

THE POWER OF BALANCING IN A DATA-RICH MATERIAL WORLD: TEACHING INTRODUCTORY MATHEMATICS AND STATISTICS TO BIOLOGY STUDENTS

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*The present study analyzed the satisfaction level of first-year biology students exposed to two sorts of learning activities while taking an introductory course on quantitative methods. Using a handbook of practices in *Quantitative Methods in Biology*, first-year Biology students carried out different activities involving data collection, statistical analysis and construction of graphical models. At the end of the term, students were asked to contrast their learning activities with and without the use of virtual learning tools. Most students declared both approaches useful in their learning process, but preferred the production of their own data without the intervention of technology or virtual/computerized tools. The pattern of responses found in the survey, along with the wide array of situations a first-year biology student may well encounter in the future, suggest that learning experiences of biology majors should balance virtualization and empirical work “in the material world”.*

INTRODUCTION

At present, we live in a world immersed in a sea of information with vertiginous waves of data pouring from computerized systems and portable devices. In the face of this overexposure to information, it is important to be selective when the education of future investigators is in our hands. At the Universidad Autónoma de Yucatán (UADY, 2013) in Mexico, the Biology degree syllabus states that student’s education must be oriented towards gaining skills in natural resource conservation and management. In particular, students are expected to attend lab and field-based courses, where the connection between biological sampling techniques and potential statistical data analyses is practiced empirically. As UADY students are faced with a variety of lab or field activities, it might be thought they yet belong to the “artisan era”, contrasting with our contemporary age pointing towards the use of virtual scenarios and technology. It has been argued that both worlds, empirical (“real” or “non-virtual”) and virtual, are necessary (Liu, 2006; Fuhrmann et al., 2012), but there are opinions promoting the giving of more weight to virtual learning resources (Peat, 2000). However, biologists’ real-world practice is diverse (Quacquarelli Symonds Limited, 2017); thus the selection of learning activities is crucial in mathematics and statistics courses for biology students. Knowing the opinions of biology majors is important as guidance in determining the relative weights of empirical and virtual activities in the course, with the ultimate purpose to diagnose whether meaningful learning has been attained. The aim of the present study was to analyze the satisfaction level of first-year biology students exposed to two sorts of learning activities while taking an introductory course of quantitative methods: one requiring data collection and analyses without the use of virtual learning tools, and the other where virtual tools facilitate data collection and analyses. These opinions are discussed and confronted with the widespread use of virtual learning tools at Bachelor’s level.

MATERIALS AND METHODS

Manual of lab and field activities

Biology students at the Universidad Autónoma de Yucatán (UADY) take a course of introductory mathematics and statistics during their first year. The contents of the course (“Quantitative Methods in Biology”) is a mixture of topics in Calculus and Statistics. Experiential learning in the course is predominantly supported by five practical activities described in the corresponding lab and field manual, containing a mixture of non-virtual (empirical) and virtual assignments, all of them being representative topics from mathematics, sampling design and statistics. Details are given in Table 1 with comments.

Table 1: Contents of the manual of lab and field activities.

<i>Activity 1. The measurement process (Non-virtual)</i>	
Topics: Significant figures, real limits and absolute and relative uncertainty of liquid volumes and lengths. A formal lab practice.	Comment: Useful for exemplifying the concepts of measurement scales, accuracy, precision, and so on. The “less attractive” activity.
<i>Activity 2. Calculation of tree height (Both virtual and non-virtual)</i>	
Topic: Trigonometric functions. Students measure tree height, using a non-electronic device (measuring tape) on one hand, and laser gauges on the other hand. For angle measurement, students manufacture a homemade clinometer.	Comment: Students practice calculations of trigonometric functions and make decisions along the way when the terrain is uneven. A popular activity.
<i>Activity 3. Gause’s paramecia: a virtual experiment in natural populations (Virtual)</i>	
Topic: Discrete and continuous rates of change. A free-access internet resource is used (McGraw-Hill Education, n.d.)	Comment: Another popular activity where students analyze how competition for resources may affect growth in two species of the protozoan <i>Paramecium</i> .
<i>Activity 4. Simple random sampling and the description of quantitative variables in Biology (Both virtual and non-virtual)</i>	
Topics: Simple random sampling; descriptive statistics. Students choose the real or virtual objective-population under the condition that the response variable be quantitative.	Comment: Students judge their decisions on the most suitable way to carry out the (on-campus) simple random sampling. Guidance is important, as students tend to concentrate more on calculations than on the sampling process.
<i>Activity 5. Phenylthiourea tasting and χ^2 testing (Non-virtual)</i>	
Topics: Test of hypothesis, chi-square goodness of fit. Phenylthiourea is a chemical compound that has a bitter taste depending on whether the individual who tastes it has a particular gene, with the compound having no taste to an individual who does not have the gene.	Comment: A favorite among students. It is an enjoyable activity useful to link concepts from population genetics and statistics. As phenylthiourea and tasteless paper strips are both tasted, the activity discusses also the concept of control treatment and false-positives.

Survey

A single cohort, containing 35 first-year Biology students taking the course, was exposed to the different practical activities indicated in the laboratory and field manual described in Table 1. At the end of the term, a population-level survey was applied by one of the authors (RBM), in order to know the students’ opinion about nine features of the course. The first two questions asked their general impression about likes/dislikes by the presence of a Mathematics course in Biology; the remaining seven questions were associated to their practical activities. The questions are listed in Table 2. The set of possible answers were placed on a *Likert scale* (*No opinion* (0), *Strongly disagree* (1), *Disagree* (2), *Agree* (3) and *Strongly agree* (4)). The course instructor (JNA) did not see the survey before analysis. As this is a single cohort study, we just analyzed the overall pattern of variation of the 5-level Likert answers with a) graphical and numerical descriptive statistics of the relative frequencies of answers for each aspect inquired and b) non-metric multidimensional scaling (NMDS) as a multivariate exploratory technique (Subkoviak, 1975; Manly & Navarro, 2017). NMDS searches for a low-dimensional spatial representation (ideally, on a plane), showing the interrelationships between objects (in this case, survey respondents). Proximities between objects are measured with similarity or dissimilarity metrics. In the NMDS analysis for the present study, the Bray-Curtis dissimilarity metric was used, looking for patterns of association between students on the basis of their answers.

Table 2: Class survey.

1. - I am aware of the importance of Mathematics in my professional training.
2. - The aspects of Mathematics applied to Biology are pleasantly taught in the course.

3. - The difficulty level of Mathematics in this course is what I expect from a freshman's course.
4. - In this sort of courses, real and virtual practical activities are necessary.
5. - Proposed practical activities are useful for the comprehension of the mathematical topics.
6. - The difficulty level in those practical activities corresponds to the level of Mathematics in this course.
7. - Practical activities in this course are related to the professional practice of any BSc. in Biology.
8. - I prefer practical activities where I can collect the data myself, not just data provided by the instructor for their analysis.
9. – The teacher-student interaction is satisfactory during the execution of the practical activities.

RESULTS

Overall, students answered positively to all items in the survey, as shown in Figure 1, with scores ranging from 80 to 100%. Particularly noteworthy were the answers for the item about awareness of the importance of mathematics in the students' professional training, where none of them expressed a negative opinion nor avoided to give an opinion. On the other hand, the greatest percentage of neutral or negative responses were found in the mathematical aspects linked to how pleasantly the mathematics are taught in the course (25.7%) and the expected difficulty level of the Maths course (20%).

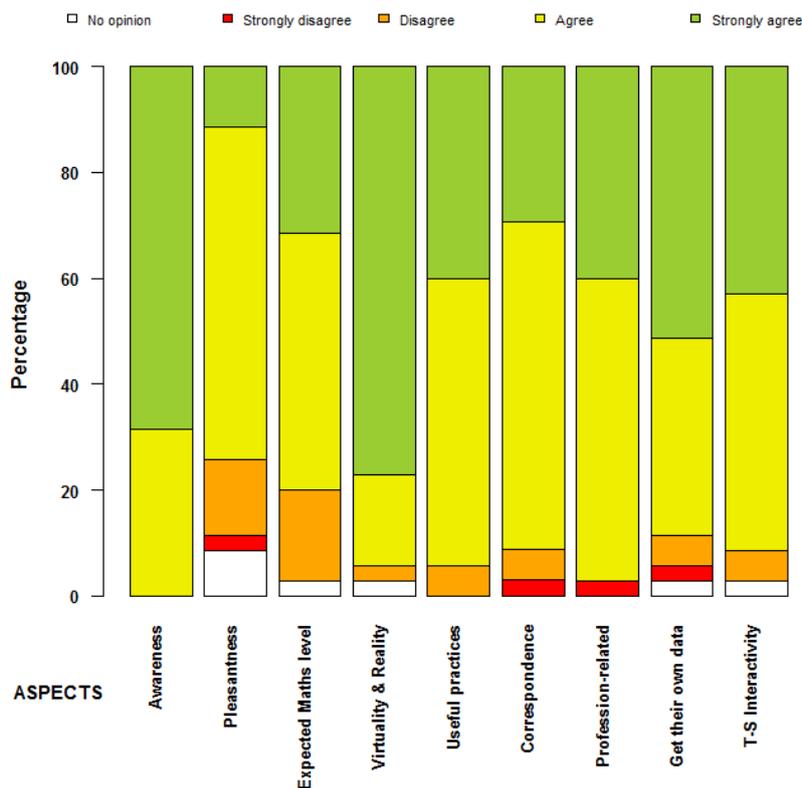


Figure 1: Relative frequencies (%) of answers in a survey on nine aspects of learning experiences in a Mathematics course taught to first-year Biology students (n=35). The order of labels on the x-axis (Aspects) follow the sequence of questions shown in Table 2.

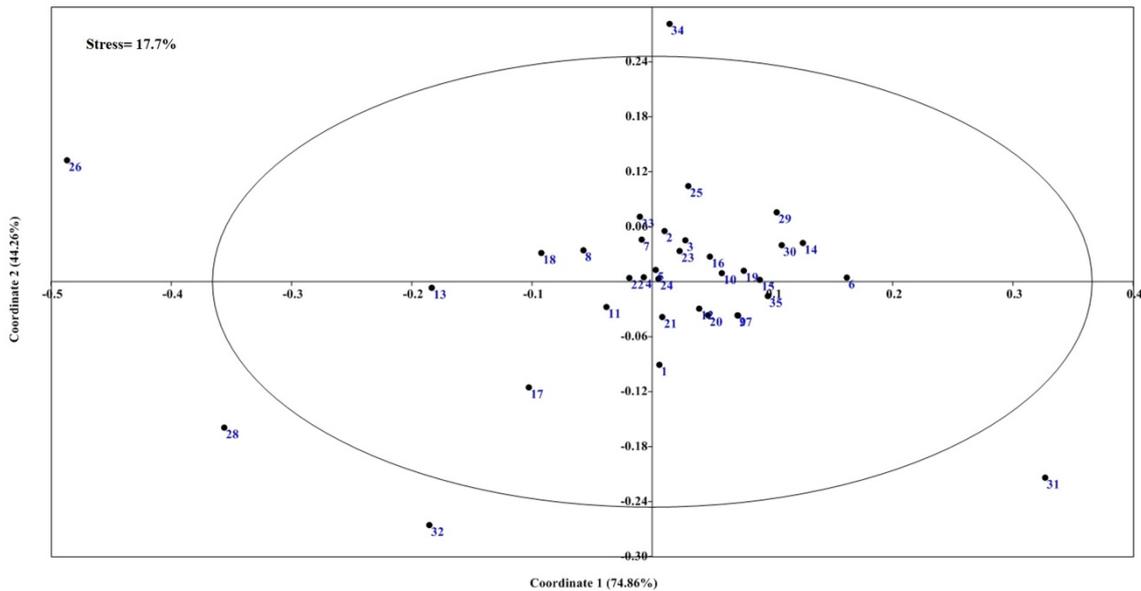


Figure 2: Two-dimensional Non Metric Multidimensional Scaling of first-year Biology student respondents (n=35) from a survey on nine aspects of learning experiences in a Mathematics course.

The stress attained in the NMDS of respondents was 17.7%, indicating a fair goodness of fit of the data in two dimensions. The diagram shown in Figure 2 displays the presence of a mass of points (students) including the 85.7% of the cases inside the concentration ellipse. Five cases lie apart from that general pattern, explained by their neutral or negative opinion about the pleasantness of the mathematics taught in the course, the correspondence between the difficulty levels of practical activities and the contents of the course, and the relation between those activities and their future professional practice.

DISCUSSION

The main purpose of practical activities in a mathematics course is to emphasize well-identified qualitative and quantitative facets of biological practice, so that students approach a “mathematical reality” of natural phenomena, either real or virtual ... or both. In their feedback evidenced by their answers of the survey, students expressed that the five practical activities included in the manual had been useful for comprehension. In fact, the idea behind the manual of practical activities is to make available a complementary support for the student’s learning process: firstly, as a motivational tool, because it is contextual by its own nature; and secondly, as an enforcement of comprehension, under the premise that activities are suitably guided. As Metz (2008) has argued, “it is clear that active learning, with components including laboratory exercises, group work, work with class-generated data, and student written and oral presentations, increases student enthusiasm for, and learning of, statistics”. Similarly, Allen et al. (2010) state that “the use of ‘real’ environmental, biological ... data creates a greater level of engagement and understanding”. The survey revealed these positive attitudes in our students. However, researchers in statistical education have discussed the pros and cons of the “data in context” for students taking statistical courses (Watson & Moritz, 2000; Hulsizer & Woolf, 2009; Wroughton *et al.*, 2013). One of the major concerns is the possibility of bias when personal beliefs dominate the collection, analysis and interpretation of contextual data. Therefore, it is important to have the instructor’s support during the theoretical sessions prior to the execution of the practical activities, and a thorough in-class discussion about formal assumptions of any method.

The selection and organization of the instructional materials is also vital in reducing biases about what it is expected from our students (Onasanya & Omosewo, 2011). Although instructor’s expertise and creativity is the critical driving force for successful instructional material, in the case of subjects where mathematics/statistics and other sciences are interlinked, inter-disciplinarity is

necessary. According to Martínez-Dawson (2003), “with this interdisciplinary approach, non-statistics majors will see how statistics is relevant to their major through the interplay of statistics with science”. One statistician (JNA) and one biologist (RCB) chose the material contained in the manual, and they both glimpsed the necessity of offering real and virtual learning strategies.

The educational model at UADY, like other universities around the world, sustains that information technologies must support the educational platform, leading to the use of innovative virtual learning tools (UADY, 2012). Instructors in Maths/Statistics courses have been encouraged to use virtual resources, but their implementation implies a reduction in the time devoted to “empirical” work. The instructor may have raised the question: Why bother in taking samples in the lab or in the field, while one can use simulation? And the instructor may add that with simulation there is no need to devote time and spend money for outdoor activities; there are excellent offline/online resources suitable for statistics laboratories, from where students can generate (e.g. take “virtual samples”) and analyze biological data (see e.g. Braun, 2003; Stirling, 2015). However, empirical work should not be reduced, as one of the biologist’s skills is the capacity to gather real biological data.

Working in the real world has potentiated the use of electronic (sampling) devices, allowing an increase in our capacities of measurement and data collection, to such an extent that it would be meaningless to throw technology away. Data loggers, gauging devices, and the alike, are easily available for the contemporary biologist, for whom the sampling process and analysis embody new challenges. Now data is becoming more and more massive and biologists are involved in retrieving “big data” already; those data are collected “in the field”. Ecology is a good example of a biological discipline where most of the data are obtained from natural systems in the field (Anderson, 2002). In fact, activities 2 and 4 in the manual illustrate quite simple ways of sampling real systems. In particular, for activity 2, the student is able to compare the accuracy produced by a laborious procedure of distance measurement using measuring tapes and the handy use of laser distance meters. In contrast, the manual also includes a activity 3, a virtual activity directed to study an ecological principle—the experiment of competitive exclusion using Gause’s paramecia. These examples illustrate that both real and virtual scenarios are relevant to biology students.

CONCLUSION

The learning process of mathematical and statistical methods in Biology entails putting hands on the collection and analysis of data, even for first-year students taking an introductory maths/stats course. Technological and non-technological tools have a place in this setting. Furthermore, as the survey evidenced, the wide array of situations a first-year biology student might encounter in the future leads us to suggest that, as far as educational strategies are concerned, both real and virtual perspectives are important. Therefore, virtualization and practical work should be balanced in the learning processes of biology (i.e., non-statistics) majors, in order to motivate and enforce comprehension.

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