Using assessment audits to understand students' learning obstacles

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Abstract: *Undergraduate science students are given opportunities to link the descriptions of scientific phenomena presented in lectures to their own observations of similar scientific phenomena in practical classes so as to reinforce key concepts. Being able to conceptually move between the scientific phenomena and the abstracted figures or equations that represent those phenomena is a key skill. Developing this skill, and confidence with applying this skill, is the implicit objective of many undergraduate practical classes. However, students seem unable to adequately explain their observations, despite the implementation of many "how to" guides, and this is of concern, which is why we seek to identify some of the factors that seem to impede students from being able to correctly translate and explain scientific data.*

We audited 118 laboratory reports in from second year molecular biology students to assess students' abilities to correctly record and calculate data, appropriately present data, and clearly explain the representation of their data. Each of these abilities were linked to criteria in the report marking scheme students had been provided and for the purpose of our audit, graded as to whether the students completed the task poorly or not at all (1), adequately with some errors (2), or correctly and clearly (3). The data showed that a high proportion of students could not complete these tasks correctly and confirms that students have difficulty moving between the phenomena they observe and its abstract presentation. Having identified and quantified where students are having difficulties, we will use this information to inform the design of an online learning module to improve the conceptual linkages between a) an observed scientific phenomenon, b) the experimental data c) how these data are presented and d) interpreted. We expect to be able to determine the efficacy of this approach by re-auditing laboratory reports, after the online module is in place.

Introduction

In order to reinforce key concepts, undergraduate science students are given opportunities to link the descriptions of scientific phenomena presented in lectures to their own observations of similar scientific phenomena (biology, physics, chemistry) in practical classes, as described in the constructivist model (Lunetta 1998). The activities therein assist students to learn with understanding and construct their knowledge by participating in the scientific phenomena (Tobin 1990). Being able to conceptually move between the scientific phenomena and the abstracted figures or equations that represent those phenomena is a key skill. Developing this skill is the implicit objective of many undergraduate practical classes. However, achieving this appears to be a complex process with many variables (Hofstein and Lunetta 2003; Hofstein and Mamlok-Naamaan 2007). We are concerned that despite the implementation of many 'how to' guides, some students still seem unable to adequately explain their observations (Quinnell 2006). We are seeking to identify factors that impede students from being able to correctly translate and explain scientific data.

A generalised model of the learning process in undergraduate science is presented in Figure 1. Successful learning involves movement from an understanding of a scientific phenomenon to the representation of this phenomenon in an abstract form, typically in the form of a figure or equation. This process involves the translation of scientific observations into presentable data using calculations. The second part of the learning process involves movement from the representation of data back to the scientific phenomena, by using writing skills to describe the patterns and relationships in the data.

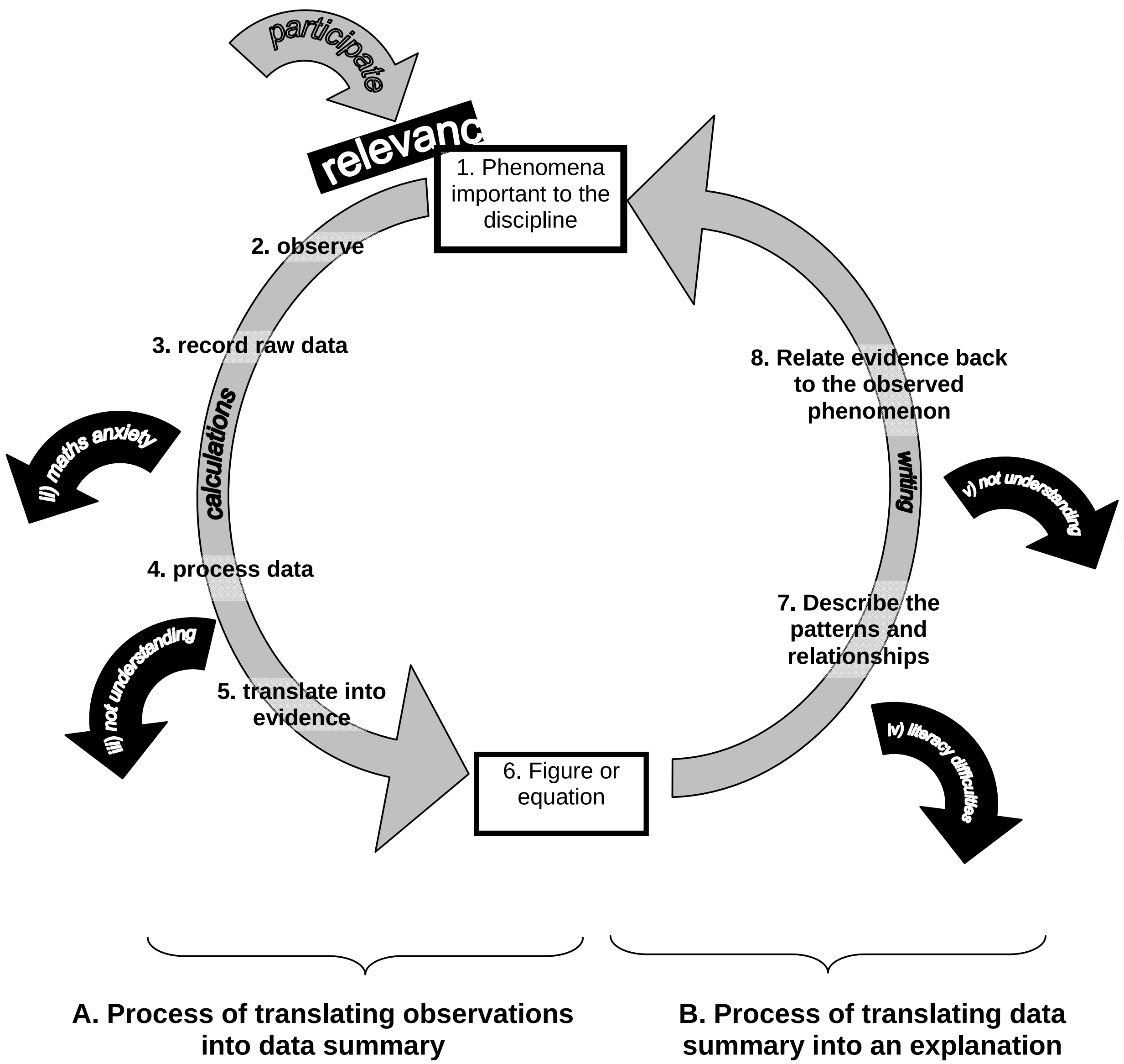

Figure 1. Generalised learning process in undergraduate science

Students experience a disconnection in the flow of their learning when there is an obstacle preventing movement between their understanding of a scientific phenomena and the abstract representation of the data that explains it. This may stem from their inability to engage if they do not see the relevance of the phenomena in their learning (Figure 1, i). Mathematics anxiety or literacy difficulties may impede students' ability to calculate or describe data (Figure 1, ii and iii, respectively). A lack of understanding about the phenomena could also disrupt the learning process, rendering students unable to move between the phenomena and its abstract representation even when explicit instructions or 'how to' guides are provided.

Our initial objective was to identify common obstacles to student learning in science related to: observing, recording, calculating, presenting and explaining phenomena in second year undergraduate Molecular Biology and this process is described here. We have identified and quantified steps where students are having difficulties by auditing students' laboratory reports and mapped these to the presented model of the learning process in undergraduate science.

We have a view to use this information in the design of an animated online learning module to improve the conceptual linkages between 1) an observed scientific phenomenon, 2) the experimental data 3) how these data are presented and 4) interpreted. Animations will form an important feature of this module as these provide powerful and dynamic ways to link the scientific phenomenon being examined with abstracted representation of that phenomenon (e.g. graph, figure). The positive impact of online animations on student learning in science has been demonstrated (Ardac and Akaygun 2003; Talib, Matthews and Secombe 2005) as has synchronously presenting several scientific representations of a phenomenon (Russell, Kozma, Jones, Wykoff, Marx and Davis 1997). By re-auditing laboratory reports, after the online module is in place, the success or failure of this approach can be determined.

Method

Our starting point was an awareness that students often appear unable to explain their observations of scientific phenomena despite being provided with "how to" guides. We set out to identify the factors that impede students' abilities to correctly present and explain scientific data, with the ultimate aim of designing an online learning module to bridge the gaps present in their process of translating observations into data and providing an explanation of this data.

A second year molecular biology course was selected that required students to submit a laboratory report based on a gene expression experiment. As part of the course, students have three lectures on gene expression and a revision tutorial to introduce the topic, followed by two laboratory sessions where they conduct an experiment. In the laboratory setting, students are in small groups of up to sixteen. A demonstrator introduces the experiment at the commencement of the session and facilitates discussion of the results at its completion. The data from each student is collected and the results pooled together and distributed on an information sheet. Each student then writes a laboratory report which requires correct interpretation and appropriate presentation of this data. The report is weighted as 5% of the final mark in the course, with 35% comprised of continuous assessment. The format consists of an introduction, a results section which includes tabulated and graphed data, and a discussion. Students are also provided with a one page marking scheme and "how to" guide, detailing how the data should be presented, compared and interpreted.

An audit of 118 laboratory reports was conducted to assess students' abilities to correctly record and calculate data, appropriately present data, and clearly explain the representation of their data. Each of these abilities were linked to criteria in the report marking scheme and for the purpose of our audit, graded from one to three, corresponding to whether the students completed the task poorly or not at all, adequately with some errors, or correctly and clearly. A single grader conducted the audit for consistency. The abilities audited can be mapped to the model for student learning presented in Figure 1. The ability to correctly record data maps to steps 2 (observe) and 3 (record raw data), to calculate data refers to the 'calculations' action required for movement to step 4 (process data), to appropriately present data refers to steps 5 (translate into evidence) and 6 (figure or equation), and to clearly explain the representation of data maps to step 7 (describe the patterns and relationships), step 8 (relate evidence back to the observed phenomena) and the writing process required in this progression.

Results

The data, presented in Table 1, showed that a high proportion of second year molecular biology students could not complete these tasks correctly and confirms that students have difficulty moving between the phenomena they observe and its abstract presentation.

Table 1. Assessed abilities of students to calculate and process, and to present and describe scientific data and the phenomena they represent.
Results of an audit of 118 laboratory reports are shown. Students' abilities to calculate and process data, present scientific data, and describe the scientific phenomena observed were investigated (shown in bold type). Reports were graded using a scale of 1 to 3 with 1 = task completed poorly or not at all, 2 = adequately with some errors, 3 = correctly and clearly. Grades are given in brackets following a more specific description of the grade as it related to the corresponding ability and the percentage of student reports that received this grade is shown beneath.

Performing calculations and processing data		
No data or raw data (1)	Inappropriate, excessive or incorrect data (2)	Data correctly calculated and clearly presented using the correct units (3)
3%	69%	28%
Presentation of scientific data		
No graph or an incorrect graph (1)	Graph shows correct trends, but contains errors (2)	Graph correctly presents the phenomena, using the correct units (3)
15%	41%	44%
Description of the phenomena		
No written description (1)	Incomplete description (2)	All observed scientific phenomena adequately described (3)
2%	38%	60%

An initial step in this translation is the use of calculations to process raw data into a meaningful form. Students that could not carry out this step (3%) submitted a report where no data or raw data was presented. Students with some difficulty (69%) presented data that was incorrect, inappropriate or excessive. In comparison, (28%) had applied a given equation to the raw data and presented it clearly in a tabulated form, using the correct units.

Clear presentation of scientific data requires sufficient understanding of the phenomena it describes. Students lacking the ability to clearly present their data (15%) did not include a graph in their report, or included an incorrect graph. Other students either included a graph that included some errors (44%), but still showed a correct trend that enabled comparison between the variables of the experiment, or a graph that clearly communicated the phenomena and used the correct units (41%).

Students were also observed to have difficulty relating their abstract presentation of the data back to the phenomena, with 2% of students including no written description of their results. Students with a limited understanding gave an incomplete description (38%), while 60% of students adequately described the scientific phenomena observed in the experiment.

Discussion

The first step in the learning process involves participating students fully undertaking the activity, which primarily occurs through their understanding of its relevance (Biggs 1999). In undergraduate science, laboratory practical sessions are a key learning tool and students that do not fully engage in conducting an experiment would normally disconnect from the learning process early on when they were required to observe and record raw data.

These activities map to our generalised model of the learning process in undergraduate science presented in Figure 1 (steps 1 and 2). The 3% of students that either did not present data or presented only raw data may include those who failed to see the relevance (Figure 1, i) or did not understand the phenomena being studied (Figure 1, step 1). In this study, students were provided with a pooled set of class results that was used for their laboratory report. However, those who were not fully engaged in the learning process would lack the understanding to link these results with the phenomena that occurred in the experiment and therefore be unable to process and present the data in a useful form (Figure 1, steps 5 and 6). In addition, mathematics anxiety (Figure 1, ii) has been shown to disrupt cognitive processing (Ashcraft 2002). Students that exhibit this tend to avoid even simple calculations and consequently often lack numeracy skills, and/or numeric confidence (Quinnell and Wong, 2007). They may therefore be unable to process raw experimental data (Figure 1, step 4) and, furthermore, may disconnect fully from their learning as this anxiety prevents them from taking in further instructions that are presented (Ashcraft 2002). This is relevant to our study as, although all students are shown how to correctly perform the calculations required for their report in a small group setting, a student with mathematics anxiety may consequently be unable to participate in discussion of the experiment during laboratory time as they become preoccupied with thoughts associated with the required calculations. Recognising mathematics anxiety as a possible reason for 3% of students not attempting to perform calculations and 81% not performing and presenting calculation competently will help inform the future design of an online learning module to assist students in this assessment task.

Although some students may possess the mathematical abilities to process the data, a lack of understanding (Figure 1, iii) would disconnect them from the learning process as they could not appropriately translate this data into evidence (Figure 1, step 5). Translating processed data obtained from an experiment into evidence is a vital skill for a scientist as a clear presentation of observations, often shown in a figure or described in an equation, allows a scientific phenomena to be communicated efficiently. A minority of undergraduate molecular biology students were able to achieve this, with 59% of the audited reports either not containing a graph or providing an inappropriate graph. These students appear to have become disengaged in the learning process, being unable to effectively translate their observations into a data summary (Figure 1, steps 5 and 6) even when provided with a ‘how to’ guide.

Interestingly, a higher percentage of reports provided an adequate description of the results than correctly presented the data (60% and 41%, respectively). This apparent anomaly occurred when students correctly described the phenomena occurring in the experiment, but did not provide the data or clearly present the data to support this. Such students understand the concepts of gene expression, as presented in their lectures and detailed in the introduction to their laboratory experiment. They could provide an explanation of the phenomena they knew must occur in the experiment, based on their knowledge of the topic, yet lacked the initial skills required to adequately translate their observations into evidence. In our model of the learning process (Figure 1), these students were unable to move through steps 1 to 5 in the process of translating observations into a data summary. The students’ literacy competence and knowledge of the topic allowed them to discuss the scientific phenomena occurring (Figure 1, step 8), but they were unable to link this to their own observations.

It should be noted that we only assessed the basic ability of students to directly describe the patterns and relationships shown by the data and to relate these to the observed phenomena, and students with deeper learning could further expand on their observations.

The conducted audit of student laboratory reports allowed us to identify steps where students can experience a disconnection from the flow of their learning process. As a key skill in the science profession is moving between observed phenomena and the abstract figures or equations that represent those phenomena, we have a view to design an online learning module that will assist students in moving between these steps. Repeating an audit of laboratory reports after this module is in place will then allow its success or failure to be determined. Although the constructivist model describes how laboratory activities can assist in student learning (Lunetta 1998), it is important to note that this is a complex process (Hofstein and Lunetta 2003; Hofstein and Mamlok-Nanmaan 2007). For this reason our study has aimed to identify where the obstacles to student learning lie on our model and not their causes. Following successful implementation of this module we will seek to survey students to uncover more details of the obstacles in their learning.

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