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Attitudes and experiences among first-year regional Australian undergraduate students toward the study of chemistry

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Abstract

Both attitude and previous experiences play a large role in shaping a student's approach to and achievement in a given subject. Similarly, students' enjoyment of their learning experiences is an important factor in determining their retention in their course of choice. Here, we explore the attitudes toward the study of chemistry amongst a cohort of first-year undergraduate students at a regional Australian university, including assessing these parameters at the beginning of their first term, the end of the first term and the end of their second term. In addition, metrics on the students' experiences of studying chemistry were collected at the latter two timepoints. Generally, student attitudes toward chemistry were positive, as were student learning experiences in most instances. Two-step cluster analysis revealed the presence of two distinct clusters of students within the data, differing significantly in their overall attitude toward the study of chemistry. Students who had studied chemistry in Year 12 did not show any significant differences in their attitudes toward chemistry, when compared to students who had not studied Year 12 chemistry; however, their learning experiences in first-year chemistry were rated as being significantly more positive. We attribute this to their increased ability to engage with and successfully learn from the topic material presented in lectures and tutorials, as their previous exposure to the 'language' of chemistry may provide them with an advantage over chemistry-naïve students.

Practitioner Notes

1. Overall, regional Australian undergraduate students appeared to have a positive attitude toward chemistry. However, this is not the case for all students. Identification of challenged students early in the semester could be useful for initiating intervention actions. 2. Students generally rate lecture classes as the least enjoyable mode of content delivery. We suggest that lecture presentations could continue to be made more engaging and less of a "lecture style". 3. Students find the practical laboratory classes engaging and enjoyable. These should continue to form an important part of the chemistry classroom. 4. With the continuing COVID-19 pandemic and concurrent shift toward online teaching, it is important that chemistry educators are able to leverage online learning platforms to provide the best experience for students. This may require upgrading their digital literacy skills and increasing the frequency of teacher-student interactions. 5. Further work is recommended to determine the impact of different styles of pedagogy and teaching approaches on student attitudes and experiences.

Keywords

First-year undergraduates, chemistry education, attitude

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Introduction

Student difficulties in the study of chemistry

There is extensive literature on student difficulties in learning science-based subjects. This literature suggests that many students find science difficult and the physical sciences such as chemistry and physics are especially problematic (Carter & Brickhouse, 1989; Kousa et al., 2018; Pfundt & Duit, 1994; Treagust et al., 2000). Research of student learning difficulties at the secondary school level (up to Year 12) suggests a variety of reasons. Students are thought to be put off by science due to its abstract nature (Zoller, 1990), the high mathematical content (Pang & Good, 2000) and a lack of enthusiastic or competent science teachers (Kind, 2009). Poor attitudes and impressions developed at high school commonly result in further learning difficulties when high school students engage in science learning at the post-compulsory school level (typically Year 10 and above). A further complication for tertiary level science learning is that new entrant students studying first-year or introductory science courses at the tertiary level comprise a highly diverse group. Many undergraduate students take a given subject, such as an introductory chemistry unit, not by choice but because it is a required part of their program or major (Dalgety et al., 2003; Naiker & Wakeling, 2015). Such students generally have low self-efficacy towards studying chemistry (i.e. they are not confident about their own ability in studying the subject). Self-efficacy mainly relates to a student's perceptions or beliefs about their own competency at performing tasks, rather than their intention or ability to perform a task. This distinguishes it from other constructs such as self-esteem and self-concept, which are more related to student's feelings about themselves (Uzuntiryaki & Çapa Aydın, 2009). In the sciences, self-efficacy is generally considered to be a predictor of academic performance (Andrew, 1998; Ardura & Galán, 2019; Hampton & Mason, 2003; Kupermintz, 2002), as it affects the behaviours of individuals, including their effort, resilience and persistence in completing tasks. However, (Rayner & Papakonstantinou, 2018) reported a disconnect between the self-efficacy of foundation biology students and their actual abilities, highlighting the need to consider both the ability and perceived ability of students. Bandura et al. (1999) postulated four sources of self-efficacy, namely mastery experiences, vicarious experiences, verbal persuasion, and emotional/physiological states.

A number of incoming students undertaking introductory chemistry courses at a tertiary level are not well-versed in the prerequisite knowledge required for the course. In some cases, they did not take chemistry in high school, or a long time has passed since their high school chemistry courses; other students may have had low course grades in high school chemistry. Regardless of the cause, such students should anticipate the requirement of additional study to perform well in university-level chemistry courses. Other students may not realize that their preparation for university-level chemistry is inadequate. Some did not take the right high school subjects, e.g. they may have taken an Integrated Science subject which was weak in chemistry content. Although Year 12 Chemistry is a pre-requisite for certain University degrees across different states, there is a declining trend in chemistry as a compulsory pre-requisite (Office of the Chief Scientist, 2017). Similarly, there is an increasing trend towards students taking less advanced mathematics courses which may not provide the in-depth mathematical knowledge required for undergraduate-level chemistry. Another commonly encountered group of students are those who received good grades in high school chemistry but still have gaps in their knowledge. For a highly sequential subject such as Chemistry, gaps in foundational knowledge must be filled in for students to fully succeed.

Some theoretical concepts on attitude in the study of chemistry

Alongside biology and physics, the discipline of chemistry is considered one of the key foundational areas of science. However, particularly compared to biology, chemistry deals with more abstract ideas and principles. For instance, one can examine the structure of a kidney in a biology class, but it is quite impossible for an undergraduate student to examine the structure of an atom. In such situations, descriptions and other visualisation techniques such as animations must be relied upon (Tasker & Dalton, 2006). In other words, it requires greater prior conceptual knowledge (Cracolice & Busby, 2015; Frey et al., 2018) and reasoning ability within a scientific framework (Cracolice & Busby, 2015).

Disciplines such as chemistry and physics also necessitate strong mathematical skills, which may cause additional difficulties for some students (Powell et al., 2020). Upon the completion of an introductory undergraduate-level chemistry unit, students are expected to be able to utilise and manipulate basic equations such as mass-to-mole conversion, dissociation constants for acids, bases and solubility, and the Henderson-Hasselbalch equation for the calculation of buffer pH (Powell et al., 2020). Mathematical knowledge is also required for basic principles in areas of chemistry such as kinetics, equilibrium, thermodynamics, nuclear chemistry and electrochemistry (Powell et al., 2020; Williamson et al., 2020). Hence in order to succeed, students require not only to have a knowledge of basic mathematical principles such as multiplication, division and equation manipulation, but also a grasp of more abstract principles such as logarithms (for pH calculations) and solving quadratic equations (for calculating concentrations of partially dissociated compounds). Although the required formulae are readily available in reference texts or online and can be used with a "plug-and-play" approach to theoretically obtain the correct answer, students should understand the principles behind such formulae in order to extend their knowledge to other situations.

Aside from these academic prerequisites, student attitude towards the study of chemistry is expected to play a large role in their overall success (Flaherty, 2020). Within an education context, a common definition of attitude is ''a mental and neutral state of readiness, organized through experience, exerting a directive and dynamic influence upon the individuals' response to all objects and situations with which it is related'' (Horowitz & Bordens, 1995). Attitude is often expressed via an individual's behaviour and hence can be perceived by others. In contrast, perception refers to how an individual views or interprets a subject.

Students who engage with the subject material with an open mind and an active learning approach are more likely to understand and remember the key concepts. In turn, these students will be better prepared to utilise such concepts in order to succeed in assessment items and in chemistry-related disciplines in the workforce. In contrast, it is likely that students who approach the subject with a negative mindset or engage with the subject material using a 'surface learning' approach (i.e. studying only to pass assessments), are likely to gain only a superficial knowledge of the topic, most of which will soon be forgotten.

In particular, students who are enrolled in non-chemistry-based programs (such as Biomedical Sciences, Geology, Food and Nutritional Sciences, and Education) often feel that the study of chemistry does not relate to their program, in spite of it often being an essential underpinning prerequisite for more advanced units of study. Often, such students will have a poorer attitude towards chemistry, as it is perceived as being a difficult and irrelevant subject. Hence there is considerable interest from educators in creating more positive attitudes toward chemistry, particularly in undergraduate non-major chemistry programs, given that a positive attitude to chemistry may facilitate a deeper understanding of the biological chemistry which underpins many other science related disciplines (Brown et al., 2015). However, this goal has been somewhat hindered by the lack of an exact concept or definition of attitudes towards the subject of chemistry, which are often poorly articulated and not well understood (Osborne et al., 2003).

Attitude is a multidimensional paradigm, which can be thought of as a tendency to respond to a certain stimulus (such as chemistry). As outlined in the tripartite theoretical model of attitude, it comprises cognitive, affective, and behavioural elements (Rosenberg & Hovland, 1960). It has been widely suggested among chemistry educators that quantifying attitude toward chemistry would be beneficial, as this information would complement the regular assessment of content-specific knowledge routinely conducted in the tertiary education setting (Bauer, 2008). Several instruments have been developed for this purpose (Cheung, 2009a; Dalgety et al., 2003; Xu et al., 2012); however, their uptake for routine purposes remains limited. Nevertheless, they remain important tools for guiding the progression of academic curricula as it evolves to satisfy the demands of the workplace (Brown et al., 2014).

Pedagogical approaches

The pedagogical approaches used by chemistry educators also has a significant impact on learning outcomes. Educators should attempt to positively engage students in learning environments which enhance engagement and interest in chemistry. Within the discipline of chemistry, one such learning environment which has received considerable attention over the years are laboratory classes (Naiker & Wakeling, 2015; Naiker et al., 2013; Pullen et al., 2018; Rayner et al., 2013). Laboratory classes are also important to reinforce concepts taught in introductory chemistry units, as they allow students to reinforce their knowledge and mathematical skills, as well as providing examples of 'real-life' applications of chemistry. In our experiences, we have found laboratory classes to be an important environment for students to practice their research skills, problem-solving skills and teamwork, amongst other benefits (Naiker & Wakeling, 2015; Naiker et al., 2020). However, it is important to note that few researchers have comprehensively compared laboratory instruction with other instruction modes. This has led some authors to question the cost-benefit ratio of practical chemistry classes, which are often quite expensive to run and staff (Bretz, 2019).

Student experiences of how the topic material is delivered will also influence their engagement with the learning resources and hence their overall performance. If the lecturing style is overly dry or presented in a complex fashion, many students will 'switch off' (either intentionally or unintentionally) and not engage with the delivered information. In contrast, if students can connect what they are learning to real-life situations, this will increase memory retention and their overall understanding. One common way to do this is through the use of analogies, so that they can visualise abstract concepts to more relatable everyday situations. Studies have also demonstrated that memory retention is significantly increased when the delivery of the subject material is associated with emotions (whether negative or positive) (Tyng et al., 2017). Hence the judicious use of anecdotes and humour is often used to engage students. Recent research has highlighted the importance of students having a sense of belonging in the chemistry learning environment (Fink et al., 2020), which fits in with the aforementioned student experiences in the topic delivery and lecture styles.

More recently, there has been increased interest in novel pedagogical approaches such as the flipped classroom approach (Koeper et al., 2020), where students learn the syllabus material at their own pace and work on problem-solving exercises during class time (Fautch, 2015). Other suggestions which have been proposed to enhance student learning include the use of concise study guides to focus students' efforts (Holsgrove et al., 1998; Wood & Donnelly-Hermosillo, 2019), application of peer-learning approaches (Thompson & Lamanna, 2020) and the use of gamification to improve student engagement (Wood & Donnelly-Hermosillo, 2019).

Similarly, laboratory classes can be designed to use an Inquiry-Oriented Learning (IOL) approach to enhance student engagement and learning outcomes (George-Williams et al., 2020). Another feature which can be incorporated into practical sessions is the use of report templates for writing up laboratory exercises, which has been found to save time without negatively impacting on learning outcomes (Paton-Walsh, 2015). However, it is important for chemistry educators to assess the outcomes of implementing such approaches, rather than relying on "gut feeling" about their efficacy.

Problem statement and aims

A sound knowledge of introductory chemistry can underpin the understanding of many subjects taught at university; however, negative attitudes and disengagement can undermine the learning of chemistry in some students. In this study we aim to use a validated instrument to quantify attitudes and experiences of students studying courses in introductory chemistry to investigate possible influential factors on student attitudes and experiences. Our findings aim to inform the future development of more engaging pedagogical practices in the delivery of these introductory courses, and form part of the on-going reflective practices consistent with the scholarship of learning and teaching.

Methods

The study population

Our study population was first-year undergraduate students at the Mt Helen campus of the University of Ballarat (now called Federation University Australia), located in regional western Victoria, who were studying introductory chemistry units. The units Chemistry I and II are delivered at first year level in the first and second semesters, respectively. These two introductory chemistry units are a key component (core unit) of certain degrees (such as Bachelor of Biomedical Science and Bachelor of Food and Nutritional Science), whilst only Chemistry I is required for other degrees such as General Science, Geology and Education, with the option of doing Chemistry II as an elective. As such, in a typical year 130 - 140 students are enrolled in Chemistry I, decreasing to about 70 - 80 for Chemistry II (Brown et al., 2015; Naiker & Wakeling, 2015; Naiker et al., 2013). Both Chemistry I and II units contain two one-hour lectures each week (on two separate days), a one-hour tutorial each week and a three-hour practical on alternative weeks. A typical semester is 12 weeks long. Assessment is based on tutorial attendance and participation (weighting 10%), completion of assigned online learning assessments (weighting 15%), laboratory practical (weighting 25%) and a final three-hour examination (weighting 50%).

Prior knowledge of chemistry is not a prerequisite for prospective students to enrol in any of the undergraduate programs at the University of Ballarat, with greater than 60 % of students having not completed chemistry in Year 11 and/or 12 (Naiker & Wakeling, 2015). Additionally, the university enrols relatively large numbers of mature age students who may not have studied science and particularly chemistry for many years. As a result, chemistry can be one of the most challenging subjects these students may encounter in their degrees. Many students often regard chemistry as a difficult subject, an observation which sometimes repels learners from continuing with studies in chemistry (Sirhan, 2007). Yet chemistry is the main service science underpinning all the other disciplines in allowing students to better grasp and understand specific aspects related to their degrees. These factors were the key motivators for the research team to explore and assess students' attitudes toward the study of chemistry, so that educators have better understanding of how they can utilise alternative active learning strategies that would inspire, motivate and engage students towards studying chemistry and allow them to enjoy their experiences.

CAEQ instrument

The instrument used in this study was a slight adaptation of the Chemistry Attitudes and Experiences Questionnaire (CAEQ) instrument (Coll et al., 2002). This survey tool uses a number of semantic differential, qualitative and quantitative responses to profile the attitudes of students toward the study of chemistry. The only change from the original CAEQ and that used in this study was that a five-point Likert scale was used to assess student attitude-towards-chemistry rather than a seven-point Likert scale. This was to ensure consistency with the "Learning Experience" portion of the survey instrument, which Coll et al. (2002) developed as a five-point Likert scale. Similar adaptations of the CAEQ using five-point scales have successfully been used by previous researchers (Winkelmann et al., 2015).

The CAEQ instrument has been utilised by numerous researchers since its development (Berg, 2005; Dalgety & Coll, 2006; Winkelmann et al., 2015), making it one of the more popular methods for researchers to assess student attitude-toward-chemistry. The first portion of the CAEQ assesses student attitudes toward chemistry, while the second portion assesses the student experience of learning chemistry. As shown in Table 1, there is a varying number of items (i.e. statements) within each subscale.

Table 1.

A summary of the information assessed in the CAEQ.

Instrument topic	**Subscale (inferred attitude)**
Attitude-towards-chemistry Scale (n=21 items)	
Chemists (n=9)	**A** (attitude toward chemists)
Chemistry research (n=4)	**S** (skills of chemists)
Chemistry in society (n=2)	**I** (attitude towards chemistry in society)
Chemistry jobs (n=5)	**C** (career interest in chemistry)
Leisure (n=1)	**L** (leisure interest in chemistry)
Learning Experience Scale (n=35 items)	
Demonstrator (n=5)	**D** (demonstrator learning experiences)
Laboratory (n=10)	**Lab** (laboratory class learning experiences)
Lecture (n=10)	**Lec** (lecture learning experiences)
Tutorial (n=10)	**T** (tutorial learning experiences)

Instrument administration

All students from two introductory undergraduate chemistry courses (Chemistry I in Semester 1, 2013 and Chemistry II in Semester 2, 2013) were invited to participate in this research project. The CAEQ was delivered in three parts. The first survey looked at only student attitudes toward chemistry and was administered as a hard copy to students at the commencement of the academic year (Semester 1, Week 1). Students were also invited to take part in two subsequent surveys. Both the second and third surveys investigated student attitudes toward chemistry and their experience of undertaking chemistry units at a university level. These were delivered either as a hard copy or in an online format. The second survey was administered at the end of Semester 1 (Week 11), while the third survey was administered at the end of Semester 2 (Week 11). In addition, selected demographic information (such as age bracket, gender and completion of Year 12 chemistry) was also collected from the participants. As all responses were collected anonymously, it was not possible to correlate or track the responses of individual students across the three time points.

Informed consent was obtained from all participants prior to the collection of their responses. Ethical approval to conduct this study was obtained from the University of Ballarat Human Research Ethics Committee (approval no. B13-007).

Statistical Analysis

To allow for comparison between subscales containing different numbers of items, the mean subscale score was calculated for each student and used in subsequent analyses. Demographic data were not provided by three students across the three time points; all data for these students were excluded from subsequent analyses. For the attitude-toward-chemistry scale, possible responses ranged from 1 (low) to 5 (high). For the learning experiences scale, possible responses ranged from 1 (strongly disagree) to 5 (strongly agree). Missing or invalid responses to an item were scored as 3.

Statistical analyses were performed in R Studio, running R 4.0.2 (R Core Team, 2020). Independent samples *t*-tests and one-way ANOVAs were used to test for statistical significance, depending on whether the data matrix comprised 2 or more groups. A value of $\alpha=0.05$ was used as the cut-off point for statistical significance. The Cronbach α-coefficient was used to estimate internal reliability of each subscale (i.e. the extent to which all items in a given subscale were measuring the same aspect of student attitude). Two-step cluster analysis was performed in R studio using the prcr package (Rosenberg et al., 2020). This package, designed for person-centred analysis, is used to create and study clusters (or profiles) of observations (individual people), and to study their change over time or differences across factors (Rosenberg et al., 2020). The average silhouette width was used to optimise the number of clusters used in the final analysis.

Results

Baseline attitudes toward the study of chemistry

A total of 114 valid responses were received from students in the initial survey (Semester 1, Week 1), termed the “baseline” data. Of these, 60 (53%) were female, while 54 (47%) were male. Most students (57%) had not completed chemistry at a Year 12 level while in high school. Approximately 72% of students were less than 21 years old, with 14% between 21-25 years of age and 9% between 26-35 years. Less than 1% of students were over 46 years of age, with the remaining 4% of students between 36-45 years.

The mean Cronbach α of the five scales was 0.70, indicating acceptable internal consistency of the data (Cortina, 1993). In addition, the Cronbach α was not improved by dropping any of the scales (Table 2). Hence all scales were included in subsequent statistical analysis. The intercorrelations between the scales were calculated through their discriminant validity indices, which quantify the extent to which each scale measured a unique aspect of student attitudes toward chemistry which was not measured by any other scale. The mean correlation values were quite low (Table 2), indicating that all scales contributed to a unique aspect of the student attitudes.

Overall, the attitude of most students toward chemistry was positive (i.e. mean value of greater than 3 for each score) aside from their leisure interest in chemistry (Table 2). However, the leisure interest scale also had the greatest standard deviation, suggesting the widest disconnect between individual students – with the attitudes of individual students ranging from being very strong to very weak leisure interest in chemistry. Scale A (attitude toward chemists) had the highest mean score, suggesting that the students typically had a positive perception of chemists. Similar trends were observed in both male and female students, with no significant difference between the genders found for any scale ($P>0.05$; Table 2).

Notably, although the mean scores across most scales were slightly higher for students who had completed chemistry at a Year 12 level, there was no significant difference found between their attitudes and those of students who had not studied Year 12 chemistry (Table 2). In other words, taking a chemistry course at a Year 12 level did not necessarily improve students' attitudes toward chemistry.

Table 2.

The attitudes of first-year undergraduate students toward the study of chemistry at the commencement of their first year of study.

Scale	Overall (n=114)			Gender			Chemistry in Year 12		
	Mean ± SD	Cronbach α, if scale dropped	Correlation with other scales	Female (n=60)	Male (n=54)	T-test	No (n=65)	Yes (n=49)	T-test
A (attitude toward chemists)	3.70 ± 0.50	0.70	0.26	3.75 ± 0.50	3.64 ± 0.50	NS	3.62 ± 0.45	3.80 ± 0.56	NS
S (skills of chemists)	4.32 ± 0.64	0.66	0.33	4.30 ± 0.66	4.35 ± 0.61	NS	4.27 ± 0.64	4.40 ± 0.63	NS
C (career interest in chemistry)	3.79 ± 0.66	0.62	0.38	3.88 ± 0.68	3.70 ± 0.64	NS	3.76 ± 0.66	3.84 ± 0.68	NS
I (attitude towards chemistry in society)	3.49 ± 0.88	0.59	0.38	3.38 ± 0.92	3.60 ± 0.83	NS	3.51 ± 0.84	3.46 ± 0.95	NS
L (leisure interest in chemistry)	3.04 ± 1.18	0.66	0.34	2.87 ± 1.19	3.22 ± 1.16	NS	2.92 ± 1.11	3.18 ± 1.27	NS

NS – not significant (P>0.05), * P<0.05, ** P<0.01, *** P<0.001

Change in attitudes toward the study of chemistry over time

Collecting data for the attitude-towards-chemistry scale at each of the three time points in this study allowed the evaluation of changes in student attitudes toward this topic over the course of their first year of undergraduate study. In Semester 1, the number of responses received for Week 11 was approximately 82% of the total number of responses from students in the same class in Week 1. Fewer students were enrolled in the Chemistry II unit in Semester 2, Week 11, as this unit is not compulsory for all students who completed Chemistry I, but only those who require more in-depth chemistry knowledge as part of their degree. Hence most respondents in Semester 2, Week 11 are likely to comprise a subset of the group of students who had completed Chemistry I.

The mean scores for most scales declined over time (Table 3); however, this change was only statistically significant for two scales: career interest in chemistry (P=0.001) and attitude towards chemistry in society (P=0.044). For both scales, attitudes declined almost linearly over the course of the study. In both cases, the mean attitudes in Semester 2, Week 11 were statistically different to those in Semester 1, Week 1, while those in Semester 1, Week 11 were not statistically different to either group (Table 3). The standard deviation increased slightly over time, particularly for the "attitude towards chemistry in society" scale. This indicates that the disparity between individual students may be increasing over time, ie. students with a positive tendency toward chemistry may increase in their interest toward a career in chemistry, whereas a larger body of students with a more negative attitude towards chemistry may be responsible for the observed overall decline in interest.

Table 3.

Changes in undergraduate student attitudes toward chemistry throughout their first year of study. Time points with the same superscript letter were not statistically different according to post-hoc Tukey testing at a confidence level of α=0.05.

Scale	**Sem 1 Wk 1 (n=114)**	**Sem 1 Wk 11 (n=93)**	**Sem 2 Wk 11 (n=60)**	**One-way ANOVA**
A (attitude toward chemists)	3.70 ± 0.50	3.52 ± 0.57	3.59 ± 0.56	NS
S (skills of chemists)	4.32 ± 0.64	4.20 ± 0.72	4.16 ± 0.68	NS
C (career interest in chemistry)	3.79 ± 0.66^{a}	$3.62 \pm 0.66^{a,b}$	3.41 ± 0.69^{b}	**
I (attitude towards chemistry in society)	3.49 ± 0.88^{a}	$3.37 \pm 1.00^{a,b}$	3.10 ± 1.06^{b}	*
L (leisure interest in chemistry)	3.04 ± 1.18	2.88 ± 1.18	2.72 ± 1.29	NS

NS – not significant (P>0.05), * P<0.05, ** P<0.01, *** P<0.001

To further investigate this possibility, two-step cluster analysis was performed on the “baseline” (Semester 1 Week 1) scale data. This is an exploratory data analysis technique that aims to identify natural groups (clusters) of different samples within the dataset that would not otherwise be apparent (Brown et al., 2014; Huberty et al., 2005). The cluster analysis revealed the presence of two moderately defined groups (average silhouette width of ~0.3), comprising 71 students (Cluster 1) and 43 students (Cluster 2). Between the two clusters, the magnitude of difference for individual scales was not necessarily consistent (Table 4). The greatest differences were observed for scales L (leisure interest in chemistry) and C (career interest in chemistry), but with minimal differences for scale A (attitude toward chemists) (Figure 1). The distribution of students within scale L appeared to show three different clusters of students based on their leisure interest in chemistry (as visualised in the violin plot shown in Figure 1), namely a low-interest, mid-interest and high-interest group, although these groups were not identified through any other data analysis techniques. No significant differences by gender, age group, or completion of Year 12 chemistry were observed between the two clusters (Chi-square test; P>0.05 for all). This indicates that there is some other driver of these intrinsic differences. To provide further insight into potential reasons for this divide, future studies could consider investigating other parameters that could affect student experiences in introductory chemistry courses, such as their attitude toward chemistry as a discipline (Brown et al., 2014), or their mathematical abilities (Spencer, 1996).

It is possible that cluster analysis could be used by chemistry educators to identify “outlier” students with a poorer attitude or experience during the early stages of an introductory chemistry unit, allowing them to be subsequently provided with additional support or targeted intervention programs (Harackiewicz & Priniski, 2018). For example, Marbouti et al. (2020) used cluster analysis to identify engineering students who were likely to achieve poorer academic results. Similarly, Cox et al. (2018) used a calibrated peer review process to identify students with a poorer chemistry knowledge during the early part of the semester, and successfully used targeted written assignments to strength the acid-base chemistry knowledge of these students. Although the formal identification of "at risk" students is not currently a widely used teaching strategy, this study highlights the potential of using near real-time data to guide effective intervention programs.

Table 4.

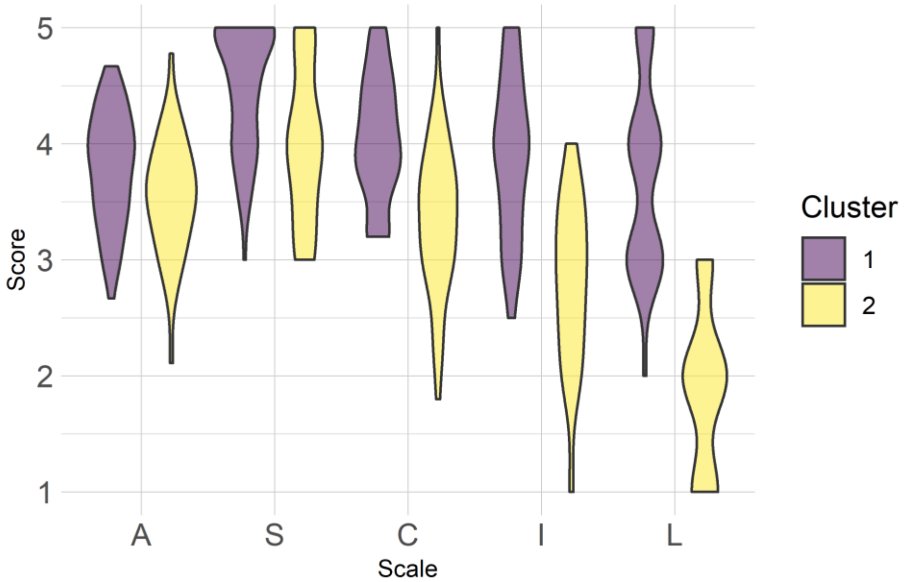
Mean scale scores for the two clusters of students identified through two-step cluster analysis performed on the baseline (Semester 1 Week 1) data.

Scale	Cluster 1 (n=71)	Cluster 2 (n=43)	T-test
A (attitude toward chemists)	3.79 ± 0.48	3.55 ± 0.5	*
S (skills of chemists)	4.52 ± 0.53	4.00 ± 0.67	***
C (career interest in chemistry)	3.90 ± 0.69	2.80 ± 0.72	***
I (attitude towards chemistry in society)	4.06 ± 0.53	3.36 ± 0.64	***
L (leisure interest in chemistry)	3.73 ± 0.81	1.88 ± 0.70	***

NS – not significant (P>0.05), * P<0.05, ** P<0.01, *** P<0.001

Figure 1.

Violin plot showing cluster distribution of students' attitudes toward each scale, measured on a scale of 1 (low) to 5 (high). The width of the bars indicate the relative number of students at each point.



Student experiences in learning chemistry

As shown in Table 5, the student learning experience at the end of the first semester was generally positive. Although a very slight decline in the mean student learning experience was observed across all four scales between the end of the first semester and the end of the second semester, this difference was not significant (P>0.05 for all).

As the data from Semester 2 comprised the experiences of a subset of students from the semester 1 dataset and hence would be likely to skew the perceived effects of demographic influence, further analysis on the student experience dataset was performed on the Semester 1 subset only. The four aspects of student experiences were strongly inter-correlated, but only weakly correlated with student attitudes toward chemistry (Figure 2). No significant differences were found when analysing the mean student experiences by gender (independent samples *t*-test; P>0.05). However, significant differences were found for all four scales when completion of Year 12 chemistry was considered (Table 6). For all four scales, students who had completed a chemistry course at a Year 12 level showed significantly more positive learning experiences, with particularly marked differences for the lecture and tutorial scales.

Table 5.

Undergraduate student learning experiences at the end of the first and second semester.

Scale	Sem 1 Wk 11 (n=93)	Sem 2 Wk 11 (n=60)	T-Test
L (lecture)	3.39 ± 0.76	3.33 ± 0.76	NS
T (tutorial)	3.64 ± 0.64	3.61 ± 0.72	NS
Lab (laboratory classes)	3.76 ± 0.61	3.68 ± 0.60	NS
D (demonstrator)	3.43 ± 0.72	3.38 ± 0.77	NS

NS – not significant (P>0.05), * P<0.05, ** P<0.01, *** P<0.001

Table 6.

Differences in undergraduate student learning experiences at the end of the first semester, based on whether students had studied Chemistry at a Year 12 level.

Scale	Yr 12 Chemistry		T-Test
	No (n=51)	Yes (n=42)	
L (lecture)	3.14 ± 0.67	3.69 ± 0.76	***
T (tutorial)	3.41 ± 0.55	3.92 ± 0.63	***
Lab (laboratory classes)	3.60 ± 0.62	3.96 ± 0.54	**
D (demonstrator)	3.26 ± 0.74	3.64 ± 0.64	**

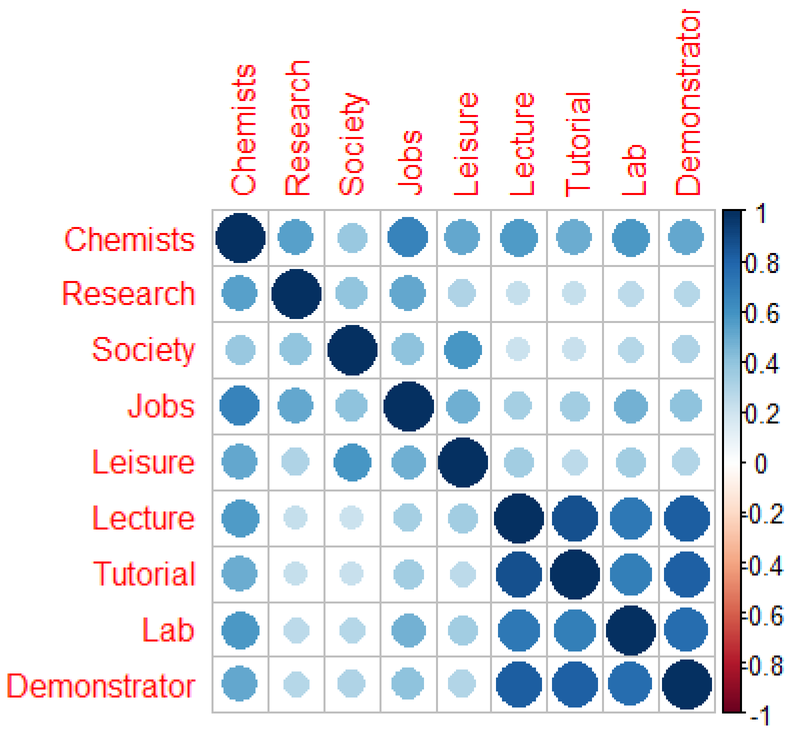
NS – not significant (P>0.05), * P<0.05, ** P<0.01, *** P<0.001

Correlation of student attitudes and experiences

As illustrated in Figure 2, only a weak correlation was found between student attitudes toward chemistry and their experiences in an introductory undergraduate chemistry unit. This analysis was performed on the Semester 1, Week 11 data, as this contained the highest number of respondents who reported both their attitudes and experiences in the study of chemistry (note that only attitude data were collected in Semester 1, Week 1, as students had not yet experienced the study of chemistry at an undergraduate level at this point in time). The strongest correlation between attitudes and experiences was found between the attitude toward chemists and the experience in lecture and laboratory classes. All measures of student experiences (lecture, tutorial, lab, demonstrator) were strongly intercorrelated, although lab experiences showed the lowest correlations among these four measures.

Figure 2.

Correlation matrix between student attitudes and experiences (analysis performed on Semester 1 Week 11 data; n=93 students). The legend shows the correlation coefficient (R).



Discussion

Student attitudes

Overall, the general attitudes of students toward the study of chemistry were positive, as evidenced by the average response to all attitude scales being greater than 3 (Table 2). This followed the general trend of positive attitudes toward chemistry previously reported for first-year undergraduate chemistry students in New Zealand (Dalgety et al., 2003) and Australia (Vishnumolakala et al., 2017). Scale S (skills of chemists) showed the highest mean score, suggesting relatively higher appreciation/acknowledgement of chemists' skills among the student population. In contrast, leisure interest in chemistry was the lowest, at a mean score of just above 3. This concurred with previous literature indicating that students generally have less leisure interest in chemistry compared to other aspects of their attitude toward chemistry (Dalgety & Coll, 2006; Dalgety et al., 2003). Similarly, student gender or prior completion of a chemistry course at Year 12 level appeared to have no significant impact on student attitude toward chemistry in this study. This stood in contrast to our initial hypothesis that students who had studied chemistry at school in Year 12 would have a more positive attitude towards the subject of chemistry, resulting from their increased familiarity with the topic. The observation also contrasted with previous work reporting a positive correlation between prior secondary school experiences and student attitude towards chemistry (Dalgety & Coll, 2006; Hill et al., 1990). Rather, our results suggest that, at least within the limitations of senior secondary chemistry education, prior exposure to and basic knowledge of chemistry does not improve student attitudes toward this topic once they commence their higher education studies. We propose that mere previous exposure toward chemistry is not sufficient to significantly improve student attitude, but rather students must have experienced a previous *positive* exposure toward the topic. This is supported by observations that considerable numbers of students who undertake chemistry in their senior secondary years do not necessarily have positive feelings toward or enjoy the topic (Cheung, 2009a, 2009b; Fraser et al., 2010). Although attitudes are not fixed and can change through positive learning experiences in the tertiary setting (Berg, 2005; Vishnumolakala et al., 2017), this highlights the crucial role that secondary chemistry educators can play in formulating positive attitudes toward chemistry among their students (Mamlok-Naaman et al., 2018).

In terms of temporal changes in student attitudes across the two semesters, a slight reduction in student attitude was observed for both scales C (career interest in chemistry) and I (attitude towards chemistry in society), but not for the other three scales (attitude toward chemists, skills of chemists and leisure interest in chemistry). Hence, we can reason that students recognise the importance of chemistry and the levels of skills required to be a chemist, regardless of their feelings toward chemistry as a subject. Similarly, Berg (2005) found a slight negative change in overall attitude among first-year chemistry students throughout the course of a 20-week semester, although they did not propose any reason for this shift. However, Dalgety and Coll (2006) did not find any consistent changes in attitudes throughout the semester among first-year students in New Zealand.

It is worthwhile noting that most students in the surveyed cohort are enrolled in introductory-level chemistry units in order to satisfy the prerequisites required to complete other units which form a major part of their degree. As such, they are not planning to graduate with a degree in chemistry, but rather pursue other programs such as biomedical, food, educational and geological sciences. For these students, successfully completing the compulsory introductory chemistry unit(s) in their first year is often seen a major obstacle (Clemons et al., 2018; Eitemüller & Habig, 2020). If these units were not compulsory, many students would avoid chemistry altogether as they typically perceive it as a difficult subject with few applications to their everyday life (Cardellini, 2012; Naiker & Wakeling, 2015). While student experiences in the lecture and tutorial sessions showed no significant differences throughout the semester, their career interest in chemistry was reduced significantly (Table 3), potentially indicating an increasing tendency for students to see chemistry as 'another unit to get out of the way'. This echoed other studies suggesting that students who do not intend to pursue the study of chemistry typically do not recognise the application of the content to their future careers (Clemons et al., 2018; Kubiatko et al., 2017). This could be one possible reason for the reduction in the career interest and attitude toward chemistry in society scales.

In addition, the University of Ballarat enrols relatively large numbers of mature age students (30 - 40%) who may not have studied science and particularly chemistry for many years (Naiker & Wakeling, 2015). As a result, chemistry may be the most challenging subject that these students may encounter in their programs. Many students are hesitant and have a fear of chemistry and perceive it as a difficult subject (Sausan et al., 2018), which is mostly driven by poor mathematical skills and very limited or no previous introduction to chemistry (Mack et al., 2019; Ross et al., 2018). Yet chemistry is one of the main service sciences underpinning many other disciplines in allowing students to better grasp and understand specific aspects related to their programs (Boddey & de Berg, 2015; Brown et al., 2015). It is crucial that these factors are taken into consideration by curriculum developers and teachers of introductory chemistry to explore alternative active learning strategies that would inspire, motivate and engage students towards studying chemistry (Winkelmann et al., 2015).

Student experiences

On average, the student experiences throughout the semester were slightly positive (Table 7), in contrast to previous results using the CAEQ, which found slightly negative learning experiences among New Zealand students (Coll et al., 2002; Dalgety et al., 2003). This may indicate that the current format of the Chemistry I and II units is providing an adequate learning experience for most students. However, there is considerable room for improvement in the student learning experiences, particularly in the lecture and demonstrator subscales. Notably, Coll et al. (2002) and Dalgety et al. (2003) also found the poorest learning experiences for the lecture subscale, indicating that this should be an area of particular focus for chemistry educators attempting to improve student engagement and learning outcomes.

The significantly higher learning experience scores for students who had completed Year 12 chemistry were notable, particularly as this group of students did not show any higher scores for their attitude toward chemistry and the study of chemistry (Table 2). Although there is limited information on the impact of Year 12 chemistry on student experiences at a tertiary level, the results appeared to concur with a study by Eitemüller and Habig (2020) on the effects of a tertiary bridging course in chemistry, which concluded that students with a higher prior knowledge gained the greatest long-term benefit from participation in the program. Similarly, Larsen et al. (2021) found that a four-week transition program improved students' confidence to perform well in subsequent chemistry units. Based on our results, we hypothesise that while the completion of Year 12 chemistry generally provides valuable foundational concepts and prepares the student to deal with more complex topics, it does not significantly alter their attitudes toward chemistry, possibly due to the introductory level of material presented at this grade. This could mean that secondary students may still find it difficult to relate the concepts to real-life situations. This is supported by observations that many chemistry courses – at both a secondary and tertiary level – fail to adequately connect the concepts with real-life applications (Clemons et al., 2018; Kubiatko et al., 2017).

Nevertheless, Year 12 chemistry appears to be quite valuable for students undertaking a first-year undergraduate level chemistry course, insofar as it allows them to better understand and engage with the content being delivered (as measured by student experiences during the lectures and tutorials). In turn, this is likely to reduce stress and allow them to better enjoy the delivered content, particularly the lecture and tutorial components. It is important to note that no data on student content knowledge or achievement in the introductory chemistry unit was collected here; hence we are not able to conclusively state if studying Year 12 chemistry improved student achievement, in addition to their improved learning experiences.

We note that while there was a significant difference in the engagement of students who had completed Year 12 chemistry and those who had not across all subscales, the magnitude of difference was lowest for the laboratory class component. This scale also displayed the highest score among students who had not studied chemistry in Year 12. From this, it may be inferred that while the chemistry knowledge gained at a Year 12 level may aid in practical components such as laboratory work, it certainly is not essential for students to successfully understand and enjoy this practical side of chemistry in the higher education environment. From a teaching perspective, it is crucial to understand that students of all abilities and backgrounds feel more connected to laboratory tasks as they can often better relate these activities to real-life experiences and situations (Mutambuki et al., 2019). When delivered effectively, laboratory tasks can stimulate and engage students' learning at different levels, challenging them mentally and physically in ways which other tasks such as tutorial and lecture experiences cannot (Matilainen et al., 2017; Rodriguez & Towns, 2018). It is well documented that students' learning experiences and achievement can be enhanced through implementation of practicals based on an Inquiry Oriented Learning (IOL) or Process-Oriented Guided-Inquiry Learning (POGIL) approach, as an alternative laboratory learning experience (George-Williams et al., 2019; George-Williams et al., 2020; Naiker & Wakeling, 2015; Rayner et al., 2013; Vanags et al., 2013). In our experiences, student attitudes toward the implementation of IOL activities is generally positive, with students reporting that they were able to develop a range of key graduate attributes, such as research skills, problem-solving skills and teamwork (Naiker & Wakeling, 2015; Naiker et al., 2020). Furthermore, Vanags et al. (2013) demonstrated that the use of a POGIL approach to laboratory sessions significantly improved long-term retention of information compared to regular laboratory classes.

Increased student engagement with the material taught in an introductory undergraduate course in chemistry may improve a student's confidence with the content of the course, and it may improve their academic performance. A student may also learn by being more positively engaged – this may have positive effects on persistence and student satisfaction when studying chemistry. Collectively, these may contribute positively to the overall student experience on an undergraduate course in chemistry, benefiting not only students, but also institutions, as they can potentially demonstrate that by engaging a student on a course, they are adding to the value of the education they provide. Also, increased student engagement may encourage a student to complete their chosen programme of study and graduate from University, but despite this, levels of student engagement are rarely quantified.

Suggestions for chemistry educators

Although student attitudes and experiences during an introductory chemistry unit were found to be generally positive in this study, education is a process that can benefit from continuous improvement (Hilliger et al., 2020). In particular, the cluster of students identified as having poorer attitudes toward chemistry may benefit from refinement of the curriculum or delivery methods. Hence, we provide several conclusions and suggestions that may assist in improving contemporary chemistry education practice.

Firstly, the lectures appeared to be the least favoured scale compared to other learning resources/support provided. Particularly in cohorts of students with little to no previous experience to chemistry, traditional verbose "lecture"-style lectures can be overwhelming. Rather than using generic slides from a textbook publisher or listing information from the textbook in long rows of bullet points, lecturers should strive to present the content material in a manner that is more palatable to the student (Dowling et al., 2003; Hunt et al., 2016; Velázquez-Marcano et al., 2004). It is also important that chemistry educators include adequate applications and connections of the content to students' everyday lives and future careers (Clemons et al., 2018; Kubiatko et al., 2017). This was evidenced by the relatively lower scores seen for the "attitude towards chemistry in society" scale. Other innovative approaches to delivering content continue to be investigated, including flipped classrooms (Eichler & Peeples, 2016; Loveys & Riggs, 2019), peer-learning approaches (Thompson & Lamanna, 2020) and gamification as a tool to improve memory retention (Tsai et al., 2020; Wood & Donnelly-Hermosillo, 2019). However, lectures remain a staple format of content delivery in most universities.

Similarly, tutorial classes should be designed with student engagement as one of the foremost priorities (Green et al., 2018). In some university settings, student attendance rates at tutorials forms part of their overall grade; hence students may turn up to the tutorial in order to get 'marked off the roll', but not engage with the class. In this study, the tutorial classes showed the second-highest score for student experiences, only exceed by the laboratory classes. We highlight that tutorials should be delivered in such a manner that students are genuinely interested in actively participating and interacting with the topic material, in order to strengthen and solidify their understanding (Hubbard et al., 2019; McLaren & Kenny, 2015).

As observed by previous researchers (Pullen et al., 2018), we note that the practical laboratory components form an important opportunity for lecturers to reinforce key concepts that have been previously delivered through the lecture content. The laboratory component had the highest average score for student experiences (Table 5), although a slight reduction in this score was observed throughout the term. It is possible that the use of more investigative and/or inquiry-based tasks within the laboratory program could allow students to garner greater engagement and ownership of the tasks (Naiker et al., 2020; Szalay & Tóth, 2016).

In light of the recent COVID-19 pandemic and the concurrent shift towards online-only teaching (Crawford et al., 2020; Johnson et al., 2021; Rapanta et al., 2020), it is also important that educators are able to leverage online learning platforms to provide the best experiences for students (Muir et al., 2020; Sharma et al., 2020; Sharma et al., 2018). The use of online-only teaching may potentially exacerbate many of the issues discussed previously (Raje & Stitzel, 2020). For instance, Perets et al. (2020) found that non-STEM major students studying introductory chemistry tended to find lectures less engaging following the transition to online learning. These authors also highlighted the importance of increasing the frequency of feedback given to students, as well as providing specialised training in online chemistry instruction to instructors. However, with adequate teacher-student interactions and thoughtful modes of content delivery, reasonable levels of student engagement can be maintained (Ranga, 2020). Although some authors have developed virtual chemistry laboratory modules which can be completed online (Dunnagan et al., 2020; Faulconer et al., 2018; Su & Cheng, 2019; Winkelmann et al., 2017), teaching adequate hands-on laboratory skills without the use of in-person instruction is likely to be one of the most challenging aspects of online-only chemistry education.

Finally, we propose that it is important that educators are aware of and are able to quantify their students' attitudes and preferences towards the study of introductory chemistry units in higher education (Montes et al., 2018), as has also been proposed in other disciplines (Brown et al., 2017). This is significant, as Brown et al. (2015) suggested that students who have less interest in chemistry may adopt a surface-style learning approach (i.e. rote-style learning), which can potentially lead to poorer learning outcomes. Routine monitoring of student attitudes and engagement could allow teaching teams to develop appropriate approaches that assist students to refine their learning habits. Regular assessment of students' approaches to learning may also guide curriculum planners in their consideration and integration of curriculum strategies, in order to encourage deeper and engaging learning experiences (Brown et al., 2014).

Limitations

It is important to note that this study has several limitations, as briefly outlined in the following sections. Firstly, data were only collected from one cohort of students. However, due to the reasonable sample size and repeated survey responses throughout Semester 1 and 2, we can have reasonable certainty that the data provided an accurate representation of the cohort's attitudes and engagement.

Due to ethical concerns, achievement data was unable to be correlated with student attitude and engagement responses. However, determining the correlation between attitude, engagement and achievement in future studies would add considerable confirmatory value to the conclusions drawn here.

Another limitation imposed by the ethics committee was that all responses had to be anonymous, meaning that individual students could not be tracked across all three time points. Consequently, this reduces the statistical power of the analysis and makes it more difficult to infer the changes in student attitude throughout the course of the study. Future studies could possibly explore alternative tracking methods, such as anonymous participant ID numbers, to follow students throughout the study period.

No data were gathered on students' mathematical abilities. As mathematical abilities form an important aspect of learning chemistry (Powell et al., 2020), it could be of interest to correlate students' mathematical abilities to their attitudes toward chemistry and learning experiences in introductory chemistry courses. Although Powell et al. (2020) found a positive correlation between arithmetic automaticity and student success in second-semester general chemistry, Adkins and Noyes (2018) found no connection between advanced mathematics skills of school leavers and their subsequent success in chemistry degrees. Hence further research in this area is recommended.

Many universities use different pedagogical approaches in teaching chemistry (Clemons et al., 2018), which may in turn have an impact on student attitudes. Hence caution should be used when generalising results from this student cohort to Australian chemistry students more broadly. Further work is required to determine the impact of different styles of pedagogy and teaching approaches (e.g. flipped classrooms) on student attitudes and experiences.

The instrument used in this study (CAEQ) does not specifically measure student engagement, and we use measures of attitude and experience to speculate on the engagement of students. Future studies which explore the student experiences of learning introductory chemistry at university should endeavour to quantify both attitude and engagement concurrently.

Conclusion

This study of first-year undergraduate students studying an introductory chemistry unit found that student attitudes toward the study of chemistry were generally positive, although some students appear to find it difficult to connect the content and concepts to their primary discipline, which is often not directly in a chemistry field. This was evidenced by a decrease in the average attitude toward a career interest in chemistry throughout the course of their first year of study. Students who had studied chemistry in Year 12 did not show any significant differences in their attitudes toward chemistry, when compared to students who had not studied Year 12 chemistry; however, their learning experiences in first-year chemistry were rated as being significantly more positive. We discuss suggestions for chemistry educators, including the use of engaging lecture and tutorial content. Finally, we highlight the role of the laboratory class as a highly engaging and interactive learning environment.

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Ethics

Ethical approval to conduct this study was obtained from the University of Ballarat Human Research Ethics Committee (approval no. B13-007). The study was explained to all participants, either verbally or via a plain language summary document, with informed consent obtained from all study participants prior to data collection. Participants were able to decline participation or withdraw at any point of the study.

Conflict of Interest

This research did not receive any specific grants from any funding agency in the public, commercial, or not-for-profit sectors. The authors declare no conflict of interest.

Availability of Data

The dataset is available from the authors upon request.

References

Adkins, M., & Noyes, A. (2018). Do Advanced Mathematics Skills Predict Success in Biology and Chemistry Degrees? *International Journal of Science and Mathematics Education*, *16*(3), 487-502. https://doi.org/10.1007/s10763-016-9794-y

Andrew, S. (1998). Self-efficacy as a predictor of academic performance in science. *Journal of Advanced Nursing*, *27*(3), 596-603. https://doi.org/https://doi.org/10.1046/j.13652648.1998.00550.x

Ardura, D., & Galán, A. (2019). The interplay of learning approaches and self-efficacy in secondary school students' academic achievement in science. *International Journal of Science Education*, *41*(13), 1723-1743. https://doi.org/10.1080/09500693.2019.1638981

Bandura, A., Freeman, W., & Lightsey, R. (1999). *Self-efficacy: The exercise of control*. Freeman.

Bauer, C. F. (2008). Attitude toward Chemistry: A Semantic Differential Instrument for Assessing Curriculum Impacts. *Journal of Chemical Education*, *85*(10), 1440. https://doi.org/10.1021/ed085p1440

Berg, C. A. R. (2005). Factors related to observed attitude change toward learning chemistry among university students. *Chemistry Education Research and Practice*, *6*(1), 1-18. https://doi.org/10.1039/B4RP90001D

Boddey, K., & de Berg, K. (2015). The impact of nursing students' prior chemistry experience on academic performance and perception of relevance in a health science course. *Chemistry Education Research and Practice*, *16*(2), 212-227. https://doi.org/10.1039/C4RP00240G

Bretz, S. L. (2019). Evidence for the Importance of Laboratory Courses. *Journal of Chemical Education*, *96*(2), 193-195. https://doi.org/10.1021/acs.jchemed.8b00874

Brown, S., Sharma, B. N., Wakeling, L., Naiker, M., Chandra, S., Gopalan, R. D., & Bilimoria, V. (2014). Quantifying attitude to chemistry in students at the University of the South Pacific. *Chemistry Education Research and Practice*, *15*(2), 184-191. https://doi.org/10.1039/c3rp00155e

Brown, S., Wakeling, L., Naiker, M., & White, S. (2014). Approaches to study in undergraduate nursing students in regional Victoria, Australia. *International Journal of Nursing Education Scholarship*, *11*(1), 155-164. https://doi.org/10.1515/ijnes-2014-0020

Brown, S., Wakeling, L., Peck, B., Naiker, M., Hill, D., & Naidu, K. (2015). Attitude to the subject of chemistry in undergraduate nursing students at Fiji National University and Federation University, Australia. *Collegian*, *22*(4), 369-375.

Brown, S., White, S., Bowmar, A., & Power, N. (2017). Evaluating an Instrument to Quantify Attitude to the Subject of Physiology in Undergraduate Health Science Students. *Journal of University Teaching & Learning Practice*, *14*(1), 12.

Brown, S., White, S., Sharma, B., Wakeling, L., Naiker, M., Chandra, S., Gopalan, R., & Bilimoria, V. (2015). Attitude to the Study of Chemistry and Its Relationship with Achievement in an Introductory Undergraduate Course. *Journal of the Scholarship of Teaching and Learning*, *15*(2), 33-41. https://doi.org/10.14434/josotl.v15i2.13283

Brown, S., White, S., Wakeling, L., & Naiker, M. (2015). Approaches and study skills inventory for students (ASSIST) in an introductory course in chemistry. *Journal of University Teaching & Learning Practice*, *12*(3), 6.

Cardellini, L. (2012). Chemistry: why the subject is difficult? *Educación Química*, *23*, 305-310. https://doi.org/10.1016/S0187-893X(17)30158-1

Carter, C. S., & Brickhouse, N. W. (1989). What makes chemistry difficult? Alternate perceptions. *Journal of Chemical Education*, *66*(3), 223. https://doi.org/10.1021/ed066p223

Cheung, D. (2009a). Developing a Scale to Measure Students’ Attitudes toward Chemistry Lessons. *International Journal of Science Education*, *31*(16), 2185-2203. https://doi.org/10.1080/09500690802189799
Cheung, D. (2009b). Students’ Attitudes Toward Chemistry Lessons: The Interaction Effect between Grade Level and Gender. *Research in Science Education*, *39*(1), 75-91. https://doi.org/10.1007/s11165-007-9075-4
Clemons, T. D., Bucat, R. B., & Spagnoli, D. (2018). First Year Introductory Chemistry at the University of Western Australia: Reflections and Perceptions. *Australian Journal of Chemistry*, *71*(4), 203-211. https://doi.org/10.1071/CH17359
Coll, R. K., Dalgety, J., & Salter, D. (2002). The development of the chemistry attitudes and experiences questionnaire (CAEQ). *Chemistry Education Research and Practice*, *3*(1), 19-32.
Cortina, J. M. (1993). What is coefficient alpha? An examination of theory and applications. *Journal of Applied Psychology*, *78*(1), 98. https://doi.org/10.1037/0021-9010.78.1.98
Cox, C. T., Poehlmann, J. S., Ortega, C., & Lopez, J. C. (2018). Using Writing Assignments as an Intervention to Strengthen Acid–Base Skills. *Journal of Chemical Education*, *95*(8), 1276-1283. https://doi.org/10.1021/acs.jchemed.8b00018
Cracolice, M. S., & Busby, B. D. (2015). Preparation for College General Chemistry: More than Just a Matter of Content Knowledge Acquisition. *Journal of Chemical Education*, *92*(11), 1790-1797. https://doi.org/10.1021/acs.jchemed.5b00146
Crawford, J., Percy, A., Kelder, J.-A., & Butler-Henderson, K. (2020). Editorial 17.5. Strengthening our focus for a post-COVID-19 environment: Learnings from a pandemic in higher education. *Journal of University Teaching & Learning Practice*, *17*(5), 01.
Dalgety, J., & Coll, R. K. (2006). The influence of first-year chemistry students’ learning experiences on their educational choices. *Assessment & Evaluation in Higher Education*, *31*(3), 303-328. https://doi.org/10.1080/02602930500352931
Dalgety, J., Coll, R. K., & Jones, A. (2003). Development of chemistry attitudes and experiences questionnaire (CAEQ). *Journal of research in Science Teaching*, *40*(7), 649-668. https://doi.org/10.1002/tea.10103
Dowling, C., Godfrey, J. M., & Gyles, N. (2003). Do hybrid flexible delivery teaching methods improve accounting students' learning outcomes? *Accounting Education*, *12*(4), 373-391. https://doi.org/10.1080/0963928032000154512
Dunnagan, C. L., Dannenberg, D. A., Cuales, M. P., Earnest, A. D., Gurnsey, R. M., & Gallardo-Williams, M. T. (2020). Production and Evaluation of a Realistic Immersive Virtual Reality Organic Chemistry Laboratory Experience: Infrared Spectroscopy. *Journal of Chemical Education*, *97*(1), 258-262. https://doi.org/10.1021/acs.jchemed.9b00705
Eichler, J. F., & Peeples, J. (2016). Flipped classroom modules for large enrollment general chemistry courses: a low barrier approach to increase active learning and improve student grades. *Chemistry Education Research and Practice*, *17*(1), 197-208. https://doi.org/10.1039/C5RP00159E
Eitemüller, C., & Habig, S. (2020). Enhancing the transition? – effects of a tertiary bridging course in chemistry. *Chemistry Education Research and Practice*, *21*(2), 561-569. https://doi.org/10.1039/C9RP00207C
Faulconer, E. K., Griffith, J. C., Wood, B. L., Acharyya, S., & Roberts, D. L. (2018). A comparison of online and traditional chemistry lecture and lab. *Chemistry Education Research and Practice*, *19*(1), 392-397. https://doi.org/10.1039/C7RP00173H
Fautch, J. M. (2015). The flipped classroom for teaching organic chemistry in small classes: is it effective?. *Chemistry Education Research and Practice*, *16*(1), 179-186. https://doi.org/10.1039/C4RP00230J
Fink, A., Frey, R. F., & Solomon, E. D. (2020). Belonging in general chemistry predicts first-year undergraduates’ performance and attrition. *Chemistry Education Research and Practice*. https://doi.org/10.1039/D0RP00053A

Flaherty, A. A. (2020). A review of affective chemistry education research and its implications for future research. *Chemistry Education Research and Practice*, *21*(3), 698-713. https://doi.org/10.1039/C9RP00200F

Fraser, B. J., Aldridge, J. M., & Adolphe, F. S. G. (2010). A Cross-National Study of Secondary Science Classroom Environments in Australia and Indonesia. *Research in Science Education*, *40*(4), 551-571. https://doi.org/10.1007/s11165-009-9133-1

Frey, R. F., Fink, A., Cahill, M. J., McDaniel, M. A., & Solomon, E. D. (2018). Peer-Led Team Learning in General Chemistry I: Interactions with Identity, Academic Preparation, and a Course-Based Intervention. *Journal of Chemical Education*, *95*(12), 2103-2113. https://doi.org/10.1021/acs.jchemed.8b00375

George-Williams, S. R., Karis, D., Ziebell, A. L., Kitson, R. R. A., Coppo, P., Schmid, S., Thompson, C. D., & Overton, T. L. (2019). Investigating student and staff perceptions of students' experiences in teaching laboratories through the lens of meaningful learning. *Chemistry Education Research and Practice*, *20*(1), 187-196. https://doi.org/10.1039/C8RP00188J

George-Williams, S. R., Ziebell, A. L., Thompson, C. D., & Overton, T. L. (2020). Inquiry-, problem-, context- and industry- based laboratories: an investigation into the impact of large-scale, longitudinal redevelopment on student perceptions of teaching laboratories. *International Journal of Science Education*, *42*(3), 451-468. https://doi.org/10.1080/09500693.2020.1714788

Green, R. A., Whitburn, L. Y., Zacharias, A., Byrne, G., & Hughes, D. L. (2018). The relationship between student engagement with online content and achievement in a blended learning anatomy course. *Anatomical Sciences Education*, *11*(5), 471-477. https://doi.org/10.1002/ase.1761

Hampton, N. Z., & Mason, E. (2003). Learning Disabilities, Gender, Sources of Efficacy, Self-Efficacy Beliefs, and Academic Achievement in High School Students. *Journal of School Psychology*, *41*(2), 101-112. https://doi.org/10.1016/S0022-4405(03)00028-1

Harackiewicz, J. M., & Priniski, S. J. (2018). Improving Student Outcomes in Higher Education: The Science of Targeted Intervention. *Annual Review of Psychology*, *69*(1), 409-435. https://doi.org/10.1146/annurev-psych-122216-011725

Hill, O. W., Pettus, W. C., & Hedin, B. A. (1990). Three studies of factors affecting the attitudes of blacks and females toward the pursuit of science and science-related careers. *Journal of Research in Science Teaching*, *27*(4), 289-314. https://doi.org/10.1002/tea.3660270403

Hilliger, I., Aguirre, C., Miranda, C., Celis, S., & Pérez-Sanagustín, M. (2020). *Design of a curriculum analytics tool to support continuous improvement processes in higher education* Proceedings of the Tenth International Conference on Learning Analytics & Knowledge, Frankfurt, Germany. https://doi.org/10.1145/3375462.3375489

Holsgrove, G. J., Lanphear, J. H., & Ledingham, I. M. (1998). Study guides: an essential student learning tool in an integrated curriculum. *Medical Teacher*, *20*(2), 99-103. https://doi.org/10.1080/01421599881174

Horowitz, I., & Bordens, K. (1995). *Social psychology*. Mayfield.

Hubbard, B. A., Jones, G. C., & Gallardo-Williams, M. T. (2019). Student-Generated Digital Tutorials in an Introductory Organic Chemistry Course. *Journal of Chemical Education*, *96*(3), 597-600. https://doi.org/10.1021/acs.jchemed.8b00457

Huberty, C. J., Jordan, E. M., & Brandt, W. C. (2005). Cluster Analysis in Higher Education Research. In J. C. Smart (Ed.), *Higher Education: Handbook of Theory and Research* (pp. 437-457). Springer Netherlands. https://doi.org/10.1007/1-4020-3279-x_8

Hunt, K. A., Trent, M. N., Jackson, J. R., Marquis, J. M., Barrett-Williams, S., Gurvitch, R., & Metzler, M. W. (2016). The Effect of Content Delivery Media on Student Engagement and Learning Outcomes. *Journal of Effective Teaching*, *16*(1), 5-18.

Johnson, J. B., Reddy, P., Chand, R., & Naiker, M. (2021). Attitudes and awareness of regional Pacific Island students towards e-learning. *International Journal of*

Educational Technology in Higher Education, *18*(1), 13. https://doi.org/10.1186/s41239-021-00248-z
Kind, V. (2009). Pedagogical content knowledge in science education: perspectives and potential for progress. *Studies in Science Education*, *45*(2), 169-204. https://doi.org/10.1080/03057260903142285
Koeper, I., Shapter, J., North, V., & Houston, D. (2020). Turning chemistry education on its head: Design, experience and evaluation of a learning-centred 'Modern Chemistry' subject. *Journal of University Teaching & Learning Practice*, *17*(3), 13.
Kousa, P., Kavonius, R., & Aksela, M. (2018). Low-achieving students' attitudes towards learning chemistry and chemistry teaching methods. *Chemistry Education Research and Practice*, *19*(2), 431-441. https://doi.org/10.1039/C7RP00226B
Kubiatko, M., Balatova, K., Fancovicova, J., & Prokop, P. (2017). Pupils' attitudes toward chemistry in two types of Czech schools. *Eurasia Journal of Mathematics, Science and Technology Education*, *13*(6), 2539-2552. https://doi.org/10.12973/eurasia.2017.01239a
Kupermintz, H. (2002). Affective and Conative Factors as Aptitude Resources in High School Science Achievement. *Educational Assessment*, *8*(2), 123-137. https://doi.org/10.1207/S15326977EA0802_03
Larsen, A., Cox, S., Bridge, C., Horvath, D., Emmerling, M., & Abrahams, C. (2021). Short, multi-modal, pre-commencement transition programs for a diverse STEM cohort. *Journal of University Teaching & Learning Practice*, *18*(3), 05.
Loveys, B. R., & Riggs, K. M. (2019). Flipping the laboratory: improving student engagement and learning outcomes in second year science courses. *International Journal of Science Education*, *41*(1), 64-79. https://doi.org/10.1080/09500693.2018.1533663
Mack, M. R., Stanich, C. A., & Goldman, L. M. (2019). Math Self-Beliefs Relate to Achievement in Introductory Chemistry Courses. In *It's Just Math: Research on Students' Understanding of Chemistry and Mathematics* (Vol. 1316, pp. 81-104). American Chemical Society. https://doi.org/10.1021/bk-2019-1316.ch006
Mamlok-Naaman, R., Eilks, I., Bodner, G., & Hofstein, A. (2018). *Professional development of chemistry teachers: Theory and practice*. Royal Society of Chemistry.
Marbouti, F., Ulas, J., & Wang, C. H. (2020). Academic and Demographic Cluster Analysis of Engineering Student Success. *IEEE Transactions on Education*, 1-6. https://doi.org/10.1109/TE.2020.3036824
Matilainen, R., Koliseva, A., Valto, P., & Välisaari, J. (2017). Reconstruction of undergraduate analytical chemistry laboratory course. *Analytical and Bioanalytical Chemistry*, *409*(1), 3-10. https://doi.org/10.1007/s00216-016-9953-6
McLaren, H. J., & Kenny, P. L. (2015). Motivating change from lecture-tutorial modes to less traditional forms of teaching. *The Australian Universities' Review*, *57*(1), 26.
Montes, L. H., Ferreira, R. A., & Rodríguez, C. (2018). Explaining secondary school students' attitudes towards chemistry in Chile. *Chemistry Education Research and Practice*, *19*(2), 533-542. https://doi.org/10.1039/C8RP00003D
Muir, T., Douglas, T., & Trimble, A. (2020). Facilitation strategies for enhancing the learning and engagement of online students. *Journal of University Teaching & Learning Practice*, *17*(3), 8.
Mutambuki, J. M., Fynewever, H., Douglass, K., Cobern, W. W., & Obare, S. O. (2019). Integrating Authentic Research Experiences into the Quantitative Analysis Chemistry Laboratory Course: STEM Majors' Self-Reported Perceptions and Experiences. *Journal of Chemical Education*, *96*(8), 1591-1599. https://doi.org/10.1021/acs.jchemed.8b00902
Naiker, M., & Wakeling, L. (2015). Evaluation of group based inquiry oriented learning in undergraduate chemistry practicals. *International Journal of Innovation in Science and Mathematics Education*, *23*(5), 1-17. http://researchbank.acu.edu.au/cgi/viewcontent.cgi?article=7680&context=fhs_pub

Naiker, M., Wakeling, L., & Aldred, P. (2013, 23 Sep). The relevance of chemistry practicals-first year students' perspective at a regional university in Victoria, Australia. Proceedings of The Australian Conference on Science and Mathematics Education (formerly UniServe Science Conference).

Naiker, M., Wakeling, L., Johnson, J., & Mani, J. (2020, 13 Oct). Inquiry-oriented learning in a first-year chemistry practical class. 2020 Scholarship of Tertiary Teaching Online Conference, Online.

Office of the Chief Scientist. (2017). *Science and maths in Australian secondary schools datasheet*. https://www.chiefscientist.gov.au/2016/07/science-and-maths-in-australian-secondary-schools-datasheet

Osborne, J., Simon, S., & Collins, S. (2003). Attitudes towards science: A review of the literature and its implications. *International Journal of Science Education*, *25*(9), 1049-1079. https://doi.org/10.1080/0950069032000032199

Pang, J., & Good, R. (2000). A Review of the Integration of Science and Mathematics: Implications for Further Research. *School Science and Mathematics*, *100*(2), 73-82. https://doi.org/10.1111/j.1949-8594.2000.tb17239.x

Paton-Walsh, C. (2015). Can Report Templates Aid Student Learning in Undergraduate Chemistry Laboratory Classes? *Journal of University Teaching & Learning Practice*, *12*(2), 3.

Perets, E. A., Chabeda, D., Gong, A. Z., Huang, X., Fung, T. S., Ng, K. Y., Bathgate, M., & Yan, E. C. Y. (2020). Impact of the Emergency Transition to Remote Teaching on Student Engagement in a Non-STEM Undergraduate Chemistry Course in the Time of COVID-19. *Journal of Chemical Education*, *97*(9), 2439-2447. https://doi.org/10.1021/acs.jchemed.0c00879

Pfundt, H., & Duit, R. (1994). Students' alternative frameworks and science education. *Institute for Science Education*, *4*(1).

Powell, C. B., Simpson, J., Williamson, V. M., Dubrovskiy, A., Walker, D. R., Jang, B., Shelton, G. R., & Mason, D. (2020). Impact of arithmetic automaticity on students' success in second-semester general chemistry. *Chemistry Education Research and Practice*. https://doi.org/10.1039/D0RP00006J

Pullen, R., Thickett, S. C., & Bissember, A. C. (2018). Investigating the viability of a competency-based, qualitative laboratory assessment model in first-year undergraduate chemistry. *Chemistry Education Research and Practice*, *19*(2), 629-637. https://doi.org/10.1039/C7RP00249A

R Core Team. (2020). *R: A language and environment for statistical computing*. In R Foundation for Statistical Computing. https://www.R-project.org/

Raje, S., & Stitzel, S. (2020). Strategies for Effective Assessments while Ensuring Academic Integrity in General Chemistry Courses during COVID-19. *Journal of Chemical Education*, *97*(9), 3436-3440. https://doi.org/10.1021/acs.jchemed.0c00797

Ranga, J. S. (2020). Online Engagement of Commuter Students in a General Chemistry Course During COVID-19. *Journal of Chemical Education*, *97*(9), 2866-2870. https://doi.org/10.1021/acs.jchemed.0c00633

Rapanta, C., Botturi, L., Goodyear, P., Guàrdia, L., & Koole, M. (2020). Online university teaching during and after the Covid-19 crisis: Refocusing teacher presence and learning activity. *Postdigital Science and Education*, *2*(3), 923-945. https://doi.org/10.1007/s42438-020-00155-y

Rayner, G., Charlton-Robb, K., Thompson, C., & Hughes, T. (2013). Interdisciplinary collaboration to integrate inquiry-oriented learning in undergraduate science practicals. *International Journal of Innovation in Science and Mathematics Education (formerly CAL-laborate International)*, *21*(5).

Rayner, G. M., & Papakonstantinou, T. (2018). Foundation Biology Students' Critical Thinking Ability: Self-Efficacy versus Actuality. *Journal of University Teaching & Learning Practice*, *15*(5), 4.

Rodriguez, J.-M. G., & Towns, M. H. (2018). Modifying Laboratory Experiments To Promote Engagement in Critical Thinking by Reframing Prelab and Postlab Questions. *Journal of Chemical Education*, *95*(12), 2141-2147. https://doi.org/10.1021/acs.jchemed.8b00683

Rosenberg, J. M., Schmidt, J. A., & Beymer, P. N. (2020). *prcr: Person-Centered Analysis*. In (Version 0.2.1) R Foundation for Statistical Computing. https://CRAN.R-project.org/package=prcr

Rosenberg, M. J., & Hovland, C. I. (1960). Cognitive, Affective and Behavioural Components of Attitudes. In M. J. Rosenberg & C. I. Hovland (Eds.), *Attitude organization and change: An analysis of consistency among attitude components*. Yale University Press.

Ross, J., Lai, C., & Nuñez, L. (2018). Student Affective State: Implications for Prerequisites and Instruction in Introductory Chemistry Classes. In *Strategies Promoting Success of Two-Year College Students* (Vol. 1280, pp. 91-114). American Chemical Society. https://doi.org/10.1021/bk-2018-1280.ch006

Sausan, I., Saputro, S., & Indriyanti, N. Y. (2018, 2018/07). Chemistry for Beginners: What Makes Good and Bad Impression. Mathematics, Informatics, Science, and Education International Conference (MISEIC 2018), Surabaya, Indonesia.

Sharma, B., Nand, R., Naseem, M., & Reddy, E. V. (2020). Effectiveness of online presence in a blended higher learning environment in the Pacific. *Studies in Higher Education*, *45*(8), 1547-1565. https://doi.org/10.1080/03075079.2019.1602756

Sharma, B. N., Nand, R., Naseem, M., Reddy, E., Narayan, S. S., & Reddy, K. (2018, 4-7 Dec. 2018). Smart learning in the Pacific: Design of new pedagogical tools. 2018 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE), 573-580.

Sirhan, G. (2007). Learning difficulties in chemistry: An overview. *Journal of Turkish Science Education*, *4*(2), 2-20.

Spencer, H. E. (1996). Mathematical SAT Test Scores and College Chemistry Grades. *Journal of Chemical Education*, *73*(12), 1150. https://doi.org/10.1021/ed073p1150

Su, C.-H., & Cheng, T.-W. (2019). A Sustainability Innovation Experiential Learning Model for Virtual Reality Chemistry Laboratory: An Empirical Study with PLS-SEM and IPMA. *Sustainability*, *11*(4), 1027. https://doi.org/10.3390/su11041027

Szalay, L., & Tóth, Z. (2016). An inquiry-based approach of traditional 'step-by-step' experiments. *Chemistry Education Research and Practice*, *17*(4), 923-961. https://doi.org/10.1039/C6RP00044D

Tasker, R., & Dalton, R. (2006). Research into practice: visualisation of the molecular world using animations. *Chemistry Education Research and Practice*, *7*(2), 141-159. https://doi.org/10.1039/B5RP90020D

Thompson, M. M., & Lamanna, A. C. (2020). Catalyzing Group Work in Introductory Chemistry: Evaluation of Five Strategies. *Journal of Chemical Education*, *97*(2), 351-357. https://doi.org/10.1021/acs.jchemed.9b00454

Treagust, D., Nieswandt, M., & Duit, R. (2000). Sources of students difficulties in learning chemistry. *Educación Química*, *11*(2), 228-235. https://doi.org/10.22201/fq.18708404e.2000.2.66458

Tsai, J.-C., Chen, S.-Y., Chang, C.-Y., & Liu, S.-Y. (2020). Element Enterprise Tycoon: Playing Board Games to Learn Chemistry in Daily Life. *Education Sciences*, *10*(3), 48. https://doi.org/10.3390/educsci10030048

Tyng, C. M., Amin, H. U., Saad, M. N. M., & Malik, A. S. (2017). The Influences of Emotion on Learning and Memory [Review]. *Frontiers in Psychology*, *8*(1454). https://doi.org/10.3389/fpsyg.2017.01454

Uzuntiryaki, E., & Çapa Aydın, Y. (2009). Development and Validation of Chemistry Self-Efficacy Scale for College Students. *Research in Science Education*, *39*(4), 539-551. https://doi.org/10.1007/s11165-008-9093-x

Vanags, T., Pammer, K., & Brinker, J. (2013). Process-oriented guided-inquiry learning improves long-term retention of information. *Advances in Physiology Education*, *37*(3), 233-241. https://doi.org/10.1152/advan.00104.2012

Velázquez-Marcano, A., Williamson, V. M., Ashkenazi, G., Tasker, R., & Williamson, K. C. (2004). The Use of Video Demonstrations and Particulate Animation in General Chemistry. *Journal of Science Education and Technology*, *13*(3), 315-323. https://doi.org/10.1023/B:JOST.0000045458.76285.fe

Vishnumolakala, V. R., Southam, D. C., Treagust, D. F., Mocerino, M., & Qureshi, S. (2017). Students' attitudes, self-efficacy and experiences in a modified process-oriented guided inquiry learning undergraduate chemistry classroom. *Chemistry Education Research and Practice*, *18*(2), 340-352. https://doi.org/10.1039/C6RP00233A

Williamson, V. M., Walker, D. R., Chuu, E., Broadway, S., Mamiya, B., Powell, C. B., Shelton, G. R., Weber, R., Dabney, A. R., & Mason, D. (2020). Impact of basic arithmetic skills on success in first-semester general chemistry. *Chemistry Education Research and Practice*, *21*(1), 51-61. https://doi.org/10.1039/C9RP00077A

Winkelmann, K., Baloga, M., Marcinkowski, T., Giannoulis, C., Anquandah, G., & Cohen, P. (2015). Improving Students' Inquiry Skills and Self-Efficacy through Research-Inspired Modules in the General Chemistry Laboratory. *Journal of Chemical Education*, *92*(2), 247-255. https://doi.org/10.1021/ed500218d

Winkelmann, K., Keeney-Kennicutt, W., Fowler, D., & Macik, M. (2017). Development, Implementation, and Assessment of General Chemistry Lab Experiments Performed in the Virtual World of Second Life. *Journal of Chemical Education*, *94*(7), 849-858. https://doi.org/10.1021/acs.jchemed.6b00733

Wood, J., & Donnelly-Hermosillo, D. F. (2019). Learning chemistry nomenclature: Comparing the use of an electronic game versus a study guide approach. *Computers & Education*, *141*, 103615. https://doi.org/10.1016/j.compedu.2019.103615

Xu, X., Southam, D., & Lewis, J. (2012). Attitude toward the subject of chemistry in Australia: An ALIUS and POGIL collaboration to promote cross-national comparisons. *Australian Journal of education in Chemistry*, *72*, 32-36.

Zoller, U. (1990). Students' misunderstandings and misconceptions in college freshman chemistry (general and organic). *Journal of research in Science Teaching*, *27*(10), 1053-1065. https://doi.org/10.1002/tea.3660271011