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RESEARCH ARTICLE

Teaching basic numeracy, predictive models and socioeconomics to marine ecologists through Bayesian belief networks [version 1; peer review: 2 approved with reservations]

Richard Stafford¹, Rachel Williams²

¹Department of Life and Environmental Sciences, Bournemouth University, Poole, Dorset, BH12 5BB, UK

²Department of Animal Conservation and Welfare, Kingston Maurward College, Dorchester, Dorset, DT2 8PY, UK

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Abstract

Teaching numeric disciplines to higher education students in many life sciences disciplines is highly challenging. In this study, we test whether an approach linking field observations with predictive models can be useful in allowing students to understand basic numeracy and probability, as well as developing skills in modelling, understanding species interactions and even community/ecosystem-service interactions. We presented a field-based lecture in a morning session (on rocky shore ecology), followed by an afternoon session parameterising a belief network using a simple, user-friendly interface. The study was conducted with students during their second week of a foundation degree, hence having little prior knowledge of these systems or models. All students could create realistic predictive models of competition, predation and grazing, although most initially failed to account for trophic cascade effects in parameterising their models of the rocky shore they had previously seen. The belief network was then modified to account for a marine ecosystem management approach, where fishing effort and economic benefit of fishing were linked to population abundance of different species, and management goals were included. Students had little difficulty in applying conceptual links between species and ecosystem services in the same manner as between species. Students evaluated their understanding of a range of variables from rocky shore knowledge to marine management as increasing over the session, but the role of the predictive modelling task was indicated as a major source of learning, even for topics we thought may be better learned in the field. The study adds evidence to the theories that students benefit from exposure to numeric topics, even very early in their degree programmes, but students grasp concepts better when applied to real world situations which they have experience of, or perceive as

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Approval Status ? ?

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1. **Vivien Sieber**, Sieber Associates, Oxford, UK

2. **Vicki N. Tariq**, University of Central Lancashire, Preston, UK

Any reports and responses or comments on the article can be found at the end of the article.

important.

Keywords

Bayesian belief networks, higher education, marine biology, rocky shore, predictive models

Corresponding author: Richard Stafford (rstafford@bournemouth.ac.uk)

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Introduction

While there are considerable differences between students' understanding and academic strengths worldwide, within much of the native English speaking world large proportions of students studying life science disciplines at higher education level have weaknesses with numeracy, and associated topics, such as statistics (Feser *et al.*, 2013). In many cases, 'fears' of mathematics have arisen and continued throughout their schooling, however, avoidance of numeric topics is not possible in many life science disciplines, especially in subjects such as ecology, where statistics form an important part of any independent research (e.g. Chalmers & Parker, 1989).

Many case studies have demonstrated that quantitative skills in ecology can be better taught if taught in a subject context (i.e. analysing data the students have collected in field based studies – Bäumer, 1999; Nolan & Speed, 1999; Yilmaz, 1996). Despite this, many students remain unconfident of quantitative elements of their courses, and few have the confidence apply even simple mathematics outside the confines of a few simple statistical tests (Grainger, 2010; Tariq, 2002; Tariq, 2004).

A possible solution to increase quantitative skills and confidence in students is the use of Bayesian belief networks. In their simplest form, Bayesian belief networks are a method of formalising uncertainty or probability from a number of events (Grover, 2013). From an ecological community perspective, this could amount to the calculated probability of a species decreasing in abundance, but based on known increases in both food supply and predation risk (Hammond & Ellis, 2002; Stafford *et al.*, 2013). However, traditional Bayesian belief networks do not cope well with reciprocal interactions (such as competition between two species), and revised methods using some aspects of Bayesian inference have been developed (Stafford R. and Gardner E. unpublished data). These revised methods also have a simple, user-friendly interface. They use Microsoft Excel as an interface, with a hidden VBA script performing the calculations. As such, the software used is familiar to the students, rather than complex modelling environments or coding platforms often used for predictive models.

Given the identified need for quantitative skills in graduates, and even in post-doctoral researchers (Grainger, 2010), the aim of this study was determine if it was possible to introduce predictive modelling to students at an early point in their education, and whether this predictive modelling would benefit student learning about ecology in general, rather than being seen as extra, and unnecessary, complexity in learning key concepts. To do this, we combined a field visit to a rocky shore, followed by an afternoon using a predictive belief network, initially based on their knowledge of the rocky shore. We quantified the success of the technique both through student questionnaires and through examining the solutions they provided to problems requiring the use of the predictive networks.

Methods

Study group

The study group consisted of 12 students enrolled on a foundation degree (UK level 4) in Marine Ecology. The students were based in an educational college normally specialising in further education

(pre-18 years old), but with some higher education (university level or post-18 courses) offered. The marine ecology course formed part of the higher education provision.

Students were in their second week of university level education, and from mixed backgrounds (~1/3rd mature students - 3 or more years after finishing school, and 2/3rd recent school or college leavers), however, none had previously formally studied ecology or ecological interactions beyond that covered in a typical school syllabus (UK A-levels or equivalent).

Field teaching

The field teaching session took place at Osmington Mills in Dorset, UK in early October 2014. Teaching consisted of an introduction lecture to rocky shore ecology, particularly examining ideas relating to vertical distribution of organisms (zonation) and exploring why small scale spatial patterns may have occurred (i.e. patches of green algae on the high shore, patches of barnacles). This gave a comprehensive introduction to physical limitations on organisms, as well as biological interactions (particularly interspecific competition and trophic interactions). Specifically eight key organisms were identified (Fucoid algae – *Fucus* spp., green algae – *Enteromorpha* spp., coralline algae – *Corallina officinalis*, barnacles – *Chthamalus* and *Semibalanus*, dogwhelks – *Nucella lapillus*, periwinkles – *Littorina littorea*, topshells – *Osilinus lineatus*, and limpets *Patella* spp.), and after a 90 min field lecture, students were told to look for these species and consider their ecological interactions with each other (the lecture had given the basic 'role' of each species – i.e. grazer, filter feeder, predator; but had not provided details of interactions between the species). These eight organisms were all common on the mid shore, and were the species incorporated in the predictive model.

Predictive model/Belief network

The full details of the belief network model used are provided as appendices (Supplementary File 1), as well as in VBA code within the downloadable Microsoft Excel files (Supplementary File 2). It comprised three 'worksheets' in a Microsoft Excel 'workbook'. One worksheet asked for an indication of which species were directly interacting (i.e. competitively, trophically, mutualistically), and simply followed a grid system whereby a species in a column on the grid is effected by a species in the row on the grid. This worksheet automatically updates a second worksheet, indicating where 'probabilities' of species interactions need to be filled in. The top table on this second worksheet asks for a number between 0 and 1 indicating the probability of a target species increasing, assuming the probability of the 'causing' species is increasing. Largely, once this table is completed, typically with 15–20 different interaction probabilities (depending on how many interactions are specified on the previous worksheet), the model is complete. However, it is possible to specify non-reciprocal relationships if desired (for example, the probability of barnacles increasing, given an increase in predatory dogwhelks could be low (e.g. $p = 0.1$). The spreadsheet would update automatically to indicate a decrease in barnacles, if dogwhelks increased would be the reciprocal of this ($p = 0.9$), although these values could be manually altered if preferred. In this case, no students altered the other probability values.

The final worksheet contained the ‘prior’ probabilities of species changes. In this case, two scenarios were given to predict community level changes. Firstly, increases in dogwhelks, and secondly increases in periwinkles. These were described in the manner of actual experiments conducted at Osmington Mills (manipulation experiments designed to increase the abundance of these species – data set provided as [Dataset 1](#)). In these belief networks, only a prior probability of directly affected species should be altered, with the remainder of probabilities for species increases or decreases remaining at 0.5 for both increase and decrease. In the specific task set, students were asked to consider interactions over a three to four week period, partly to compare with experimental data that was collected over this time frame, and partly to simplify bottom up relationships (starvation is likely to take much longer than this in typical intertidal molluscs). Equally, while slow growing seaweeds will be unlikely to exhibit growth and therefore increased percentage cover, rapid growing green algae will be able to increase in abundance ([Lubchenco, 1978](#)).

Pressing a ‘calculate’ button then runs the VBA code and calculates posterior probabilities, indicating the likelihood of species increasing or decreasing. Results were then discussed in small groups, and where errors were made, the reasons for these errors were discussed.

Marine management scenario

A marine management scenario was then conducted, using the same spreadsheet template and underlying VBA code. A scenario based upon common commercial fish and shellfish (cod, haddock, whiting, sole and scallops) as well as important biotic habitat types (sea fans) was given. This time, however, trawling effort and fisher income were two non-biological interactions ([Supplementary File 3](#)). Students were asked complete the network in the same way, just considering what species or service was effected by others, and then parameterising the network with probabilities, in the same manner as before. In this case, they were asked to explore

options for enhancing sea fan populations, without reducing fisher income.

Student evaluation of learning

An anonymous questionnaire was provided to each student, asking how much they had learned about various topics during the day (from rocky shore ecology through to understanding probability and uncertainty – [Figure 1](#); [Supplementary File 4](#)). In addition to ranking each on a 1–10 scale, they were asked to provide an answer as to where they thought they had learned most about the topic (either during the field lecture, or the afternoon computer session). Again, this was on a 1–10 scale, where 1 was only from the morning field session, 5 was equally from both sessions, and 10 was only from the afternoon session. The collection of these data from students was approved by the Science, Technology and Health ethics committee of Bournemouth University.

Results

After a few questions regarding ‘what to do’, students (working in pairs) all produced sensible interaction links in the model. Typical initial questions involved which worksheets to fill in and a general reluctance to ‘break’ the software by doing something wrong. Filling in the probability values resulted in a minor problem of students not considering exactly what they were trying to predict (the probability of a species increasing, given that another species had increased – in this example, where most species interactions are negative, it may be easier to parameterise the model as probability of a species decreasing, given another had increased). Four of the six groups needed this re-explaining, however, once this was pointed out and otherwise independently, all groups managed to produce working belief network simulations which accurately predicted real results from previously conducted experiments. The only area where the majority of groups (five out of six) struggled was in complex, indirect interactions, which only occurred as a result of a trophic cascade. Most groups failed to predict the competitive interactions for space between seaweed species, despite correctly

Figure 1. Contribution of the two different teaching approaches to student understanding of different learning outcomes. For each learning outcome examined, the median score was 7. Contribution was calculated using the equations $C_1 = M_1 \cdot ((10 - M_2) / 10)$ and $C_2 = 10 - C_1$, where C_1 is the contribution made by field-based lecture, M_1 is the median value of the students' response to how much they learned about the topic (in this case, all equal to 7) and M_2 is the median value of the students' response to how much they learned from the different teaching methods (1 indicating fully from the field-based lecture and 10 indicating fully from the computer-based practical).

predicting the trophic relationships between grazers and green algae, but other than this one interaction, results were almost identical to the 'expert' parameterised networks created by the authors, and produced similar values to real experiments conducted on rocky shores (see [Dataset 1](#) for real experimental data).

Student evaluations showed that students felt they had learned significant amounts about each topic, with median scores of 7 for all questions (with 25% and 75% quartiles between 6.5 and 9 in all cases). Knowledge of rocky shore ecology and ecological interactions was ranked as equally learned between the field and computer sessions (both with median values of 5) and knowledge of marine management and probability was greater in the computer based sessions (median scores of 7 and 8 respectively; [Figure 1](#)). In all cases, the full IQR was 2 or less indicating the majority of students scored in a similar manner ([Dataset 2](#) provides the full data for each student – note, as the survey was optional, only 11 of the 12 students present completed this).

Dataset 1. Data from manipulative experiment to assess community effects of dogwhelk manipulation (addition of 10 dogwhelks to each of 5 × ~1.5 × 1.5 × 1.5 m boulders) or periwinkle manipulation (addition of 10 periwinkles to 5 different, but similar sized boulders)

<http://dx.doi.org/10.5256/f1000research.5981.d41189>

'Before' values are before manipulations, 'after' values are after 3 week period. Additional columns for dogwhelks and periwinkles indicate values immediately after manipulation and should equal 'before' values + 10 for the manipulated boulders. Treatment codes (final column) DW = dogwhelk manipulation, LL = periwinkle (*Littorina littorea*) manipulation, C = control

Dataset 2. Raw data values of student responses to surveys

<http://dx.doi.org/10.5256/f1000research.5981.d41190>

Refer to [Supplementary File 4](#) for details of questions asked and scoring system.

Discussion

This study indicates that students (even at a very early stage in their academic journeys) are capable of understanding and applying quantitative techniques if presented in a logical and intuitive way. Furthermore, it demonstrates that their ability to learn these techniques can be integrated with development of ecological knowledge and understanding; acting not as a hindrance to, but as a complement to the understanding of key concepts.

Much previous research has demonstrated that quantitative methods need to be taught in the context of the academic discipline ([Bäumer, 1999](#); [Nolan & Speed, 1999](#); [Yilmaz, 1996](#)). However, this approach can often seem rather forced to students, especially early in their studies. Examples are often based around simple data collecting exercises rather than conceptual issues or real research projects. Although students are capable of performing statistical tests, for example, on a specific dataset at the time, they find it difficult to remember and transfer the knowledge to a novel situation ([Chance, 2002](#)). However, embedding more quantitative

elements regularly to courses to enhance learning of key concepts may result in less fear being associated with dealing with numbers, and a greater ability to synthesise more quantitative information such as inferential statistics when required.

The role of technology in education is becoming a prominent issue, with a number of case studies demonstrating how it can be useful in the classroom and even during field work ([France & Welsh, 2012](#); [Webb & Stafford, 2013](#); [Welsh & France, 2012](#)). Simulations have also been used to teach complex ecological concepts such as experimental design in place of (or in addition to) field or laboratory based studies ([Stafford *et al.*, 2010](#)). With on-going improvements to technology (e.g. development of specific apps for tablet computers), it may be possible to use spreadsheet models such as this directly in the field. An advantage of such an approach would be that the simulation app could be combined with field guides and information on the species being studied, potentially allowing a more fully immersive learning experience.

The simplicity of use of belief networks, especially when combined with a familiar user interface, was clearly demonstrated here, with students being able to make, parameterise and run simulations of ecological systems and coupled socio-ecological systems. These results add further weight to the intuitiveness of the approach. Combined with uncertainty in detailed knowledge of many marine ecosystems (in terms of exact population sizes, recruitment and species interactions - [Hilborn & Walters, 1992](#); [Magnusson, 1995](#); [Pope, 1991](#)), and the need to adhere to what could be perceived as 'crude' policy measures (e.g. no decrease in the population size of a certain species - [DEFRA, 2012](#)), models such as these used in this study would fit well with the demands and requirements of policy makers, providing sufficient detail for achieving policy goals with limited data and in an intuitive manner.

Data availability

F1000Research: Dataset 1. Data from manipulative experiment to assess community effects of dogwhelk manipulation (addition of 10 dogwhelks to each of 5 × ~1.5 × 1.5 × 1.5 m boulders) or periwinkle manipulation (addition of 10 periwinkles to 5 different, but similar sized boulders), [10.5256/f1000research.5981.d41189](http://dx.doi.org/10.5256/f1000research.5981.d41189) ([Stafford & Williams, 2014a](#)).

F1000Research: Dataset 2. Raw data values of student responses to surveys, [10.5256/f1000research.5981.d41190](http://dx.doi.org/10.5256/f1000research.5981.d41190) ([Stafford & Williams, 2014b](#)).

Author contributions

RS wrote the code for the Bayesian belief model. RS and RLW both conceived the study, conducted the taught sessions and collected, analysed the results and contributed to writing the paper. Both authors have agreed the content of the final draft of the manuscript.

Competing interests

No competing interests were disclosed.

Grant information

The author(s) declared that no grants were involved in supporting this work.

Supplementary information

Supplementary File 1: Mathematical details and description of the belief network model.

[Click here to access the data.](#)

Supplementary File 2: Microsoft Excel file (with VBA script and macros) realising the belief network model for the rocky shore scenario.

The file is parameterised as per authors' values, but is fully editable to allow students to alter these.

[Click here to access the data.](#)

Supplementary File 3: Microsoft Excel file (with VBA script and macros) realising the belief network model for the marine management scenario.

The file is parameterised as per authors' values, but is fully editable to allow students to alter these.

[Click here to access the data.](#)

Supplementary File 4: Copy of survey provided to students to determine what they considered they learned, and whether they learned it from field lectures or computer based practical classes.

Note – survey was explained orally to students before completing it.

[Click here to access the data.](#)

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Reviewer Report 15 April 2015

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Vicki N. Tariq

School of Social Work and Social Policy, University of Central Lancashire, Preston, UK

A useful contribution to strategies aimed at helping life sciences undergraduates appreciate the importance of quantitative skills, develop their own quantitative skills and (hopefully) become less anxious about mathematics and statistics within the first few weeks of their transition onto a higher education programme.

Introduction

2nd paragraph: Suggest changing to "in ecology can be better learned/developed if they are taught in a subject context ....." Also ..... "and few have the confidence to apply....."

3rd paragraph: A simple diagram might help readers understand Bayesian belief networks in an ecological context.

4th paragraph: "..... the aim of this study was to determine ....." ; "..... seen as an extra, and unnecessary complexity....."; "..... we combined a field visit to a rocky shore with an afternoon using ....." .

Methods

1st paragraph: "The students were based in a college normally specialising in further education (pre-18 years old), but offering some higher education courses."

Predictive model/Belief network: requires more clarification for non-specialists. It might also help if the three individual worksheets in Supplementary File 2 were numbered (and referred to by these numbers in the text) and each worksheet contained more explanation so that the reader wasn't trying to move back and forth between the manuscript and the Excel worksheets. Also in sentence 3 – "effected" should be "affected".

Marine management scenario: 4th sentence – "Students were asked to complete ....." ; "effected" should be "affected".

Student evaluation of learning: the rubric in the questionnaire should have been presented only once at the beginning – its repetition before each question is tedious (to say the least) to students and readers of this article alike.

Results

Figure 1: the horizontal axis needs to be labelled as 'Contribution'

The two references in the text to "trophic cascade" should be "trophic cascade"

The authors state that "Student evaluations showed that students felt they had learned significant amounts about each topic .....", "students (working in pairs) all produced sensible interaction links in the model", and "[they produced] working belief network simulations which accurately predicted real results from previously conducted experiments", but did the authors use any other means to assess each individual student's quantitative skills (e.g. their understanding of probability) and knowledge of rocky shore ecology (e.g. species interactions, marine management)? – the students, particularly when working in pairs, may have over-estimated the extent of their learning, in which case their self-evaluation of their knowledge and competence may not have matched their actual knowledge and competence? The authors may have needed to do more than "[quantify] the success of the technique ..... through examining the solutions [the pairs of students] provided to problems requiring the use of predictive networks." (final sentence of the Introduction).

Discussion

2nd paragraph, final sentence: "However, embedding more quantitative elements regularly in courses to enhance ...."

The discussion would benefit from the authors addressing the points raised by Vivien Sieber.

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Reviewer Report 14 January 2015

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Vivien Sieber

Sieber Associates, Oxford, UK

This is an interesting and relevant study on a topic that is, increasingly, recognized as important. The authors restrict their discussion to Life Sciences, in particular marine ecology whilst this study is potentially of wider interest to the scientific community. The authors may find some of the included references helpful in expanding their argument.

Assuming this paper is interesting to a wider community rather than restricted to specialist marine ecologists; it would be helpful to give a brief definition of Bayesian belief networks.

Methods

Please give the HE qualification/s participants were working towards to facilitate comparison with other studies.

Predictive model/Belief network

This text would benefit from clarification as it is rather difficult to follow for non-specialists. Might a diagram or flow chart help?

Sentence 3: 'effected' should be 'affected'

Survey

It would be conventional to insert the rubric once at the top of the questionnaire rather than repeating it in every question. Respondents might be discouraged by this additional burden.

Results

Developing new approaches to teaching are always difficult as teaching is constrained by practicalities such as timetabling. It would be interesting if it were practically possible to compare outcomes after switching the field-work element with the simulation.

It would be easier for the reader if the responses to the survey were summarized and presented graphically.

Remove the link to Supplementary file 4 0c718f4f-6cb7-4030-823c-94f3687abe47.docx from the legend Dataset 2 to avoid confusion.

Discussion

Again, the discussion might usefully be expanded to include a wider range of subject fields, perhaps including evidence supporting the role of simulations in generating understanding. The authors might wish to comment on the difference between the ability to carry out a calculation and the skills needed to interpret data.

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Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

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