe through structural models how different bonds contribute to the overall structure of a protein. You will gain hands-on experience investigating protein structure, using the computer program *RasMol*. You will each have the opportunity to research how a unique protein was purified in large quantities and how its structure was determined. You will gain expertise in graphically illustrating protein structures and be able to demonstrate how the structure of your protein is suited to its particular function in vivo (in the cell/organism).

Task:
Imagine that you are a graduate protein biochemist working for a medical research facility. On your first day of employment, you have been assigned a particular protein of interest to your research group. Your research group has not researched this protein before, and ask you to perform some background research into what is known about the structure of this protein.

You are required to:

- prepare a Protein Structure Review Article. This exercise is akin to publishing your findings in a scientific journal; and
- give a short (5 minute) oral presentation, summarising what you have discovered about the structure and function of your protein to the class during the residential school. This exercise is akin to presenting your research at a scientific conference.

Review Article
There will be 4 features to the Review Article:

1. A discussion of method(s) used to purify the protein of interest. There are many different methods used to purify proteins. The individual method chosen often depends on whether native protein is being purified from a tissue source or whether artificially synthesised protein is being purified from a bacterial source. The method chosen may also depend on how much protein is required in a later experiment.

2. A discussion of which method was chosen to investigate the structure of your protein of interest, and why it may have been chosen. The two common methods used are Nuclear Magnetic Resonance Spectroscopy (NMR) and X-Ray crystallography.
3. A discussion of the primary, secondary and tertiary structure of your protein, supported by structural images of your protein. You can obtain the primary sequence of your protein from the online medical database PubMed. Once you have obtained the .pdb file for your protein from the Protein Data Bank, you will use the *RasMol* program to view the secondary and tertiary structure of your protein in 3D. You will prepare 4 different images of your protein using *RasMol*, which will highlight different types of non-covalent interactions found within the protein.
4. A discussion on how the structure of the protein is related to the function of the protein. You will use the PubMed (or other) database to obtain journal articles which discuss the function of your protein. You may find that different protein domains have different functions, and you would need to discuss how the structure of each domain related to its individual function. You will need to explain where other molecules (e.g., DNA, RNA, cofactors, coenzymes – these are all collectively known as ligands) interact with the protein.

Oral presentation
In your oral presentation, you need to summarise, in no more than 5 minutes, the key features relating what is known about the structure and function of the protein. You will need to include:
- details about the structure of the protein, using appropriate visual aids (overheads or *PowerPoint* presentation);
- details about the function of the protein; and
- details about how the function of the protein is related to the structure of the protein.

Assignment 2: Experiment Discussion and Design

Length: 5 A4 pages (not including figures, figure legends, references or evidence of communication with your research partner)

Rationale:
In addition to understanding what the structure of a given protein is, it is crucial to be able to examine the function of a protein. Different function experiments, or assays, are used to examine protein function. These may be as varied as enzyme assays (for enzymes), DNA-binding and transcription assays (for transcription factors), or even cell localisation experiments, which indicate where a protein is found within the cell (all intracellular proteins).

Protein engineering is one tool which is then commonly used to alter the primary sequence of a protein. Functional assays can then be performed to see how protein function may be altered by small changes in primary sequence. Commonly, protein engineering is used to generate a mutant protein for study purposes in a research laboratory, which may be produced naturally as a result of genetic disease.

This assignment will provide you with additional experience in reading and interpreting scientific articles, a skill of great importance for biotechnologists! You will build on the practical skills developed during the residential school, by delving into the detailed experiments used to study the function of a protein of interest. By studying the same protein as you investigated in Assignment 1, you will gain a greater appreciation of how function is related to structure, and why different methods may be used to study different proteins. You will also have the opportunity to design an experiment for the first time. In a research laboratory, the ability to design experiments is highly regarded, and often an expected duty of employment.

Task:
Your research laboratory was pleased with your growing expertise into the protein of interest, as presented in your Protein Structure Review article (assignment 1). Your second task is now to closely examine experiments which have been used to investigate the function of the protein and design a simple experiment which could be used to further examine the function of your protein. You will present your research and experimental design in the form of an essay. To assist in the research and design process, you will gain advice from a fellow researcher, working on a similar project, just as you will assist them with their project.

In researching for this essay, you will need to obtain 2-4 journal articles which have investigated the function of the protein. Most journal articles which discuss scientific experiments will contain an introduction, material and methods, results and discussion sections. Your essay will begin by:

- explaining what experimental methods have been used to study protein function;
- discussing why each experimental method was used;
- commenting on the design of experiments, and note if the appropriate controls were used; and
- relating the findings of the experiments to the structure of the protein you studied in Assignment 1. For more information on a particular method, you may need to do further background research. A good starting point is often the reference given within the methods section of an article.

The second component of your essay will require some background research on protein engineering. Once you feel you understand the purpose of protein engineering, you will design an experiment which would use an engineered/mutated protein in one of the functional assays you have studied. You will need to

- identify the aim of your experiment;
- identify which amino acid(s) of the protein you would engineer/mutate;
- explain which functional assay you would choose;
- outline the steps involved in the functional assay;
- outline what control(s) you would include; and
- postulate the types of possible results you may expect.

During the design process, you will be expected to communicate regularly with your chosen ‘research partner’, a fellow class member. You will be required to submit with your assignment (in an Appendix) evidence which documents:

- your responses to comments made by your partner regarding your experimental design, including any changes you made to your experimental design on the basis of your partner’s comments. If you feel your partner’s comments are inappropriate or you feel you have already addressed the comments raised, you need to communicate this to your partner.
- thoughtful critique of your partner’s experimental design

You are not expected to give details on volumes, or buffers or chemical concentrations, but focus on the scientific principles of the methodology chosen. You are also not expected to explain how you would engineer a protein. This will be covered in later subjects.