Developing A Survey Instrument To Evaluate Tertiary Chemistry Students' Attitudes And Learning Experiences†

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Introduction

New Zealand tertiary institutions, like others worldwide, have experienced a decline in science and chemistry enrolments in recent times as students seek other career paths that they perceive to be more lucrative. In a previous article we described a qualitative study of the learning experiences of students enrolled in a first year chemistry course at a New Zealand tertiary institution.[1] Researchers in education and science education have two choices of methodology, a qualitative or a quantitative approach, and each possesses advantages and disadvantages. Qualitative studies typically use resource intensive data gathering techniques such as interviews. These studies are useful in that they allow researchers to study issues of interest in great depth and, for example, allow investigators to probe for underlying reasons about students' views for abstract scientific concepts.[2] However, because qualitative studies are more labour intensive, they typically involve only small numbers of participants, which in the minds of many researchers and teachers results in a lack of generalisability. In other words, it is not necessarily clear what implications the findings hold in other contexts. In contrast, quantitative studies involve larger numbers of participants. By the judicious use of statistical analysis, researchers can investigate changes and trends, and extrapolate their findings to a large (or target) population. However, whilst the results from quantitative studies are more generalisable, they are often less detailed. Hence researchers are confronted with a trade-off situation in which they must choose between the depth of understanding provided from qualitative studies, versus the generalisability of a quantitative approach: because of this dilemma, increasingly researchers employ a mixed methodology approach.[3]

In this paper we describe a quantitative study that complements previous qualitative work.[1] We report on the development of a questionnaire that investigates tertiary level learning experiences of chemistry students, along with their attitude toward chemistry and chemistry self-efficacy.

Measuring Student "Attitude-Towards-Science" and "Attitude-Towards-Chemistry"

Students' attitudes towards science as reported in the science education literature are usually measured using purpose-designed questionnaires (more commonly referred to as instruments). The two most widely used instruments employed to measure attitude-toward-science are the *Scientific Attitudes Inventory II* (SAI II)[4] and the *Test of Science Related Attitudes* (TOSRA).[5] However, SAI II measures scientific attitude, which is different from attitude-toward-science. Scientific attitude is a response to statements such as: "Scientists discover laws that tell us exactly what is going on in nature." In contrast, attitude-towards-science is a response to statements such as: "Working in a science job would be fun." The SAI II has been criticised extensively in the literature for its lack of theoretical grounding and lack of validity, *i.e.*, an indication of how effective a method is in answering the questions asked.[6,7] The TOSRA instrument is considered to possess better validity than SAI II, but is based on a secondary school context. Hence it is not appropriate for a tertiary environment. For example, statements in TOSRA regarding the enjoyment of science 'lessons' are inappropriate for undergraduate students, because the term 'lesson' could be taken to mean lecture, laboratory, or tutorial in the university environment. Thus for a tertiary level study TOSRA requires major revision.[8]

There has been much less research into students' science self-efficacy, *viz.* a student's perception of his/her ability to undertake (a) specific scientific task(s). Although there has been some recent interest in the measurement of science self-efficacy,[9,10] most self-efficacy research has been concerned with mathematics students.[11] Self-efficacy is task specific and so an instrument that measures science self-efficacy of, for example nursing students, is not appropriate to measure the science self-efficacy of first year chemistry students.[9]

Research into student learning experiences, like studies of science self-efficacy, is limited. There is a considerable body of literature on the measurement of student perceptions of their learning environment,[12] and the relationship between student attitude and self-efficacy, and their learning environment.[13] However, research into student learning experiences is different from learning environment research, in that the former also incorporates experiences and work required outside structured classes. White *et al.*[14] developed an instrument to measure the learning experiences of first-year tertiary physics students. However, based upon anecdotal evidence, the instrument possesses no theoretical framework and is specific to the educational context in which it was developed.

Instrument design is a complex task, particularly for holistic concepts such as attitude toward science or chemistry. Research in this area has been extensively criticised for lack of *construct validity*, which examines the question:[15] Are we really measuring what we think and say we are measuring? For example, consider the question: "Are your chemistry classes presented in an interesting manner?" This may seem like a straightforward enough question. However, a first-year chemistry student attempting to answer such a question in a survey instrument may think, "What do they mean? Are they talking about my lectures, tutorials or maybe my laboratory classes?" Such ambiguity about the term 'classes' means that the question has low construct validity, in that the researchers may believe they are measuring students experiences in a lecture environment. However, the students involved in the study may consider the term 'classes' to mean lectures, tutorials, or practical classes, and answer the question accordingly.

There are a number of ways to maximise construct validity. Firstly, the instrument structure must be based on a well-defined theoretical framework. Secondly, instruments must be subjected to a pilot study using a sample that is similar in demographics to that of the target group. Whilst it is inappropriate to rely solely on expert opinion, such a panel can contribute to clarity ensuring, for example, that scientific terminology is used appropriately.[7,16,17]

Development of the Chemistry Attitudes and Experiences Questionnaire (CAEQ)

An examination of the literature indicated that to understand students' attitude-towards-chemistry, chemistry self-efficacy and perceptions of their learning experiences (in tutorials, lectures, and practical classes), it would be necessary to develop a new instrument. Moreover, the instrument needed to be soundly grounded theoretically, and appropriately trialed with a group similar to that of the target population. Because we wished to measure what influence students' learning experiences might have upon their attitude towards chemistry and chemistry self-efficacy, we developed the *Chemistry Attitudes and Experiences Questionnaire* (CAEQ). The final version of the CAEQ consists of three scales, each containing a number of subscales as shown in Table 1. The attitude-toward-chemistry scale contains a total of 22 questions across the five subscales: *attitude toward chemists*, *skills of chemists*, *attitude toward chemistry in society*, *leisure interests in chemistry*, and *career interest in chemistry*. The self-efficacy scale, containing 17 questions, consists of one scale with students not appearing to have different efficacious beliefs for the different tasks in chemistry.[18a] The learning experiences scale, consisting of 35 questions, has four subscales: *demonstrator learning experiences*, *i.e.*, graduate assistants, that supervise practical classes, *laboratory class learning experiences*, *lecture learning experiences,* and *tutorial learning experiences.*

The development of the CAEQ entailed comprehensive statistical analyses. A detailed description of this process has been reported elsewhere.[18a] In this paper, we focus on two aspects of the development of the CAEQ that we believe have been neglected in instrument development in the past: a well-defined theoretical framework, and techniques designed to ensure high construct validity. We conclude with an illustration of the utility of the CAEQ, using data gathered at two different tertiary institutions in New Zealand.

Developing a Theoretical Framework for the CAEQ

The theoretical framework for the development of the CAEQ is based on current thinking in behavioural theory and has been adapted from the *Theory of Planned Behaviour* (TPB) (Figure 1). The TBP is an all-encompassing theory that maintains behaviour is determined by many influences including significant individuals in one's life. According to the TBP, the behaviour of an individual is influenced by his/her attitude toward that particular behaviour, the attitude of associates, *e.g.,* peers, family and mentors, toward the behaviour, and the perceived control of the individual over the behaviour.[19] The focus of the CAEQ is on the *antecedents* of attitude toward enrolling in chemistry, namely their learning experiences, attitude-toward-chemistry and chemistry self-efficacy (in other words the concepts detailed on the left side of Figure 1). The influence associates' attitude and perceived behavioural control has also may influence students' attitude towards enrolling in chemistry. This influence is not addressed by the CAEQ, but has been investigated by us previously in a qualitative study.[1,18b]

As a first step in developing a theoretical framework for the CAEQ, we defined chemistry, attitude-toward-chemistry and chemistry self-efficacy. Chemistry is defined as the learned patterns for thinking, feeling and acting, that are transmitted via the acquisition of chemistry theory, skills and values. We used Allport's definition of attitude,[20] namely "a mental and neutral state of readiness, organised through experience, exerting a directive and dynamic influence upon the individuals' response to all objects and situations with which it is related", and Bandura's definition of self-efficacy,[21] as "people's judgements of their capabilities to organize and execute courses of action required to attain designated types of performance". Learning experiences were considered to be any experience resulting in a belief formation about chemistry (where that belief is attitudinal, knowledge, or skill based).

Maximising Construct Validity for the CAEQ

As mentioned above we sought to maximise the construct validity of the CAEQ during its development. Firstly, we employed the 'panel of expert's' technique. This involved subjecting the instrument to analysis by experts in the field that the instrument examines; in the case of this study, three chemistry academics.[17,22] The experts read the questions and provided detailed feedback about items addressed in the questionnaire. We then checked the readability of the instrument for participant comprehension by asking 19 participants to complete the instrument; the participants were subsequently interviewed. We also employed the skills of an experienced teacher of students from a non-English speaking background to examine the items for comprehension by non-English speaking students. Next, the instrument was piloted in a first-year chemistry course (n=129). The data from the pilot study were subject to statistical analyses that enabled us to assign group questions under specific concepts or constructs, resulting in the formation of subscales, *i.e.*, the subscales of Table 1. After the pilot, we administered the CAEQ to students in first-year chemistry courses at the beginning and at the end of the first semester at two different New Zealand tertiary institutions. In the first administration, the participants completed only the attitude-toward-chemistry and chemistry self-efficacy components (n=469). The presumption was that these students had not experienced any tertiary chemistry learning experiences at this point, and hence it was inappropriate to ask them about their learning experiences. At the end of the semester the participants completed all three scales (n=337) and about one half had completed both versions of the questionnaire (n=177). After statistical analyses (factor analysis, reliability, and discriminant validity) two other tests of construct validity were undertaken. The first was predictive validity, which examines whether the instrument predicts something that it is expected to predict. The second was concurrent validity, which examines whether the instrument differentiates between two groups it is expected to differentiate between.

Evaluation of Predictive Validity for the CAEQ

An instrument has predictive validity if it successfully predicts something it is expected to.[23] To determine predictive validity for the CAEQ, the learning experiences subscales were correlated with the attitude and self-efficacy subscales from the data collected at the end of the semester using Pearson's correlation (Table 2).

The correlations are not particularly strong as the closer the correlation is to 1.0, the closer to linear is the relationship between the variables. However, all correlations were statistically significant ($p<0.01$), suggesting, for example, that perceptions of practical chemistry classes exert some influence on the participants' ability to recognise the required skills of chemists. Hence, according to the data obtained from the CAEQ as administered here, students' learning experiences are influenced by both their attitude and self-efficacy and *vice-versa* , as one might expect. In other words, the CAEQ predicts a result that it was designed to do, and hence it possesses high predictive validity.

Evaluation of the Concurrent Validity of the CAEQ

An instrument has concurrent validity if it differentiates two groups that it is expected to differentiate between such as subject majors and non-majors.[24] The theoretical framework used here, *i.e.*, the modified TPB, suggests that students intending to enrol in a second chemistry paper after completing their initial chemistry course would likely have a more positive attitude-toward-chemistry, a higher chemistry self-efficacy, and be more positive about their learning experiences, than those who do not intend to take chemistry beyond first year. We examined the data from our administrations of the CAEQ for concurrent validity from the data collected at the beginning of the year and found this to be the case. All of the subscale differences were found to be statistically significant ($p<0.01$), suggesting that the CAEQ also possess high concurrent validity (Table 3). Hence, overall the CAEQ possesses high construct validity, as measured by predictive and concurrent validity. This suggests then that the conclusions drawn from the theoretical constructs of the subscales will be valid.

Using the CAEQ to Develop an Understanding of Tertiary Chemistry Students' Learning Experiences

To illustrate the usefulness of the CAEQ, we used data obtained from administration at two New Zealand universities to investigate student perceptions of their tertiary chemistry learning experiences. This serves to illustrate how tertiary chemistry teachers and researchers can use the CAEQ to gain an understanding of the learning experiences of chemistry students at the first-year tertiary level.

It is important to note that the classes from the two institutions involved in the study have significantly different demographic compositions. The first institution, *University A*, had approximately 200 students enrolled in the first year-first semester chemistry class, of whom the majority were of New Zealand European decent. Over half of these students were enrolled in applied science degrees. The second institution, *University B*, had a larger first year-first semester chemistry class with over 600 enrolments. In the chemistry paper at University B a large number of the students were studying medicine or pharmacy and the university also had a wide ethnic diversity with, for example, a large proportion of participants identifying themselves as being of Asian ethnicity.

Each lecturer has a distinct personal style of teaching chemistry and the CAEQ can be used to investigate the impressions students have of different teaching styles. The two first-year chemistry courses offered at the universities represent the first encounter the participants have with tertiary chemistry learning. Despite having similar overall objectives and the same three learning experiences, *i.e.*, lectures, practical, and tutorial classes, the classes at the two universities are structured quite differently and cover different content. University A teaches basic chemical concepts, solution chemistry, and atomic theory while University B teaches organic chemistry and kinetics. The practical classes at University A are of three hours duration each. These are assessed on the basis of the completion of worksheets that are handed in at the end of the class for the first six weeks, with a write up in a laboratory book completed outside the practical classes for the second six weeks. All the experimental information and some theory are presented in a separate laboratory manual. In University B the practicals are of two hours duration each and are assessed purely on worksheets handed in at the end of the class. These worksheets include details of experimental procedure along with some background theory about the experiment. University A provides regular tutorial classes in which all students are formally enrolled, whereas University B offers weekly tutorials that are voluntary.

Table 1. Scales, subscales and sample questions for the *Chemistry Attitude and Experience Questionnaire* (CAEQ).

Scale Name/Subscale	Sample Item			
Attitude-toward-chemistry				
Attitude-toward-chemists	Chemists:	athletic	_ _ _ _ _ _ _	unfit
Skills of chemists	Chemists:	inquisitive	_ _ _ _ _ _ _	indifferent
Attitude-toward-chemistry in society	Chemistry research:	solves problems	_ _ _ _ _ _ _	creates problems
Leisure interest in chemistry	Science fiction movies:	exciting	_ _ _ _ _ _ _	tedious
Career interest in chemistry	Chemistry jobs:	interesting	_ _ _ _ _ _ _	boring
Chemistry Self-efficacy	*Please indicate how confident you feel about:*			
	Achieving a passing grade in a chemical hazards course	Totally confident	_ _ _ _ _ _ _	Not confident
	Applying a set of chemistry rules to different elements of the periodic table	Totally confident	_ _ _ _ _ _ _	Not confident
	Ensuring the data obtained from an experiment is accurate	Totally confident	_ _ _ _ _ _ _	Not confident
	Propose a meaningful question that could be answered experimentally	Totally confident	_ _ _ _ _ _ _	Not confident

Scale Name/Subscale	Sample Item					
Chemistry Learning Experiences						
Lecture Learning Experiences	The lecture notes were interesting	SA	A	N	D	SD
Tutorial Learning Experiences	My tutors have encouraged me to study more chemistry	SA	A	N	D	SD
Practical Learning Experiences	The practical experiments were related to the lectures	SA	A	N	D	SD
Demonstrator Learning Experiences	It is easy to find a demonstrator to discuss a problem with	SA	A	N	D	SD

Table 2. Predictive Validity for *Chemistry Attitudes and Experiences Questionnaire* (CAEQ) as evaluated from Pearson's Correlation[a] between learning experiences subscales with attitude-toward-chemistry and chemistry self-efficacy subscales.

	Lectures	Tutorials	Practicals	Demonstrators
Attitude toward Chemists	0.43	0.30	0.39	0.38
Skills of Chemists	0.43	0.27	0.45	0.38
Attitude toward Chemistry in Society	0.34	0.24	0.39	0.35
Career Interest in Chemistry	0.41	0.25	0.38	0.32
Leisure Interest in Chemistry	0.42	0.24	0.38	0.37
Self-efficacy	0.38	0.29	0.47	0.34

[a]All correlations are statistically significant ($p<0.01$)

Table 3. Estimated means for subscales for the *Chemistry Attitudes and Experiences Questionnaire* (CAEQ).[a]

Subscale	Mean[b] Planning to enrol in second-year chemistry	Not planning to enrol in second-year chemistry
Attitude Toward Chemists	4.5	4.2
Skills of Chemists	5.2	4.9
Attitude Toward Chemistry in Society	5.8	5.5
Leisure Interest in Chemistry	4.4	3.9
Career Interest in Chemistry	5.3	4.5
Self-efficacy	4.8	4.3
Lecture Learning Experiences	3.5	3.2
Tutorial Learning Experiences	3.6	3.3
Practical Learning Experiences	3.8	3.6
Demonstrator Learning Experiences	3.7	3.4

[a]Attitudinal and self-efficacy responses were measured using a seven point semantic differential scale (1=negative, 7=positive) whereas and learning experiences used the five point Likert scale (1=negative, 5=positive).
[b]All differences in estimated means are statistically significant ($p<0.01$)

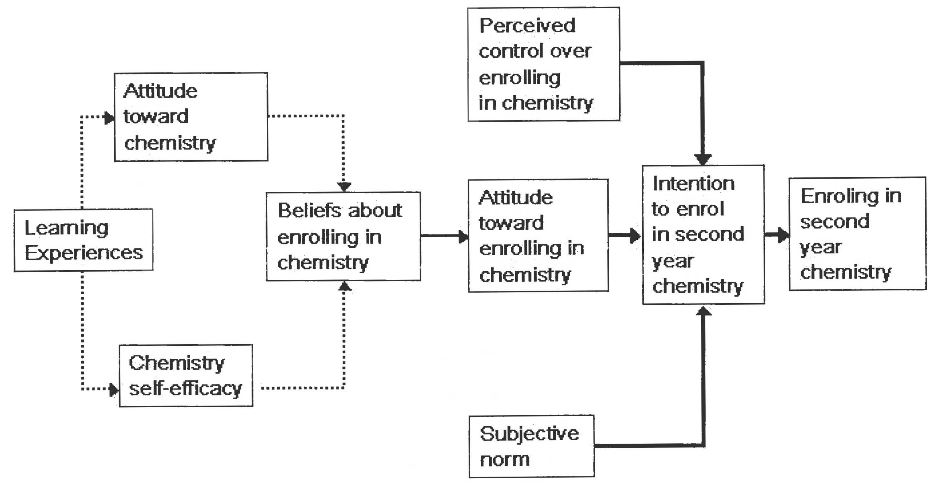

Figure 1. Theoretical framework used in developing the *Chemistry Attitudes and Experiences Questionnaire* (CAEQ). The focus in instrument development is on antecedents of enrolling in second year chemistry.

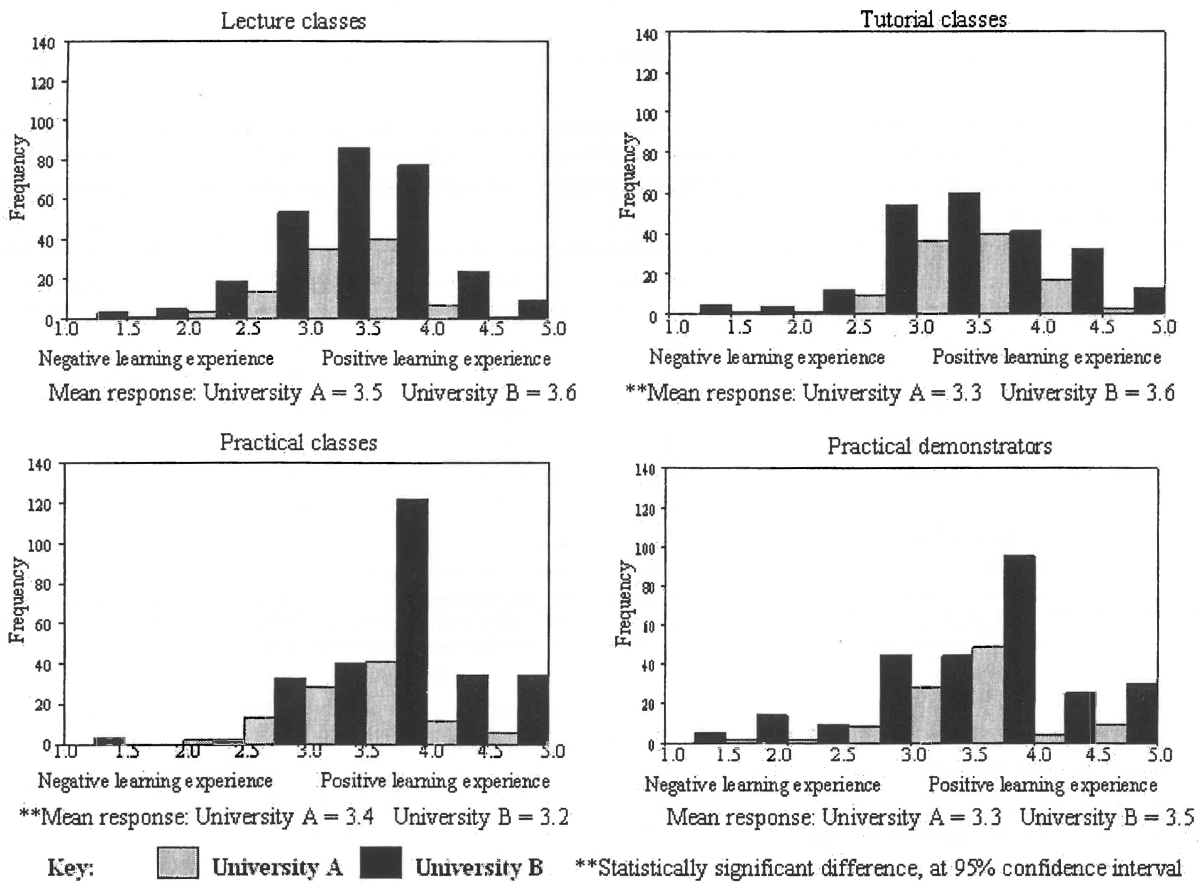

Figure 2. Student perceptions of their first-year chemistry learning experiences (n=337) as measured using the *Chemistry Attitudes and Experiences Questionnaire* (CAEQ).

A comparison of the participants' perceptions of their learning experiences at the end of their first semester courses is given in Figure 2. Participants were generally positive about their learning experiences with very few students identifying their learning experiences to be very negative in all four subscales (Table 1). There were, however, statistically significant differences in the participants' perceptions of tutorial and practical classes. Fewer participants attended at least one tutorial class at University B (82%) than at University A (96%). Participants at University A were more positive about their tutorial classes, suggesting that they found the more structured nature beneficial. The participants likewise preferred more structure in their practical classes. It is interesting to consider this apparent preference for more structured learning opportunities. As mentioned above, the first year chemistry classes represent the participants first encounter with tertiary chemistry. Having come to university directly from high school, it seems likely that their school experiences may influence their expectation of appropriate pedagogy. Hence, as their most recent learning experience, *i.e.*, their high school learning, was relatively structured it is perhaps not surprising that, as reported elsewhere, these participants are happier in a more directive environment.[24]

Conclusions

The CAEQ was developed to measure first-year chemistry students' attitude-toward-chemistry, chemistry self-efficacy, and tertiary level learning experiences. Instrument development, as well as using the conventional statistical evaluation tools such as factor analysis, sought to address the validity issues that have adversely affected other attitudinal survey instruments. Construct validity was addressed by means of predictive and concurrent validity. Predictive validity was established by the development of a sound theoretical framework, derived from modern behavioural theory, specifically the TPB, along with definitions of chemistry, attitude and self-efficacy. Concurrent validity was evaluated by investigation of the instruments' ability to distinguish between two different cohorts of participants, intending majors and non-majors. These analyses revealed that the CAEQ possesses both high predictive and concurrent validity, and this, along with other statistical analyses,[18a] suggests that the CAEQ will prove to be a useful probe for tertiary chemistry teachers and institutions that wish to investigate the learning experiences of first year chemistry students. An investigation of student learning experiences illustrates the utility of the instrument and revealed that students investigated here prefer more structure in their teaching style than they currently experience. Given the broad scope of the CAEQ as evidenced by the subscales, there are many aspects of student attitude-toward-chemistry, self-efficacy, and learning experiences that are open to investigation. It is up to tertiary education researchers and teachers to decide if this instrument will be useful in gaining an understanding of their classroom practice and the perception students have.

The instrument is available from the authors in electronic form upon request.

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