Creating a reliable instrument to assess students' conceptions of studying biology at tertiary level

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***Abstract**: As part of a study to assess the impact on tertiary biology students of changes to the NSW HSC biology curriculum, we developed a questionnaire to survey student conceptions of biology. This required the creation of multiple Likert-scale items in two sub-scales: (i) fragmented conception of biology (e.g., Biology is just the study of facts); and (ii) cohesive conception of biology (e.g., Biology allows predictions to be made about everyday life and situations). Before implementing the questionnaire to address our main research questions, and because this was the first time, to our knowledge, that a Conceptions of Biology Questionnaire had been designed, we needed to validate its use in distinguishing between students who have different conceptions of biology as a science discipline. We used data from students, collected in their first week of tertiary biology, to analyse the reliability of the Conceptions of Biology items. Analysis using SPSS software indicated that items in the two conceptions sub-scales were individually reliable (Cronbach μ values > 0.6). However, factor analysis indicated that items in the fragmented sub-scale were not being discriminated from items for cohesive sub-scale by students. This result allowed us to reword the fragmented conception items before re-administering the questionnaires and thus demonstrate improvement in students' ability to discriminate between fragmented and cohesive statements. We are now confident that the questionnaire will accurately discriminate between students with different conceptions of biology and recommend this practice for all future such investigations.*

Introduction

Important advances in approaches to educational research have been made in recent years. Statistical analyses of Likert-scale survey results have allowed for increasingly rigorous quantitative analyses of student experiences of learning. The use of these analyses, together with phenomenographic analysis of student responses to open-ended questions, puts us in a strong position to measure how students modify their approaches to learning, and their conceptions of subject disciplines and learning experiences, in response to curriculum change.

In 2000, the NSW Board of Studies introduced a new secondary science curriculum for the Higher School Certificate. Our main research objective was to measure the effects of changes to the high-school biology curriculum on student learning and conceptions of biology. As part of this large study we first needed to develop a *Conceptions of Biology Questionnaire* and test its reliability before engaging on the main research objective, as discussed by Northcote (2003). Our aim was to design the *fragmented* and the *cohesive* sub-scale items so that a student with a cohesive conception of biology would have a low score on the *fragmented* items and a high score on the *cohesive* items, i.e., the scales would be loaded negatively to one another. To verify that students were able to discriminate between the sub-scales, we assessed the factorial relationship of the *Conceptions of Biology* sub-scales with the *deep* and *surface* sub-scales of the *Approaches to Study Process Questionnaire* (SPQ) (Biggs 1987, Biggs, Kember and Leung 2001). The SPQ is a well-established survey instrument in the tertiary educational literature and the Australian context, e.g., Biggs et al. (2001) carried out a reliability analysis of their SPQ and used the results to reduce the number of questions while retaining the desired rigour. This paper focuses on determining the reliability of our *Conceptions of Biology Questionnaire*.

The *Conceptions of Biology Questionnaire* required the creation of multiple items in the sub-scales of *fragmented* (e.g., 'Biology is just the study of facts') and *cohesive* (e.g., 'Biology allows predictions to be made about everyday life and situations'). Instruments that assess conceptions of other science/mathematics discipline areas were available to us (e.g., the conceptions of mathematics

instrument of Crawford, Gordon, Nicholas and Prosser (1998)) and this provided us with a model from which to develop items specific to biology.

Here we present evidence that validates the use of our *Conceptions of Biology Questionnaire*. Evidence presented includes a reliability analysis of the items in the *fragmented* and *cohesive* sub-scales, in addition to an assessment of the way these sub-scales load (positively or negatively) relative to each other and to the *Approaches to Study Process Questionnaire* sub-scales.

The way the scales load relative to each other is an important parameter for the major objectives of this project. With a robust instrument, we should be able to identify four groups of students: one comprising students who take a deep approach to learning coupled with a cohesive conception (*deep-cohesive*); and groups comprising *deep-fragmented*, *surface-cohesive* and *surface-fragmented*. This approach has proved successful in mathematics (Crawford et al. 1998) and will ultimately allow us to compare cohorts of students from different years, within the context of our over-arching aim of determining the impact of changes to the high-school biology curriculum. A robust instrument will additionally allow us, and future researchers, to examine how students change their approaches and/or conceptions in response to completing a semester of tertiary level biology.

Method

The *Conceptions of Biology Questionnaire* was created based on the instrument used to assess conceptions of mathematics (Crawford et al. 1998). This included items on two sub-scales (Likert type): *fragmented* conceptions of biology (n = 10) and *cohesive* conceptions of biology (n = 10). This questionnaire, along with the SPQ, was administered to students. Both were scored using Likert-scale items, which were analysed statistically.

The survey was administered to students enrolled in first-year biology at The University of Sydney who were beginning their first semester of study at a tertiary institution (Survey 1) and again at the end of the thirteen-week semester (Survey 2). Thus Survey 1 assessed students as close as possible to their departure from secondary education and their entry into tertiary biology, and Survey 2 assessed students after one semester of tertiary biology. As this was the first time, to our knowledge, that a *Conceptions of Biology Questionnaire* had been designed and used, the data from Survey 1 were used to analyse the reliability of the conceptions of biology items and to determine how they factored with the SPQ sub-scales.

Using the SPQ based on Biggs (1987), and modified for use in biology, we scored students on the *surface* approach to study sub-scale (14 items) and the *deep* approach to study sub-scale (14 items). Items assessing approaches to studying biology were included in both surveys: in Survey 1 to determine a student's approach to study prior to commencing a tertiary biology course; and in Survey 2 to determine a student's approach to study after taking a tertiary biology course.

Using our *Conceptions of Biology Questionnaire* we scored students using two sub-scales, *fragmented* conceptions (10 items) and *cohesive* conceptions (10 items) using Likert-scale questions. Survey 1 assessed a student's conception of the biology science discipline prior to commencing a tertiary biology course; and Survey 2 assessed a student's conception of the biology science discipline after taking a tertiary biology course. A student who agrees with statements such as 'For me, Biology is just the study of facts' and 'Biology is just about figuring out how living systems work' would score highly on the fragmented sub-scale. A student who agrees with statements such as 'Biologists have devised a set of theories over many years to help investigate and explain matters in the living world' and 'Biology allows predictions to be made about everyday life and situations' would score highly on the cohesive sub-scale. The items of the *Conceptions of Biology Questionnaire* are given in Table 1.

Analysis

Likert-scale responses to survey items were scored on a five-point scale and sub-scale scores were calculated as averages of scale item scores. All statistical analyses were performed using SPSS software. Reliability analysis was performed to determine the validity of the questions in the sub-scales of the *Approaches to Study and Conceptions of Biology*. Cronbach ∝ values ≥ 0.6 indicate that variable sub-scales are individually reliable. Principal component factor analysis, followed by Varimax rotation, was used to examine the factor structure between combinations of variables in the *Approaches to Study* and the *Conceptions of Biology* questionnaires.

Table 1. *Conceptions of Biology Questionnaire* items

***Conceptions of Biology Questionnaire* sub-scale items**	
fragmented	***cohesive***
1. For me Biology is just the study of facts	2. By doing Biology we can generate new understanding
3. Biology is just about the world around us	4. Biology is a process of making and testing models about the way things work in the living world
5. For me Biology is just a lot of facts that must be rote learnt	6. Biology is a set of principles that have been developed to explain the living world and relationships in it
8. Biology is just figuring about how living systems work	7. I think Biology provides an insight into the complexities of living systems
11. In Biology we study the world around us and the way it works	9. Biology is a theoretical and experimental framework we use to help us understand the living world
12. Biology is about making observations about living systems	10. Biology is like a universal language, which allows people to describe and understand the living world
15. Biology is a subject where you study patterns in nature to explain the living world	13. Biology is about using models to solve and explain real life problems
16. Biology is just about naming organisms	14 Biology allows predictions to be made about everyday life and situations
18. Biologists study the world by making and recording observations	17. Biology is a logical system that enables us to explain the things around us
20. Biology is just about doing experiments	19. Biologists have devised a set of theories over many years to help investigate and explain matters in the living world

Numbers indicate the order in which the item appeared in the questionnaire. *Fragmented* items (1, 5, 8, 16, 20) were modified by inclusion of the word 'just' when the *CBQ* was implemented for Survey 2, to discriminate more reliably between students with different conceptions of biology.

Results

Initial reliability and factor analyses used all available responses from students who completed Survey 1. Cronbach ∝ values ≥ 0.6 indicate that variable sub-scales are individually reliable; this was the case for all sub-scales in our analysis, with Cronbach ∝ values ranging from 0.64 – 0.82 (Table 2).

Table 2. Reliability analysis of *SPQ* and *CBQ* variable sub-scales used in Survey 1

Variable	**Sub-scale variable** *(number of items)*	**Survey 1** Cronbach ∝ values *(number of students)*
Approach to Study	Surface approach *(14)*	0.70 *(726)*
	Deep approach *(14)*	0.82 *(727)*
Conception of Biology	Fragmented conception *(10)*	0.64 *(730)*
	Cohesive conception *(10)*	0.70 *(723)*

What factor structure is evident in the *SPQ* and *CBQ* variables from Survey 1, implemented before students commenced tertiary biology?

Principal component factor analysis examined the relationship(s) between the *Approaches to Study* and the *Conceptions of Biology* variables. Student responses from the start of semester (Survey 1)

resolved into two factors, indicating the sub-scales for approaches to study (*surface* and *deep*) loaded negatively to each other, (Table 3, factor 2); whilst, in the *Conceptions of Biology* scale, *fragmented* and *cohesive* loaded positively to each other (Table 3, factor 1). Together with the relatively low Cronbach ∝ values, the factor analysis indicated that Survey 1 items in the *fragmented* scale were not being discriminated from items for *cohesive* concept by students, and hence needed rewording.

Table 3. Factor structure of *SPQ* and *CBQ* variables from Survey 1, implemented before students commenced tertiary biology

Variable	**Sub-scale variable**	**Survey 1**	
		factor 1	**factor 2**
Approach to Study	Surface approach	0.38	-0.77
	Deep approach	0.31	0.82
Conception of Biology	Fragmented conception	0.85	
	Cohesive conception	0.85	
	eigenvalue	*1.7*	*1.4*

Principal component factor analysis of approach to studying biology and conception of biology at the start of tertiary biology. (Varimax + Kaiser normalised). Factors shown are supported by eigenvalues ≥ 1. Number of students = 742; loadings between ≤ |0.30| deleted. Principal components explained 77% of the variance.

What effect did the reworded *CBQ* items in Survey 2 have on variable sub-scale reliability?
To ensure our *fragmented* and *cohesive* statements discriminated between students with different conceptions, the *fragmented* conception questions were reworded for Survey 2 (Table 1, revisions in *fragmented* conception items of *CBQ* as indicated). Reliability and factor analyses of Survey 2 responses using the revised *CBQ* items gave Cronbach ∝ values that were slightly higher, ranging from 0.70 – 0.84 (Table 4), than those obtained for the same sub-scales in Survey 1. The greatest increases in reliability occurred in the *Conceptions of Biology* sub-scales.

Table 4. Reliability analysis of *SPQ* and *CBQ* variable sub-scales used in Survey 2

Variable	**Sub-scale variable** *(number of items)*	**Survey 2** Cronbach ∝ values *(number of students)*
Approach to Study	Surface approach *(14)*	0.73 *(476)*
	Deep approach *(14)*	0.84 *(473)*
Conception of Biology (with some items reworded)	Fragmented conception *(10)*	0.70 *(474)*
	Cohesive conception *(10)*	0.79 *(478)*

What factor structure is evident in the *SPQ* and *CBQ* variables from the modified Survey 2, implemented after students had completed a semester of tertiary biology?
Principal component factor analysis was again used to determine how the sub-scales were loading relative to each other. As in Survey 1, the *Approaches to Study* sub-scales loaded negatively to one another (Table 5, factor 1), but this time the *surface* approach loaded positively to *fragmented* conception (Table 5, factor 1) and the deep approach loaded positively to cohesive conception (Table 5, factor 1). The relationships between variables in Survey 2 indicate that questions now discriminate between students with *cohesive* and *fragmented* conceptions.

Table 5. Factor structure of *SPQ* and *CBQ* variables from the modified Survey 2, implemented after students had completed a semester of tertiary biology

Variable	Sub-scale variable	Survey 2	
		factor 1	factor 2
Approach to Study	Surface approach	0.826	
	Deep approach	-0.304	0.813
Conception of Biology	Fragmented conception	0.806	
	Cohesive conception		0.819
	eigenvalue	*1.5*	*1.4*

Principal component factor analysis of survey implemented at the end of a semester of tertiary biology. (Varimax + Kaiser normalised). Factors shown are supported by eigenvalues ≥ 1. Number of students = 487; loadings between ≤ |0.30| deleted. Principal components explained 72% of the variance.

Factor analysis restricted to data from students who returned both Survey 1 and Survey 2: is the factor structure for *SPQ* and *CBQ* variables similar to that of the complete data set?

In future studies we will be using matched surveys (i.e., responses from students who submitted both Survey 1 and Survey 2), so we needed to confirm these factorial relationships in a matched data set. When the fragmented scale was omitted from the analysis of Survey 1 data, two factors were evident (Table 6), viz.:

- *deep* approach to study loaded positively to *cohesive* conception of biology; and
- *surface* approach to study loaded negatively to *deep* approach to study.

The fact that *deep* approach loaded negatively to *cohesive* conception in Survey 1, using the matched data-set and omitting the *fragmented* sub-scale, supports the need for the changes made to items of the *fragmented* conception scale. As the *fragmented* sub-scale questions were reworded, for Survey 2, all sub-scales were included in the analysis of matched surveys, giving two factors, viz.:

- *deep* approach to study loaded positively to *cohesive* conception of biology; and
- *surface* approach to study loaded positively to *fragmented* conception of biology.

Table 6. Factor structure of *SPQ* and *CBQ* variables restricted to data from students who returned both surveys

Variable	Sub-scale	Data from students who submitted both surveys			
		Survey 1		Survey 2	
		factor 1	factor 2	factor 1	factor 2
Approach to Study	Surface approach		0.94		0.83
	Deep approach	0.75	-0.45	0.85	
Conception of Biology	Fragmented conception[1]	-	-		0.81
	Cohesive conception	0.87		0.80	
	eigenvalue	*1.3*	*1.1*	*1.3*	*1.5*

Principal component factor analysis used data from students who submitted both surveys. Rotation Method: Varimax with Kaiser Normalisation; all factors are supported by eigenvalues ≥ 1. Loadings < | 0.30 | deleted. Principal components explained 82% and 72% of the variance for Survey 1 and Survey 2 data, respectively. [1]For Survey 1 fragmented conception data omitted from analysis. N = 285

Discussion

We have now extended, to include biology, the range of disciplines in which the *SPQ* has been married to a discipline-based conceptions questionnaire; hitherto only mathematics (Crawford et al. 1998) and physics (Sharma and Stewart 2004) had taken this approach. We are confident that the *CBQ* we have developed, and now validated, will accurately discriminate between students with a *fragmented* or *cohesive* conception of biology. We recommend validating such questionnaires, as demonstrated here, for all future such investigations.

As we have aligned our *CBQ* with the well-established *SPQ* by examining the factor structure between all sub-scale variables, we can undertake further analysis to reliably profile student cohorts

and determine how their approach to study aligns or misaligns with their conception of biology. We are now in a strong position to assess changes, if any, in a student's approach to study and conception of biology throughout the degree program. Further, by determining any correlation between student performance and approach to study, we will be able to determine how our assessment processes may be driving student learning strategies. Clearly this gives us enormous potential to assess the impact of changes in the biology curriculum.

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