EMPHASISING RESEARCH IN UNDERGRADUATE OPERATIONS RESEARCH

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ABSTRACT

This paper will describe how undergraduate research is being incorporated into the learning experiences of third-year mathematics students. As suggested by Beckman and Hansel (2009), we will provide our own definition of undergraduate research as 'an inquiry or investigation that is original in scope, of an experimental, a theoretical or a creative nature, undertaken in a rigorous manner by undergraduate students, that is open to public scrutiny, and that makes a contribution to a discipline(s)'. Here then, we seek to engage students with the full range of research activities, from the formulation of the research questions, to the dissemination of results. Further, students are empowered to lead the research in collaboration with each other and with academic staff, with the product a publication in a peer-reviewed journal.

INTRODUCTION

Operations Research (OR) education has an enviable history of engaging undergraduate students in inquiry-based learning. Every student studying an Operations Research or a Management Science subject has first-hand experience in activities related to the application of scientific method and the technology and practice of OR. Such activities, while typically new to students, are carefully designed and implemented by their teaching staff. That is, while there is an emphasis on inquiry and problem-solving, and students are active participants, activities are educator-lead (Healey, 2005). While many activities, including undertaking case studies, advance the knowledge and skills sets of students, they do not provide students with the full range of experience in the practice of research. Further, such activities are unlikely to constitute advances in the frontiers of knowledge. Rarely do undergraduate OR students undertake research to any significant degree. The first significant exposure to research a student is likely to receive is in an honours year. It is proposed that OR students can, and should, undertake research in their undergraduate programs.

The benefits to students in undertaking research are obvious. Undergraduate research:

- Stimulates students' interest;
- Encourages students' independent thought and intellectual self-reliance;
- Develops in students the full range of skills required to undertake research (Jewell and Brew 2010, p10; Beckman and Hensel 2009, p42);
- Empowers students to discover and share new knowledge and endeavour (Beckman and Hensel 2009, p42);
- Engages students with the discipline and their community of practice and allows students to see themselves as part of that community (Jewell and Brew 2010, p10);
- Encourages students to grow in confidence and facility (Beckman and Hensel 2009, p43; Cochran 2012, p660);
- Improves communication, interpersonal and, time and resource management skills (Beckman and Hensel 2009, p42);
- Prepares students for Honours programs and higher research degrees (Jewell and Brew 2010, p10; Beckman and Hensel 2009, p40);
- Extends the frontiers of the discipline.

How then can research be integrated into undergraduate OR teaching and learning in a way that fulfills the potential benefits outlined above? In this paper, we will examine a case study that incorporates undergraduate research into a Mathematics program, with one aim being publication in a peer-reviewed journal.

BACKGROUND

Quantitative Management Practice (QMP) is a subject in the Mathematics major of the Bachelor of Science degree program at the University of Technology, Sydney. When designed in 2007 the underlying theme of QMP was professional practice of the operations researcher or management scientist. Students undertaking QMP have undertaken at least two other subjects in OR prior to enrolling in QMP, and are most commonly in the third and final year of their degree. QMP introduces students to real-life problems in all their complexity, and from 2009, the scope was extended to include professional practice in the research domain. Hence, in QMP we see "integrated exposure to professional practice" (UTS, 2011) where primary focus is on the first of the subject objectives – to identify, model and solve real-life and realistic problems involving the application of OR methodology.

Teaching and learning are "research-inspired and integrated" (ibid), with a little over half the subject devoted to on a student-faculty collaborative research project. As far as possible students lead the research from selecting the topic through model formulation to solution analysis and discussion. In addition to classes where the research is undertaken, activities include workshops and discussions on research methodology, literature reviews, data searches and tips and hints on managing research and working with others. The final outcome of the research activities is a research paper to be submitted for publication in a peer-reviewed journal. The research projects concern matters of importance to society including the placement of tsunami detectors in the Mediterranean region and the allocation of water resources in the Murray-Darling Basin.

The subject has run every year since 2007, and the number of students undertaking the research project has varied from 18 to a low of 2 to 10 in 2013. Other students in the class focus solely on the analysis of case studies and similarly realistic problems.

IMPLEMENTING UNDERGRADUATE RESEARCH – THE LEARNING DESIGN

The unifying thread for the subject is the OR methodology and Scientific Method. The research topic can be student-initiated, or faculty-initiated (Beckman and Hensel 2009, p41), or indeed a combination of the two. As there are many factors affecting the successful completion of the project, an area of interest is selected by the teaching staff and students discuss the relative merits of tackling the problems arising in the area. Students are encouraged to set their own direction within the context of the selected topic, with students self-allocating different components of the research activities. This is necessarily overseen by the teaching staff to ensure equity in physical and intellectual workload. Students are treated more as peers than as research assistants (ibid). That is, students are encouraged to think of themselves as part of a research team, working towards a common goal (ibid, p42). The role of leader of the team then falls to the teaching staff, at least until such time as leaders within the students emerge.

We will now go on to consider each of the main elements of the learning design – the learning activities and the learning environment.

LEARNING ACTIVITIES

The learning activities (including assessment) will be presented and discussed in the order in which they were undertaken, that is, following scientific method and the OR methodology.

Identifying a problem

What is the extent of the problem and what do we aim to achieve?
The research area is selected such that a set of problems exist which are amenable to students' backgrounds. That is, students possess the theoretical and practical background appropriate. In addition, data should be available or be able to be estimated or constructed, and literature should exist which support and extend students' knowledge and skills sets. The area should contain solutions to problems that are of interest to society and, importantly, the problems selected should be able to be addressed in the time available. The first research project was to determine the optimal location of detection components of a tsunami warning system in the Mediterranean region given the existing and planned infrastructure of tsunameters and coastal sea-level monitoring stations. We were interested in assessing the NEAMTWS implementation plan (ICG/NEAMTWS-III, 2007) and seeing if additional detectors would improve the proportion of the coastal population receiving a timely warning. The second research project was to examine a water resource plan area in the Murray Darling Basin (MDB) and determine a water allocation plan for that area based on the MDB Plan.

Once the problem has been specified and preliminary research task allocated, resource requirements are discussed. A rough schedule is determined to enable time and resource management. The students commence work on the first steps of scientific method (this is referred to as the pre-work, this being based on the way the assessment is structured) – problem definition and research questions, background and rationale, literature review, preliminary data collection and preliminary model(s) and solution methodology(ies) suggested by the literature. Some tasks are job-shared. Some class time is allocated for the lecturer to provide guidance and facilitate the execution of the activities. Further details on these steps follow. Students are also encouraged to interact on the tasks they have given the interplay of the components of the OR methodology.

Background and Rationale

What is the context of the problem and why is it important?

Once the problem has been selected, some time needs to be spent on discussing why the problem represents a contribution to the advancement of knowledge and/or its application. This informs part of the literature review and contributes to the introductory sections of the final research paper.

Literature Review

What has been done before?

Here we place the problem in the context of the literature. Here, students require a tutorial/workshop on the practice of internet search techniques for literature review and data collection.

The class is set a time frame for collecting papers/articles/websites/data relevant to their tasks. This reflects the due date for the first components of the assessment tasks for the project. Students complete an annotated bibliography for their task and make a relatively informal presentation to the remainder of the group. These activities form part of the first assessment tasks. All items are gathered together in one area of the subject's BlackBoard® site (serving a similar purpose to Google Docs®), and all students are asked to familiarise themselves with the material. Students work collaboratively refining each aspect of collected resources. These activities culminate in the construction of draft sections of the paper.

Data and technology

What do we need to address this problem?

This issue is simultaneously addressed with the resourcing questions in the early stages of work allocation. However, analysis of the problem and the literature naturally lead to selection of a mathematical model and/or methodology. This in turns leads to the selection and collection of relevant data. Students interact on these issues as the annotated bibliography develops. Key in this component of the application of scientific method to undergraduate activities is the question as to whether students have the technology toolkit required and does it need to be supplemented? The answer to this question is partly a function of the choice of problem, the nature of the research, the time frame available and the choices made by the students based on their literature reviews and current knowledge and skills. In the first research project, after students reviewed the collected materials, a facilitated discussion on how we would seek to address the problem was undertaken, that is, we sought to answer 'What is the preferred methodology?' and 'What data needs to be collected to implement this methodology?'

Methodology

How are we going to implement the model?

This question is addressed in a similar way to the data and technology issues, with the students interacting through the collected materials in BlackBoard ® and both within class time and outside it. The interplay with the data, literature and methodology comes sharply into focus as students work together to complete their own tasks. Once the interactions have stabilised, and with some direction from the teaching staff, students make final decisions on the methodology and data and then write up draft sections for the Introduction, Background, Literature Review and Model and Solution Methodology sections of the research paper. This completes the first assessment tasks of the project.

Implementing the methodology - results

This marks the beginning of the second set of assessment tasks for the project. In the first instance, students employed technology they were familiar with to calculate travel times using a spreadsheet and worked collectively on the calculations. It was then a relatively easy matter to determine whether populations receive a timely warning by using spreadsheet functions. From there it was also a simple step to calculate warning potentials and determine the average and weighted average warning potentials for the systems as described in the Implementation Plan. Students selected this option in preference to a mathematical program, as the model could be transparently implemented in a spreadsheet environment in contrast to a 'black box' optimiser.

Analysing the results in the context of the aims of the research
Again, discussion was facilitated and guided, rather than lead. For the tsunami warning problem, students used set-covering techniques to identify the areas where coverage could be improved, suggesting locations where additional detectors could be deployed.

Disseminating results
The earlier collated material is revisited, and the previously written sections were modified based on the implementation of the methodology and the results found. Small groups of students work on the Results and Discussion sections, with the aim of getting the paper in a mostly-complete form by the end of semester. This marks the end of the final assessment tasks where students are responsible for the final form of the research paper. Peer assessment is used to determine the relative merit of the contributions made by students with the lecturer assessing the final paper produced. In the case of the tsunami warning paper, some small additional work was required over the semester break with the paper being submitted to an international journal early the following year (Groen et al, 2010).

LEARNING ENVIRONMENT – SPACE AND RESOURCES
It is perhaps obvious that the learning environment for an undergraduate research project is the environment under which the research would otherwise be conducted. For the Operations Researcher, this includes a research space, computers of appropriate specifications, and access to the relevant data and literature. All of these resources were (and are) available to mathematical sciences students – there are a variety of appropriate spaces throughout the campus, these include access to appropriate computers; the internet and library provide comprehensive access to databases and literature. In 2013, the classes were held in a collaborative learning space in the library.

CONCLUSION
In conclusion, embedding a research project in an undergraduate OR subject proved to meet many of the benefits to students listed in the Introduction of this paper. This included providing a strong grounding in research to the point of encouraging students to proceed to an honours year. In addition, undergraduate research provides academic staff with assistance in ongoing research projects, creates new knowledge within the discipline, in the form of scholarly peer-reviewed articles, and conference and seminar presentations, and develops the ability of academic staff to carry out higher degree research supervision.

Emphasising the "research" in Operations Research for undergraduate students is a win-win situation.

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