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Students' attitudes, self-efficacy and experiences in a modified Process-Oriented Guided Inquiry Learning undergraduate chemistry classroom

Abstract

This one-semester, mixed methods study underpinning social cognition and theory of planned behaviour investigated the attitudes, self-efficacy, and experiences of 559 first year undergraduate chemistry students from two cohorts in modified process-oriented guided inquiry learning (POGIL) classes. Versions of attitude toward the study of chemistry (ASCI v2), and chemistry attitudes and experiences questionnaire (CAEQ) were adopted, modified, and administered to understand and gauge students' affective outcomes before (pre) and after (post) POGIL intervention. Students' post-POGIL perceptions of their attitudes, self-efficacy and experiences were statistically significantly higher. In addition to confirmatory testing of reliability of data obtained from ASCI v2 and CAEQ in an Australian POGIL context, the findings suggest that POGIL intervention provides positive affective experiences to students who are new to chemistry or have limited prior chemistry knowledge.

Introduction

The objective of this research was to explore chemistry students' attitudes, self-efficacy and learning experiences in a classroom employing a modified Process Oriented Guided Inquiry Learning – POGIL (Moog, *et al.*, 2009) student-centred active learning pedagogy. For the successful development and implementation of instructional methods like POGIL, understanding the causal influence of students' affective characteristics on their learning is important; for this reason, the present study explores to what extent this is possible in an Australian context. For any innovative pedagogy that keeps students at the centre of the learning experience, the affective constructs of attitude and self-efficacy play a significant role in improving students' cognitive outcomes (Linnenbrink and Pintrich, 2003; Fowler, 2012; Ferrell and Barbera, 2015). Contemporary chemistry education research on innovative pedagogical practices like POGIL is more focused on cognitive constructs such as student achievement and their learning than the affective constructs (Kahveci and Orgill, 2015). The interactive nature of students' prior cognitive and affective characteristics (see Fig. 1) during the POGIL instructional process may lead to both relevant cognitive learning outcomes and affective outcomes (Bloom, 1976; McCoach, *et al.*, 2013). These affective outcomes, according to McCoach *et al.*, help guide

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students' future feelings about course content and issues (attitude), feelings of personal abilities (self-efficacy) and interests.

Owing their specificity to the nature of the task and the situation, the attitudinal and self-efficacy judgements quite often refer to some type of goal or outcome. The evaluation of attitudes and self-efficacy has become vital to emerging student-centred pedagogies, like POGIL, and their utility and transferability in a wide range of classrooms. Also, such evaluation can be very informative in first year undergraduate courses, where chemistry becomes one of the foundation subjects for preparing students intending to specialise in STEM disciplines.

Chemistry educators and/or researchers need to periodically examine changes in students' attitude, self-efficacy, and learning experiences to ensure academic quality in terms of chemistry teaching and learning. A well-designed chemistry preparatory course not only focuses on improvement of students' chemistry content knowledge but also their affective outcomes. As an example, for students who start with a lower-self efficacy, scaffolding of tasks from easy to hard (Villafane, *et al.*, 2014) may provide the necessary academic support for cognitive growth. Prior to providing information on the research aspects of the study, it is important to have a clear understanding of the intervention u, and the theoretical background of affective aspects, *viz.* attitude and self-efficacy.

Teaching-Learning Process

In traditional lectures there may be limited opportunities for student-teacher and student-student interactions such that the teacher-centred learning environment may not ideally facilitate the development of critical thinking skills. Owing to these limitations, the focus of college-level instruction has gradually shifted from teacher's presentation to students' active discussion of the content in undergraduate chemistry courses (Moog and Spencer, 2008). Eberlein, *et al* (2008) compared and contrasted the characteristic features of various active learning approaches for the benefit of new practitioners in sciences. In conclusion, Eberlein et al. advocated that, teaching through Problem Based Learning (PBL), Peer-led Team Learning (PLTL), and POGIL makes a difference as they tend to focus on students' learning and their understanding when compared to content-driven curriculum.

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POGIL is a student-centred instructional strategy that provides opportunities, simultaneously, to teach both content and key process skills such as problem solving, deductive reasoning, communication, self-assessment, team-work, and time management (Eberlein, *et al.* 2008; Moog and Spencer, 2008). The philosophical foundations of POGIL involve "an interactive process of thinking carefully, discussing ideas, refining understanding, practicing skills, reflecting on progress, and assessing performance" (Moog et al., 2009, p. 90). In a POGIL class, instructors facilitate learning rather than serve as a source of information and students work in small self-managed groups on activities to explore concepts by examining the data or information provided in the course (Spencer and Moog, 2008). The POGIL learning materials are highly structured following a learning cycle paradigm (Karplus and Butts, 1977) and contain several models, critical thinking questions, and application level questions to promote students' active engagement.

Cole, et al. (2012) identified theoretical foundations for small group active learning pedagogies like POGIL from Vygotsky's social constructivism which views the origin of knowledge construction as being the social interaction of learners where interactions involve sharing, comparing and debating. Vygotsky's (1978) sociocultural theory of learning accentuates the supportive guidance of peers, mentors for the development of higher order functions, and independent competence. In a POGIL class, learners identify the concept and refine their meaning of it by exploring the information, critically. To date, almost all evaluations of POGIL-interventions in undergraduate classes have focussed on the cognitive learning outcomes (Farrell, *et al.*, 1999; Ruder and Hunnicutt, 2008; Straumanis and Simons, 2008; Hein, 2012); fewer studies have examined the affective domain and those that have only focussed on short-term impacts of POGIL (Brandriet, *et al.*, 2011; Chase, *et al.*, 2013).

When appropriate learning experiences are provided by POGIL practitioners, the affective behaviours are simultaneously developed as much as the cognitive behaviours (Pierre and Oughton, 2007). Affective constructs are useful for measuring any observable change in affective characteristics as a consequence of students' experiences in modified POGIL environment. There are many potential affective constructs that could be chosen for examination.

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In this study, attitude and self-efficacy were chosen explicitly to match the instructors' intent of implementing modified POGIL classrooms.

Attitudes

The term attitude, according to Eagley and Chaiken (2007), is "a psychological tendency that is expressed by evaluating a particular entity with some degree of favour or disfavour". Attitude is an overall evaluation of a highly specific behaviour that is defined in terms of action, target, context, and time (Koballa and Glynn, 2007). Social psychologists proposed a three-component model (Eagly and Chaiken, 1993; Engel, *et al.*, 1995) to explain the *psychological* nature of attitudes: 1) cognitive (belief-based); 2) affective (emotion-based); and 3) behavioural (observable reaction). The cognitive and affective components can be measured using *psychometric* tests (*viz*. questionnaires) whereas; the behavioural component is fulfilled through observations. For example, in a POGIL class, the instructor observes students' behaviour through (a) students' active engagement in small group discussions, and/or (b) students exploring models or data presented in the POGIL worksheets.

Research on a non-cognitive factor like students' attitude toward the study of chemistry has been widely conducted as a predictor of chemistry achievement (House, 1995; Xu, *et al.*, 2013; Kahveci, 2015). At the same time, there were very few studies focusing on changes in students' attitudes as a result of collaborative learning approaches (Bartle, *et al.*, 2011). Ferreira and Trudel (2012) used a 14-item attitudinal instrument before and after a problem-based instructional program and reported changes in students' attitude toward learning of chemistry. Following a study using an attitudinal instrument, Kahveci (2015) inferred that a meaningful alignment of curriculum development and pedagogical practice is essential to enhance students' attitudes toward study of chemistry. Small-group cooperative or collaborative engagement of students often leads to their development of positive attitudes toward chemistry (Bowen, 2000). Therefore, this study seeks to follow students' attitude toward the study of chemistry before and after POGIL instruction.

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Self-efficacy

Self-efficacy can influence people's behaviour, either positively or negatively, based on their perception of their abilities, concerning a particular task (Hutchison, *et al.*, 2006). Bandura (1997) outlined self-efficacy as a generative capability wherein cognitive, social, emotional, and behavioural subskills are blended for effective functioning. The perceived self-efficacy, according to Bandura, is an important contributor to performance accomplishments. Perceived self-efficacy is not a measure of individual's skills, but a belief about what one can do under different sets of conditions with whatever skills the individual possesses.

According to Bandura (1993), self-efficacy is a derivative of students' actual experiences *(mastery experiences)*, their observation of others *(vicarious experiences)*, and their social persuasion in a disciplinary area. Information acquired from these sources does not influence efficacy automatically but is cognitively appraised (Schunk, 1990). Though the terms confidence and efficacy refer to the strength of a belief in one's abilities, they differ from each other in the level of attainment. Efficacy is based on a specified level of attainment and the strength of one's belief that this level of attainment is successfully achieved (Hutchison, *et al*. 2006). In an educational context, self-efficacy is an important variable that positively influences the levels of motivation (Hassankhani, *et al.*, 2015), disciplinary interest (Miura, 1987), and academic accomplishment (Bong, 2001; Dorit, 2015; Hackett, *et al.*, 1992). It is believed that students' collaborative classroom interactions promote higher performance attainments (Johnson, *et al.*, 1981). As a result, students tend to judge themselves more capable, and self-satisfied. Through his commentary on self-efficacy beliefs in academic settings, Pajares (1996) characterised an individuals' self-efficacy as perceived capabilities to attain designated types of performances and achieve specific results.

With reference to first year undergraduate level courses, students' self-efficacy beliefs in chemistry education are considered a potential factor influencing students' achievement and retention in STEM careers (Hutchison, *et al.*, 2006; Villafane, *et al.*, 2014). Available research revealed varied objectives for the exploration of students' self-efficacy in chemistry classes, for example: structuring of courses to suit diverse learners (Villafane, *et al.*, 2014; Glazer, 2015), problem-solving ability (Taasoobshirazi and Glynn, 2009); promoting competence and

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confidence (Zeldin, *et al.*, 2008); impact of teaching practices and/or innovations (Bauer, 2005; Ferrell and Barbera, 2015; Mataka and Kowalske, 2015). All of these studies somehow indicate that, the construct of self-efficacy remained an important factor contributing to the educational success (Bandura, 1993) of diverse learners of chemistry.

Design and Procedures

In the context of a POGIL facilitated chemistry instruction, the questions that the present study sought to answer pertained to the students' attitude toward the study of chemistry, self-efficacy beliefs and their learning experiences.

The research questions that guided this research were:

1. What evidence is there to determine whether the instruments intended to measure relevant constructs in this POGIL intervention are reliable?
2. What are the undergraduate chemistry students' attitudes towards chemistry before and after the introductory POGIL-intervention chemistry course?
3. What are the undergraduate chemistry students' levels of efficacy with regards to chemistry before and after the introductory POGIL-intervention chemistry course?
4. What are the undergraduate chemistry students' learning experiences in chemistry before and after the introductory POGIL-intervention chemistry course?

Theoretical Background

The research is contextualised in the theoretical foundations of *social cognition* and *planned behaviour*. These theories portray environmental, personal, and behavioural characteristics as major factors for the determination of learners' behaviour (Wang and Ha, 2013). According to social cognitive theory proposed by Bandura (1991), self-efficacy is a determinant of students' behaviour in a given cognitive environment where affective constructs like attitudes, interest and beliefs are key factors that effect students' self-efficacy and pursuit of chemistry courses (Rice, *et al.*, 2013). All of these affective constructs, depending on the aims of the research study, may serve as multiple lenses to view the manner in which appropriate actions can be undertaken to improve students' learning. These actions may include improving students' emotional states, their faulty self-beliefs, or habits of thinking (Pajares, 2008).

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The theory of planned behaviour (TPB) highlights several factors including the individual in the determination of one's behaviour. Proposed by (Ajzen, 1991), TPB (see Fig. 1) provides a framework to predict one's behavioural intentions based on his or her attitudes toward the behaviour, subjective norms for the behaviour, and perceived control over that behaviour. Coll, *et al*. (2002) utilised and extended this theory for their Chemistry Attitudes and Experiences Questionnaire – CAEQ, which focused students' attitudes towards the study of chemistry, their learning experiences and chemistry self-efficacy. As shown in Fig. 1, attitudes toward chemistry refer to the degree to which a student has a favourable or unfavourable evaluation or appraisal toward the study of chemistry. The second predictor, *subjective norm*, refers to perceived social pressure to learn or not to learn. The degree of *perceived control over chemistry learning* refers to the perceived ease or difficulty of learning chemistry based on the experience gained from lectures, workshops, and laboratory. Additionally, the model also represents the research questions that the present study has undertaken in order to explore students' affective beliefs in modified POGIL classes.

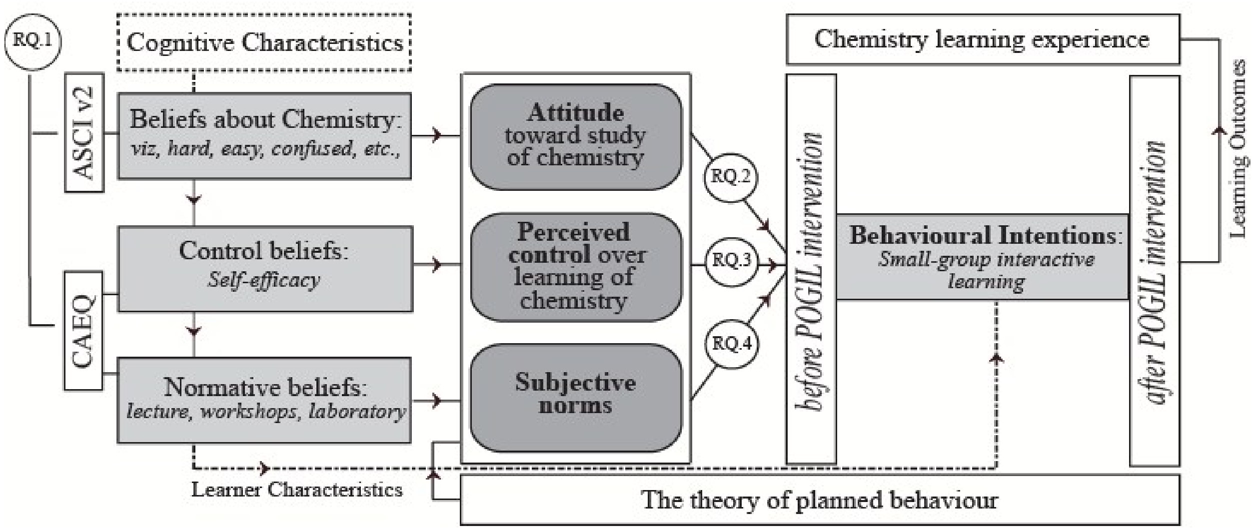

Fig. 1 Theoretical framework and research design (after Coll, *et al*. 2002)
Cognitive characteristics are not included in the study

The study is theoretically informed by a curriculum evaluation framework (comprising *intended*, *implemented*, *perceived* and *achieved* aspects of curriculum) of Goodlad (1979) and modified by Van den Akker (1988) and subsequently used in a number of studies in science (Friedel and

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Treagust, 2005; Treagust, 1991). The presented study focused only on the exploration of actual learning experiences as perceived by students (*perceived curriculum)* in first year chemistry POGIL classes. The rationale for the use of perceived curriculum from the literature, which collectively indicated that research focusing the affective measures in POGIL classes is scarce; therefore, results from the study may help expand knowledge in this domain.

Research design

The research reported in this article was approved by the Human Research Ethics Committee (HREC) of the investigators' institution. The design consisted of a post-positivist paradigm using a quasi-experimental – one group – pre and post-test design with no comparison group and with the data was collected using convergent parallel mixed methods (Creswell, 2003). In this study, quantitative data formed the core of the research and qualitative findings were used to compliment quantitative findings. Quantitative data, therefore, were intended to explore chemistry students' attitudes, self-efficacy beliefs, and learning experiences before and after POGIL, whereas, qualitative data were utilised for the purpose of triangulation (Creswell, 2003). Post-positivism was considered appropriate for this study because it offered the researchers an impersonal position to make context-dependent generalisations. Post-positivist researchers regard themselves as learners rather than testers; thereby recognising common humanity that connects researchers and people participating in the research (Ryan, 2006). This notion exemplifies a meaningful way toward acknowledgement of a problem with a traditional scientific method (Henderson, 2011). The post-positivist methodological orientation often deals with the quality of input data, the use of a more integrated approach within the context of a studied phenomenon (Adam, 2014). Following the post-positivist philosophy, we attempted to show how students' learning experience vary before and after POGIL interaction with the utilisation of theoretical models as explained in the earlier sub-section.

Chemistry course

The course of study examined here is intended for first year undergraduate students who have not previously studied chemistry, and who do not intend to major in the discipline. The course covers topics relating to: chemical processes that include differences between chemical and mathematical representations of reactions and reactivity; properties of natural and man-made processes and materials; basic principles of organic chemistry covering reactivity and functions

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of organic molecules. Pedagogically, it has been reported in the literature (Cooper, 2010; Fowler, 2012) that teaching non-major science students is a challenge, particularly, making the content of the course understandable to the students so that they realize its relevance to their lives. POGIL had been viewed as an alternative pedagogical practice to actively engage students during the delivery of the course. The chemistry unit was delivered via lectures and a POGIL intervention facilitated by workshops throughout the semester.

In this study, the POGIL intervention was modified in accordance with the institution's learning environment. Fig. 2 represents an illustration of how POGIL is organised. The modified approach utilised mini-lecture presentations with small group activities in workshop sessions. Students attended a two-hour workshop once a week that typically followed the POGIL format utilising group roles. POGIL worksheets were written in accordance with the curriculum at the study institution. Guided by facilitators, students actively discuss the content of the models presented in POGIL worksheets; identify and understand chemical concepts by answering several critical thinking questions; and lastly, students' developed and understood concepts are further reinforced and extended by answering several exercises presented in the POGIL learning materials. The lead facilitator (also a chemistry faculty member) consolidates student understanding following feedback received from POGIL groups.

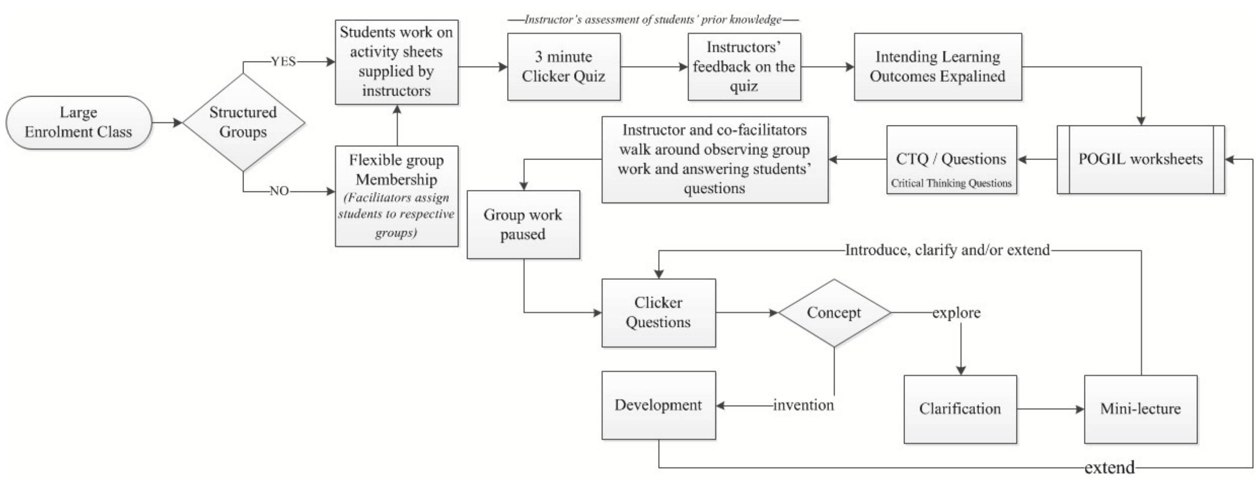

Fig. 2 Implementation of POGIL in a typical first year undergraduate chemistry class

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Sample

The data pertaining to the two cohorts enrolled over two semesters (Semesters 1 and 2 in 2015) were utilised. The cohorts comprised first year Australian domestic and international undergraduate students who were enrolled in an introductory chemistry course. The student sample during Semester 1, 2015 was 405 and in Semester 2, 2015 was 154. The student cohorts comprised traditional high school leavers and mature age students. Some of these students have had a relevant chemistry background at the pre-requisite (secondary) level or they may be learning chemistry for the first time. The non-teaching co-author of this investigation was engaged to invite students at the start of the semester and later at the end of the semester for their voluntary participation in the study. At every stage of the investigation, students were informed of: the purpose of the research study; no reinforcement for their participation; and their freedom to withdraw from the research study at any time.

Methodology

Instrumentation

The chosen instruments were assessed against established guidelines (AERA, 1999) for evidence of the reliability and validity of instruments (Blalock, *et al.*, 2008), and the relevance of the measured constructs to the intentions and theoretical background of the study was verified. Two instruments were combined to address the research questions, and each instrument attempted to assess different affective dimensions of relevance to this study. The instruments utilised in this study can be found in Appendix 1.

For measuring students' attitudes, Attitudes toward the Study of Chemistry Inventory – ASCI v2 (Xu and Lewis, 2011) was used. Originally developed by Bauer (2005), the instrument was later modified and validated at several institutions in USA and Australia (Xu and Lewis, 2011; Xu, *et al.*, 2012). ASCI v2 is an 8 item 7-point semantic differential scored instrument with two subscales – 1) *intellectual accessibility;* 2) *emotional satisfaction.*

For measuring students' self-efficacy and learning experience, the Chemistry Attitudes and Experiences Questionnaire (Coll, *et al.*, 2002; Dalgety, *et al.*, 2003) was used. CAEQ has 7-point Likert score items organised into four subscales as shown in Table 1. CAEQ was modified

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morphologically to make it suitable to POGIL contexts in Australia. For example, the word *tutorial* in the original CAEQ was replaced with *workshop*, and *tutor* as *facilitator*, etc.

Both ASCI v2 and CAEQ were administered firstly, at the start of the 12-week semester (referred as pre-test) and secondly, at the end of the semester (referred as post-test). A sample of items from the ASCI v2 and CAEQ surveys are presented in Table 1. A complete list of items for ASCI v2 and CAEQ are made available as Appendix 1.

Table 1 Research instruments used, their subscales, and sample items

Instrument	Subscales	Sample Items
ASCI v2	Intellectual Accessibility	Chemistry is: • Easy ………… hard • Confusing ……clear
	Emotional Satisfaction	• Satisfying …….frustrating • Chaotic ……….organised
CEAQ	Self-efficacy	Indicate how confident you feel about: • Learning chemistry theory • Tutoring another student …. • choosing appropriate formula to solve a problem
	Lecture learning experience (LLE)	• My lecturers were interested in my progress • The lectures were presented in an interesting manner
	Workshop learning experience (WLE)	• The material presented in workshops is useful • It was easy to find a facilitator to discuss a problem with
	Laboratory class learning experience (LCLE)	• The theory behind the experiments was clearly presented • The experiments were interesting
	Demonstrator learning experience (DLLE)	• The chemistry demonstrators have made me feel I have the ability to continue in science • My demonstrators were interested in my progress

The original CAEQ had 48 items whereas the version used in this study contained 47 items. An item from the self-efficacy subscale – ‘achieving pass grade in chemical hazards course’ was dropped as did not fit within the scope of the study.

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The pre-test surveys were completed by 405 (Semester 1, 2015) and 154 (Semester 2, 2015) students and the post-test surveys were completed by 248 (Semester 2, 2015) and 87 (Semester 2, 2015) students, respectively. For answering research questions #2 to 4; only the data obtained from students who participated in both pre and post-test ASCI v2 and CAEQ were considered. Therefore, the final sample comprised 213 and 67 students respectively in Semesters 1 and 2 in 2015. Items 1, 4, 5, and 7 (see Appendix 1) of ASCI v2 are negatively worded and hence their scores were reversed before proceeding with the statistical analyses. As explained in the earlier section, because the CAEQ was modified, the data obtained from the instrument were re-examined for any underlying factorial structure (see Appendix 2) using IBM AMOS (Arbuckle, 2013).

The qualitative data collection utilised semi-structured interviews to obtain participants' feedback on their attitudes, self-efficacy beliefs, and chemistry learning experience in POGIL facilitated classes. The interviews were conducted during the final weeks of the semester soon after the post-test CAEQ. The students (n = 10) who consented to participate in interviews were first asked how they responded to the items of the instruments and later, the reasons for their chosen rating. For example, in case of the first item of ASCI v2, students are required to rate whether chemistry is easy or hard for them. Based on their responses, the interviewers further interrogated whether or not they had done any high school-level chemistry and how useful were the POGIL interactions in making chemistry easy to learn. This type of approach prompted participants to express their views and opinions about their chemistry learning experience.

Data Analysis Procedures

While there is some discussion in the literature about analysing ordinal data from Likert scales with parametric tests, we have followed the procedures of Lalla (2016), Lovelace and Brickman (2013), and Norman (2010). In support of this decision, we accepted Lalla's (2016, section 3.3) argument that "parametric statistics can be applied if it is assumed that the observed ordinal variable is the result of a crude and approximate measurement process which evaluates a continuous underlying variable". The fit indices of the confirmatory factor analyses do reveal the integrity of the latent constructs of the CAEQ and are shown in Appendix 2. Therefore, the data were analysed by parametric t-tests using a *two-tailed* tests of significance (t-test) in order to

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indicate any inferential stability of the observed results, thus enabling researchers to conclude that chances of variability are an unlikely explanation for the results (Winkelman, 2001). The selection of two-tailed t-test over the one-tailed was based on authors' deliberate unawareness of the direction of the predicted mean differences (Ringwalt, *et al.*, 2011).

The CAEQ was used for the first time in POGIL context; therefore the authors were unable to predict which of the two test conditions (pre or post) will have a more indicative score for self-efficacy and experience in learning of chemistry. Additionally, the effect size (*d)* values (Cohen, 1988) were also computed to understand the strength of difference between students' perceptions as measured from pre and post surveys. The effect size varies according to a range in Cohen's *d* value: a value of 0.20 to 0.30 is considered a *small* effect; 0.40 to 0.70, *medium* effect; and 0.80 or above, *large* effect (Cohen, 1988).

QSR International's NVivo 10 (2012) qualitative data analysis software was used. Interview data were analysed following Creswell's (2012) guidelines that included, organization of data for analysis, reading through all data for obtaining a general sense, coding of text and subsequent generation of themes or categories, and finally, interpretation of data. The participants (n = 10) were assigned codes from ICS1 to ICS10. For ease of discussion, the subscales of ASCI v2 and CAEQ (see Table 1) are utilised as overarching themes for grouping students' responses.

Findings

Quantitative Data

To respond to Research Question #1: What evidence is there to determine whether the instruments intended to measure relevant constructs in this POGIL intervention are reliable?, Cronbach's alpha reliability values were computed for the data obtained from ASCI v2 and CAEQ. As shown in Table 2, the pre and post-test values for all the subscales were ≥ 0.70 and hence are considered highly reliable (Creswell, 2003). These reliability results for the ASCI v2 subscales were comparable to those reported by Xu, *et al.* (2012), and Kahveci (2015). The borderline Cronbach's alpha value (0.70) for pre-test subscales of ASCI v2 may have resulted due to the first time undertaking of a college-level chemistry course by some students without strong background discipline knowledge. However, there has been a substantial movement in

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post-test Cronbach's alpha values for intellectual accessibility and emotional satisfaction. Xu, *et al.* (2015) have reported a similar trend in their cross-cultural validation study of ASCI v2 undertaken simultaneously at three universities in three different countries.

Table 2 Cronbach's alpha values for pre and post-tests ASCI v2 and CAEQ

Instrument	Subscales	No of items	Pre-Test *(n=405)*	Post-Test *(n=248)*
ASCI v2	Intellectual Accessibility	4	0.69	0.82
	Emotional Satisfaction	4	0.71	0.79
CAEQ	Self-efficacy	16	0.93	0.94
	Lecture learning experience	9	0.88	0.92
	Workshop learning experience	9	0.87	0.92
	Laboratory class learning experience	9	0.90	0.93
	Demonstrator lab learning experience	4	0.81	0.88

To respond to Research Question #2: What are the undergraduate chemistry students' attitudes towards chemistry before and after the introductory POGIL-intervention chemistry course?, the pre and post-test mean scores of students' responses to the items of ASCI v2 were compared with paired samples t-tests. As shown in Table 3 for the cohort in Semester 1, the differences were statistically significant [t (212) = 5.08] for intellectual accessibility, and [t (212) = 3.84] for emotional satisfaction at $p < 0.001$. For the cohort in Semester 2, 2015, the differences were statistically significant [t (66) = 2.30] for intellectual accessibility and [t (66) = 2.13] for emotional satisfaction at $p<0.05$. The lower mean scores for the subscales - intellectual accessibility and emotional satisfaction - may have resulted due to the nature of the incoming cohort; these first year non-major chemistry students tend to start their course with low interest because of the mandatory requirement of the core curriculum. Nevertheless, these pre-post differences indicate, overall for this cohort, that chemistry is accessible and that it is emotionally satisfying to students when studying the modified POGIL materials in the first year chemistry classes. Additional evidence in support of the impact of POGIL is also available in the form of Cohen's *d* values as shown in Table 3. The construct of emotional satisfaction in both cohorts appeared to have had a *small* effect whereas, for the intellectual accessibility, the effect size was large for the larger cohort (Semester 1, 2015).

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Table 3 Pre and post-tests for students' attitudes - descriptive statistics and paired samples t-test results

ASCI v2 Subscales	Cohort	Pre-Test		Post-Test		Paired Differences		*t*	*df*	Sig. (2-tailed)	Cohen's *d*
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.				
Intellectual Accessibility	Sem. 1, 2015 *(n = 213)*	3.75	0.72	4.19	1.06	0.44	1.24	5.08	212	0.001*	0.47
Emotional Satisfaction		4.10	0.88	4.41	0.98	0.32	1.20	3.84	212	0.001*	0.33
Intellectual Accessibility	Sem. 2, 2015 *(n = 67)*	3.45	1.18	3.72	0.99	0.28	1.00	2.30	66	0.025**	0.25
Emotional Satisfaction		3.87	0.92	4.17	0.99	0.29	1.13	2.13	66	0.037**	0.31

*($p<0.01$); **($p<0.05$)

In addition to the analysis shown Table 3, we have grouped students' responses to the items of ASCI v2 into two categories. For example, in case of item 1 of ASCI v2, those who find chemistry easy (rating scores 1 to 3) as Category 1, and those students who find chemistry difficult (rating scores 4 to 7) as Category 2. These results are shown in Appendix 3.

To respond to Research Question #3, what are the undergraduate chemistry students' levels of efficacy with regards to chemistry before and after the introductory POGIL-intervention chemistry course?, students' responses to the items *(n=16)* of the CAEQ self-efficacy subscale were utilised. The pre and post-test mean scores and the paired samples t-test results are presented in Table 4. For the cohort in Semester 1, 2015, the students' self-efficacy had improved over the semester and the paired sample t-test result [t (212) = 7.01] between pre and post-test scores for self-efficacy was statistically significant at $p < 0.001$. The data collected from the cohort in Semester 2, 2015 also displayed a consistent and statistically significant t-test result [t (66) = 6.83]. The improvement in mean score for the construct of self-efficacy and a consistent *medium* effect size (Cohen's *d*) for both cohorts indicated that, students' feel comfortable and confident about their learning of chemistry and applying their knowledge in these POGIL classes.

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Table 4 Pre and post-tests for students' self-efficacy - descriptive statistics and paired samples t-test results

CAEQ Subscale	Cohort	Pre-Test		Post-Test		Paired Differences		*t*	*df*	Sig. (2-tailed) (* *p<0.01*)	Cohen's *d*
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.				
Self-efficacy	Sem. 1, 2015 *(n = 213)*	4.43	1.00	4.84	0.93	0.41	0.85	7.01	212	0.001*	0.42
	Sem. 2, 2015 *(n = 67)*	3.97	1.17	4.76	1.13	0.79	0.94	6.83	66	0.001*	0.69

To respond to Research Question #4, What are the undergraduate chemistry students' learning experiences in chemistry before and after the introductory POGIL-intervention chemistry course?, descriptive statistics and paired samples t-test results from students' responses to the items of CAEQ subscales: *lecture learning experience (LLE), workshop learning experience (WLE), laboratory class learning experience (LCLE), and demonstrator lab learning experience (DLLE)* were used. As shown in Table 5, the post-test mean scores for all subscales were higher than those in pre-test scores. Further, the improvement in students' learning experience was evident from the statistically significant paired samples t-test results.

Table 5 Pre and post-test for students' learning experiences - descriptive statistics and paired samples t-test results

CAEQ Learning experience subscales	Cohort	Pre-Test		Post-Test		Paired Differences		*t*	*df*	Sig. (2-tailed)	Cohen's *d*
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.				
LLE	Sem. 1, 2015 *(n = 213)*	4.27	0.91	4.42	1.13	0.14	1.04	2.03	212	0.044**	0.15
WLE		4.94	0.81	5.13	1.00	0.19	0.99	2.88	212	0.004*	0.21
LCLE		4.52	0.89	4.96	1.01	0.45	1.02	6.37	212	0.001*	0.46
DLLE		4.57	1.03	5.01	1.16	0.44	1.15	5.60	212	0.001*	0.40
LLE	Sem. 2, 2015 *(n = 67)*	4.68	0.98	4.80	1.09	0.13	1.09	0.96	66	0.342	0.12
WLE		4.66	0.96	5.18	1.03	0.51	0.99	4.26	66	0.001*	0.52
LCLE		4.49	0.64	4.94	1.10	0.46	1.08	3.46	66	0.001*	0.47
DLLE		4.61	1.53	5.07	1.28	0.47	1.72	2.23	66	0.029**	0.32

**(p<0.01); **(p<0.05)*

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The higher post-test mean scores for the constructs of WLE, LCLE, and DLLE indicate that POGIL is influential in students' learning of chemistry. Further, students have assigned higher scores for the items of WLE which ascertains that the aspects of POGIL - like learning materials (worksheets), group discussions, and interaction with facilitators appear to be beneficial for students developing positive perceptions about their learning of chemistry. Finally, the effect sizes for measures of students' experience in lecture and laboratory classes, as reported in Table 5, followed a similar pattern for cohorts in Semesters 1 and 2. Surprisingly, the effect size for students' learning experience in POGIL workshops in Semester 2, 2015 was higher compared to their predecessors.

Qualitative Data

The results obtained from thematic content analyses of interview transcripts are presented in three sections: attitude towards chemistry, self-efficacy, and classroom experiences.

Attitude towards chemistry

For qualitative exploration of students' attitudes towards chemistry, the coded themes were categorised as *intellectual accessibility* and *emotional satisfaction.* As evidenced from the following, students' intellectual accessibility in chemistry is influenced by their levels of prior knowledge of chemistry and participation in POGIL workshops:

> *Chemistry is hard to me as I have not studied chemistry while at high school, so it is a whole new concept to me. Chemistry is* ***complicated*** *and challenging to me as I did not have the basic knowledge. Chemistry is* ***confusing****. Chemistry concepts are hard to grasp and then to put them into practice. (ICS1)*

> *Chemistry is somewhat* ***easy****. I still remember some of the concepts I have learnt from my high school chemistry. It (chemistry) is little bit complicated initially, but once you start remembering the formulae and the rules, it then becomes lot easier and lot more simple. Chemistry is* ***clear*** *because, when we are thorough with the rules it (chemistry) becomes very clear unlike other subjects where there may be ambiguous where one answer may mean two different things. (ICS3)*

The above excerpts indicate that ICS1 had no prior knowledge of chemistry, whereas ICS3 acknowledges improvement in intellectual accessibility upon gaining familiarity with formulae and rules.

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The improvement in students' emotional satisfaction over the semester is evident from their responses to items of ASCI v2. The small group learning environment characterised by students' interaction and active facilitation by a team of instructors appeared to have an impact on the improvement of students' emotional satisfaction. For instance, ICS1 felt that chemistry may not lead to frustration in group situations and every member of the group works co-operatively to enhance their conceptual understanding of chemistry:

> *I am **uncomfortable** in chemistry just because, I have never done it before. Chemistry is **frustrating**, because some students do equations easily, but we still have trouble with them. But in a group situation, it becomes better. When you're doing it by yourself, it is frustrating. Chemistry is **organised**, when we understand the concepts and rules, we can make it very organised for learning. While working as small groups, we understand the content much better because, we have a boy in our group who has done chemistry before and like me, another girl who is also new to the subject and he is able to help us and we are able to help each other for better understanding of concepts. (ICS1)*

Similarly, ICS2's perspective on learning chemistry is emotionally satisfying given the reasons of quality of facilitation and organisation of workshops:

> *Chemistry was **challenging** initially, but now I am finding it **interesting** because of the way it has been set-up (small group learning). Last semester, I dropped out of another unit that had well over 100 students where students had no opportunity to interact with others. Whereas, in this unit, there are students working in about 10 to 15 small groups and four facilitators are helping us to understand concepts better. I do not think, lot of groups need help. Some groups work better than others. I understand chemistry lot better in this course. (ICS2)*

In summary, viewing through the lens of intellectual accessibility and emotional satisfaction in the POGIL-facilitated classes, it is evident that students appeared to have developed positive attitude toward chemistry as a result of small group active learning.

Self-efficacy

The qualitative investigation on students' self-efficacy beliefs focused on several themes such as mastery experiences promoting confidence in chemistry, scientific inquiry, and ability to communicate chemistry with peers. In general, students reported enhanced confidence as a result of participation in POGIL classes. For instance, the following excerpt from ICS5 indicates one student's ability to peer-tutor others as a result of enhanced confidence in her understanding of chemistry:

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> *I understand chemistry well but I'm just not good at communicating. So while I can understand what I'm saying, other people may not understand it. I'm just not good at communicating Ideas though. It's about my ability to communicate not my knowledge. If it were based on my knowledge I strongly agree that I am **confident** to tutor another student in the class. (ICS5)*

In addition to being confident in chemistry, ICS4 felt that a thorough preparation is necessary to peer-tutor others:

> *No, I understand [chemistry] and I'm doing well but I'd rather have the full background to teach someone just in case if they have a random question. (ICS4)*

ICS6 felt totally confident in his ability to determine appropriate units for a result determined using a formula and writing a laboratory report:

> *I am very **confident** of writing up results section (in a laboratory report) and determining units for a result. Everyone makes mistakes, I don't believe I'm going to be right a 100% of the time. (ICS6)*

ICS8 felt that he is confident of applying a set of chemistry rules to different elements of the periodic table:

> *Yes, I can. I've improved a lot in terms of gaining information from chemistry. For example in stoichiometry, I have learnt a great deal about the calculations and balancing of equations. (ICS8)*

Based on the above mentioned feedback obtained from students, it appears that mastery experiences gained from POGIL classes may have an impact on their ability to communicate chemistry with peers, and application of theoretical principles and skills of scientific inquiry in their chemistry learning.

Classroom experiences

The findings from students' feedback on their learning experience in lectures, workshops, and laboratory classes are presented in this section. The students appeared to be less enthusiastic about their learning from lectures. The following excerpts indicate that students are more interactive in workshops and laboratories than in lectures because of the POGIL-oriented learning environment.

> *Definitely not. The lecturers normally do not talk to us unless we ask a specific question. They do not answer some of the specific questions that we ask. Lecturers are more distant, if it were a tutor/facilitator or lab demonstrator, they are more willing to know*

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you but the lecturers present the lecture and leave. However, I found that lecturers are very approachable. (ICS4)

Workshops and labs are more helpful than lectures. Sometimes in the lectures, you are not really expanding on anything else. (ICS7)

The theme - workshop learning experience, is characterised by students' perceptions on the usefulness of POGIL activity worksheets, organisation and implementation of POGIL by facilitators, and their participation.

ICS9 felt that the problems presented in worksheets are relevant to the course and the activity sheets are helpful in understanding the lecture course:

Yes, some worksheets are full of equations but with this workshop today, it's very group interactive because we have to do models and try to show an organic bond. ***Workshops*** *are more interactive. I enjoy the* ***workshops****; they are helpful in consolidating my ideas (of the topics) when I go through them. (ICS9)*

ICS10 agreed that the material presented in workshops was useful and the facilitators helped them understand difficult concepts. ICS also felt that self-evaluation of prior knowledge is helpful prior to attending workshops:

I usually do the work before and confirm with what I already know, I ask the group questions which I do not understand. With the group interaction, I find it easy to undertake as everyone is sociable and easily communicating. (ICS10)

Speaking on the role of facilitators in workshops, ICS2 agreed that finding and seeking help from facilitators was easy:

*Yes definitely, we have three people (****facilitators****) in this class to talk to. They all know what they are talking about. They are all very knowledgeable. (ICS2)*

The thematic analysis of laboratory class and demonstrator learning experiences focused students' understanding of i) theory behind the experiments; ii) relationship between the data and the results; and iii) calculations required for laboratory work. ICS9, ICS1, and ICS8 expressed satisfaction on their ability to understand the relationship between data and the results. They felt that time spent on completing pre-laboratory work was helpful in various ways as outlined from the following excerpts:

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> *I think the* ***prelab sessions*** *are quite good, by doing the prelab we are introduced to the topic that's going to be talked about. (ICS9)*

> ***Pre laboratory sessions*** *help a lot. I would not know what I was doing unless I read the prelab. (ICS1)*

> *Definitely, I try to look through my lecture notes and workshop questions before attending the laboratory so that I am also contributing to the group. I found some experiments easier than others however if I run into a problem I would ask the* ***demonstrator****. (ICS8)*

ICS6 felt that finding demonstrators was easy to discuss and seeking help on problems.

> *Yes definitely, it's one of those things when you have to seek help on your own initiative. The demonstrator had explained four or five times over the course of the unit but generally before the experiment to explain the hazards but if multiple students had the same question, the* ***demonstrator*** *would explain to the whole class. (ICS6)*

Discussion and conclusions

Consistent with the implied theoretical framework, the study explored students' behavioural intention in modified POGIL classrooms (that is, learning of chemistry utilising structured POGIL worksheets and small-group discussions facilitated by chemistry faculty members) by investigating students' beliefs about chemistry (attitudes), perceived control over learning of chemistry (self-efficacy), and normative beliefs (learning experiences). This study further contributes to the growing literature on affective characteristics in POGIL classes. It expands the literature on 1) evidence-based effective curriculum innovations striving to promote positive attitudes toward the study of chemistry and improvement of disciplinary knowledge; and 2) confirmatory testing of reliability of ASCI v2, and CAEQ.

Reliability of instruments:

As an outcome of the first research question, the study reported evidence in support of the robustness of ASCI v2 and CAEQ in the form of acceptable Cronbach's alpha values, indicating not only reliability of the data obtained from these instruments, but also internal consistency of their subscales. The results of Cronbach's alpha reliability obtained in this study have generally coincided with those reported by Coll, *et al*. (2002), Dalgety and Coll (2006), and Mataka and Kowalske (2015) for CAEQ subscales, and were substantiated with a confirmatory factor analysis by Kahveci (2015) and Villafane, *et al*. (2014) for ASCI v2 subscales. Therefore, the

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psychometrics of ASCI v2 and CAEQ may find a great degree of *affective-related* applicability in POGIL classes.

Attitude toward study of chemistry:

The mean pre-test scores for intellectual accessibility and emotional satisfaction are low (3.75; 4.10) because of the heterogeneous chemistry background of students. The textual analyses of student interviews reaffirm this quantitative finding. The significant results from parametric t-tests and effect sizes, and findings from interview transcripts (see *ICS1*, *ICS2*, and *ICS*3) supported the efficacy of POGIL in terms of improvements in intellectual accessibility and emotional satisfaction. The improvement in students' feeling and thinking of chemistry as a result of their active participation in POGIL classes reflect their understanding of the relevance of conceptual chemistry and supports the view that the traditional approaches to chemistry education are less favourable to the academic needs of non-major science students (Fowler, 2012; Fan, *et al.*, 2015).

The development of positive attitude towards chemistry as evidenced from statistically significant post-test scores further supports the findings of Brandriet (2011) and Rajan and Marcus (2009); active engagement of students in small group POGIL discussions does improve students' attitudes. A similar positive outcome in terms of effect size was reported by Xu, *et al.* (2012) from a validation study with respect to ASCI v2 in an Australian context. Therefore, findings from this study further re-established 1) the relevance of an attitudinal scale like ASCI v2 in the student-centred chemistry pedagogical context of Australia, and 2) the positive change in students' attitude toward study of chemistry as a result of participation in POGIL classes.

Self-efficacy:

The study observed improvement in students' belief of their perceived control of learning of chemistry (self-efficacy construct). A semester-long participation in POGIL workshops by students has positively influenced their efficacy levels in understanding chemistry content and applying the gained knowledge. These results were in line with those reported in the literature (Villafane, *et al.*, 2014; De Gale and Boisselle, 2015; Şen, *et al.*, 2015; Qureshi, *et al.*, 2016).

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It is interesting that Mataka and Kowalske (2015) used CAEQ in problem-based learning (PBL) chemistry classes and demonstrated significant increase in mean scores for the self-efficacy subscale, a finding echoed in the presented study. The enhancement of students' self-efficacy beliefs in POGIL classes may have emerged from 1) the synchronisation of cognitive characteristics from structured learning materials, 2) strategic facilitation by faculty, and 3) self-managed small group interactive learning. These kinds of efforts were considered conducive for providing authentic mastery experiences to students in other research contexts (Lopez, *et al.*, 2013; Zeldin, *et al.*, 2008).

Learning experiences:

One of the objectives (*viz.* applicability of the instrument in various contexts) that Dalgety, *et al.* (2003) have underlined for the development and validation of CAEQ served as a helpful measure to explore and understand the impact of *alternative* pedagogical interventions like POGIL in chemistry courses. The rigor and applicability of CAEQ was evident in the form of statistically significant results for all subscales – LLE, WLE, LCLE, and DLLE, when used in POGIL classes over one semester. Consistent achievement of statistically significant results for the measures of WLE, LCLE, and DLLE indicate not only the POGIL environment offered by the faculty members, but also students' improvement in affective characteristics. Students appeared to have developed positive feelings about their ability to perform in chemistry classes.

The qualitative data pertaining to classroom experiences confirm the quantitative findings on the impact of POGIL in chemistry classes. The structured organisation of workshops and laboratory classes offered students more opportunities for interaction with faculty members and other students as compared to lectures. More importantly, the students' improved perception of their control over learning from workshops and laboratory classes helped prepare them for further education in chemistry and/or STEM courses, meeting a goal of the Australian government to increase students' participation in these courses (Office of the Chief Scientist, 2013). In other words, the student-centred instructional strategies may help in enhancing students' perceived control of learning, eventually resulting in improved cognitive achievement in the case of students *ICS4*, *ICS5*, and *ICS9*.

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Findings from this study support the view in the literature (Dalgety and Coll, 2004, 2006; Chase, *et al.*, 2013) that student-centred pedagogical practices that are alternative to traditional classroom discourses provide positive affective experiences to students who are new to the disciplinary area or who undertake courses with limited discipline-related prior knowledge. The trustworthiness of the impact of POGIL in this study may be evident from the reconfirmation of results with two student cohorts enrolled in different semesters. The only variable that distinguished these two cohorts is the size of the sample. Interestingly, the larger sample resulted in a smaller effect size, whereas, the smaller sample led to a larger effect size (WLE in Table 5); *t*-tests were statistically significant. At the outset, the study reconfirms the enhancement of students' learning related attitudes, values, beliefs, and skills, following the feedback obtained from two cohorts. In contrast to other studies previously discussed, CAEQ and ASCI v2 were collectively used in their native *factorial* format to provide a snapshot of affective characteristics in POGIL classes.

Limitations

The study had relied on inferential statistics like t-tests; sometimes a small effect may yield a statistically significant result or vice versa. The study did not take into consideration factors (e.g. gender, age, Nationality, etc.) other than learners' chemistry experience/background that may have an impact on affective characteristics. Information on inter-rater reliability was not included because the coding of qualitative data was performed by one of the authors and was for the purposes of identification of cases to illustrate observations from quantitative findings. Researchers, and educators interested in examining or implementing POGIL in their setting should take into account the context of the study – course content and methods of POGIL implementation.

It must be acknowledged that the implementation of the modified POGIL classroom was undertaken by the instructors with full knowledge of the intentions of the research agenda of the presented study. This may have influenced the attention of the instructors on factors that disproportionately influenced the already subjective nature of the self-reported measures utilised in this study. However, the authors have attempted to address these limitations through the

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research design and procedures and placed caution in their interpretation of the outcomes of this study.

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Appendix 1

Attitude and self-efficacy survey

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Instructions

This survey has three parts on four pages. To identify yourself please completely fill each bubble underneath each digit in your student ID. Please complete the remaining three sections of questions by completely filling the bubble ● with a blue or black ballpoint pen. Read all instructions carefully. If you make an error, cross out the unwanted response ● and completely fill the circle corresponding to your wanted response. Do not make any other stray marks on the page.

Student ID								Name	
								Family Name	Given Name(s)

0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	5
6	6	6	6	6	6	6	6
7	7	7	7	7	7	7	7
8	8	8	8	8	8	8	8
9	9	9	9	9	9	9	9

INSTRUCTIONS

- To register a response completely fill the bubble ● with a blue or black ballpoint pen.
- Completely fill each bubble underneath each digit in your student ID.
- Completely fill a single bubble corresponding to your answers and reasons given on the test.
- If you make an error, cross out the unwanted response and completely fill the circle corresponding to your wanted response.
- Do not make any other stray marks on the page

Part 1: Attitude toward chemistry

A list of opposing words appears below. Rate how well these words describe your feelings about **chemistry**. Think carefully and **try not to include** your feelings toward chemistry teachers or chemistry courses. For each line, choose a position between the two words that describes **exactly how you feel**. Mark that number here by shading a single bubble. The middle position is if you are undecided or have no feelings related to the terms on that line.

CHEMISTRY IS				middle				
easy	1	2	3	4	5	6	7	hard
complicated	1	2	3	4	5	6	7	simple
confusing	1	2	3	4	5	6	7	clear
comfortable	1	2	3	4	5	6	7	uncomfortable
				middle				
satisfying	1	2	3	4	5	6	7	frustrating
challenging	1	2	3	4	5	6	7	not challenging
pleasant	1	2	3	4	5	6	7	unpleasant
chaotic	1	2	3	4	5	6	7	organised
				middle				

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Part 2: Confidence

This part of the questionnaire investigates the confidence you have in undertaking different tasks. For example: If you do not feel very confident about talking to a scientist about chemistry then you would answer the following questions as shown:

Please indicate how confident you feel about talking to a scientist about chemistry

	Not confident			neutral			Totally confident
1 Applying a set of chemistry rules to different elements of the Periodic Table	①	②	③	④	⑤	⑥	⑦
2 Tutoring another student in a first-year chemistry course	①	②	③	④	⑤	⑥	⑦
3 Ensuring that data obtained from an experiment is accurate	①	②	③	④	⑤	⑥	⑦
4 Proposing a meaningful question that could be answered experimentally	①	②	③	④	⑤	⑥	⑦
5 Explaining something that you learnt in this chemistry course to another person	①	②	③	④	⑤	⑥	⑦
6 Choosing an appropriate formula to solve a chemistry problem	①	②	③	④	⑤	⑥	⑦
7 Knowing how to convert the data obtained in a chemistry experiment into a result	①	②	③	④	⑤	⑥	⑦
8 After reading an article about a chemistry experiment, writing a summary of the main points	①	②	③	④	⑤	⑥	⑦
9 Learning chemistry theory	①	②	③	④	⑤	⑥	⑦
10 Determining the appropriate units for a result determined using a formula	①	②	③	④	⑤	⑥	⑦
11 Writing up the experimental procedures in a laboratory report	①	②	③	④	⑤	⑥	⑦
12 After watching a television documentary dealing with some aspect of chemistry, writing a summary of its main points	①	②	③	④	⑤	⑥	⑦
13 Achieving a passing grade in later chemistry course	①	②	③	④	⑤	⑥	⑦
14 Applying theory learnt in a lecture for a laboratory experiment	①	②	③	④	⑤	⑥	⑦
15 Writing up the results section in a laboratory report	①	②	③	④	⑤	⑥	⑦
16 After listening to a public lecture regarding some chemistry topic, explaining its main ideas to another person	①	②	③	④	⑤	⑥	⑦
	Not confident			neutral			Totally confident

Part 3: Classroom experiences

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Please answer these questions about your **lecture** classes	Strongly disagree			neutral			Strongly agree
1 My lecturers were interested in my progress in chemistry	①	②	③	④	⑤	⑥	⑦
2 The concepts introduced in the lecture material were explained clearly	①	②	③	④	⑤	⑥	⑦
3 My lecturers encouraged me to take further chemistry papers	①	②	③	④	⑤	⑥	⑦
4 The lecture notes were interesting	①	②	③	④	⑤	⑥	⑦
5 The chemistry lecturers have made me feel that I have the ability to continue in science	①	②	③	④	⑤	⑥	⑦
6 The lecture notes were clearly presented	①	②	③	④	⑤	⑥	⑦
7 It was easy to find a lecturer to discuss a problem with	①	②	③	④	⑤	⑥	⑦
8 The lectures were presented in an interesting manner	①	②	③	④	⑤	⑥	⑦
9 The lecturers explained the problems clearly to me	①	②	③	④	⑤	⑥	⑦

Please answer these questions about your **workshop** classes	Strongly disagree			neutral			Strongly agree
10 The workshop problems covered all parts of the course	①	②	③	④	⑤	⑥	⑦
11 The problems in the activity sheets were relevant to the course	①	②	③	④	⑤	⑥	⑦
12 My facilitators encouraged me to take further chemistry papers	①	②	③	④	⑤	⑥	⑦
13 The activity sheets helped me understand the lecture course	①	②	③	④	⑤	⑥	⑦
14 The chemistry facilitators have made me feel I have the ability to continue in science	①	②	③	④	⑤	⑥	⑦
15 The material presented in workshops was useful	①	②	③	④	⑤	⑥	⑦
16 The material covered in workshops was presented in an interesting manner	①	②	③	④	⑤	⑥	⑦
17 It was easy to find a facilitator to discuss a problem with	①	②	③	④	⑤	⑥	⑦
18 The facilitators explained problems clearly to me	①	②	③	④	⑤	⑥	⑦

Please answer these questions about your **laboratory** classes	Strongly disagree			neutral			Strongly agree
19 When writing up experiments in my laboratory book, the relationship between the data and the results was clear	①	②	③	④	⑤	⑥	⑦
20 My demonstrators were interested in my progress in chemistry	①	②	③	④	⑤	⑥	⑦

Part 3 continued on the next page

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	Strongly disagree			neutral			Strongly agree
21 The practical experiments were related to lectures	①	②	③	④	⑤	⑥	⑦
22 What is required in the write up of an experiment is clear	①	②	③	④	⑤	⑥	⑦
23 The theory behind the experiments was clearly presented	①	②	③	④	⑤	⑥	⑦
24 The purpose of the calculations required for laboratory books write up was clear	①	②	③	④	⑤	⑥	⑦
25 The chemistry demonstrators have made me feel I have the ability to continue in science	①	②	③	④	⑤	⑥	⑦
26 The laboratory manual, experimental techniques and write up were all interlinked	①	②	③	④	⑤	⑥	⑦
27 What was required in the questions when writing up the laboratory book was clear	①	②	③	④	⑤	⑥	⑦
28 It was easy to find a demonstrator to discuss a problem with	①	②	③	④	⑤	⑥	⑦
29 The experiments were interesting	①	②	③	④	⑤	⑥	⑦
30 The amount of work required when writing up the laboratory book was appropriate for the amount of the assessment	①	②	③	④	⑤	⑥	⑦
31 The demonstrators explained problems clearly to me	①	②	③	④	⑤	⑥	⑦

Thank you for participating in this survey.

Appendix 2

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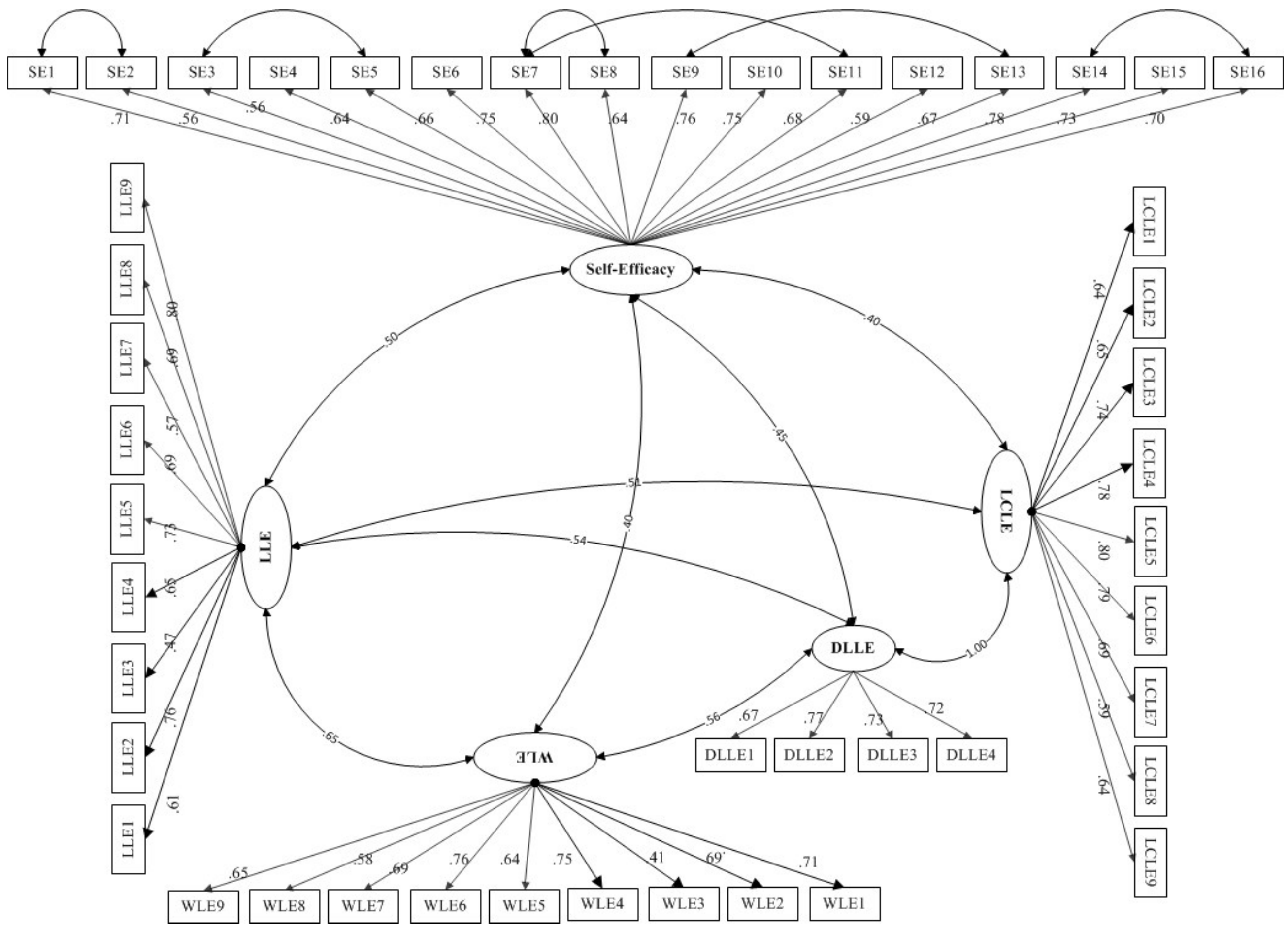
CFA: CAEQ Subscales



Structural Model: CAEQ factors

The items of the five-factor CAEQ structural model were organised as five subscales – Self-Efficacy (16 items), Lecture Learning Experience (9 items), Workshop Learning Experience (9 items), Laboratory Class Learning Experience (9 items), and Demonstrator Learning Experience (4 items).

The overall fitness of the five-factor CAEQ structural model to the collected data was assessed against alternate fit indices such as chi-square ($\chi 2$), Comparative Fit Index, and the Standardized Root Mean Square Residual (SRMR).

The criteria of CFI value greater than 0.95 and SRMR value less than 0.05 were used to indicate a good model fit, while CFI > .9, and SRMR <.08 indicates an acceptable fit (Bentler, 1990; Hu & Bentler, 1995).

The fit indices of the model also revealed acceptable fit (CFI = .903; SRMR = .06; $\chi 2$ (987) = 2058.69, p<0.001).

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Model Fit Summary

CMIN

Model	NPAR	CMIN	DF	P	CMIN/DF
Default model	188	2054.688	987	.000	2.082
Saturated model	1175	.000	0		
Independence model	94	12103.135	1081	.000	11.196

Baseline Comparisons

Model	NFI Delta1	RFI rho1	IFI Delta2	TLI rho2	CFI
Default model	.830	.814	.904	.894	.903
Saturated model	1.000		1.000		1.000
Independence model	.000	.000	.000	.000	.000

Parsimony-Adjusted Measures

Model	PRATIO	PNFI	PCFI
Default model	.913	.758	.825
Saturated model	.000	.000	.000
Independence model	1.000	.000	.000

NCP

Model	NCP	LO 90	HI 90
Default model	1067.688	941.536	1201.570
Saturated model	.000	.000	.000
Independence model	11022.135	10671.640	11379.106

FMIN

Model	FMIN	F0	LO 90	HI 90
Default model	5.086	2.643	2.331	2.974
Saturated model	.000	.000	.000	.000
Independence model	29.958	27.283	26.415	28.166

RMSEA

Model	RMSEA	LO 90	HI 90	PCLOSE
Default model	.052	.049	.055	.179
Independence model	.159	.156	.161	.000

AIC

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Model	AIC	BCC	BIC	CAIC
Default model	2430.688	2481.385		
Saturated model	2350.000	2666.854		
Independence model	12291.135	12316.483		

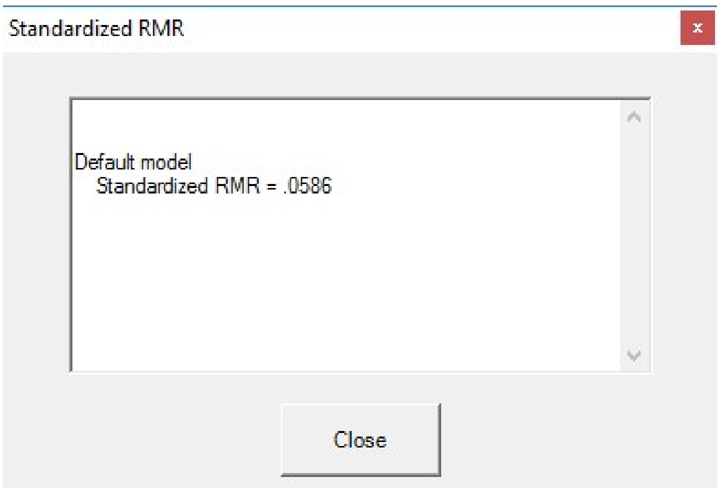
ECVI

Model	ECVI	LO 90	HI 90	MECVI
Default model	6.017	5.704	6.348	6.142
Saturated model	5.817	5.817	5.817	6.601
Independence model	30.424	29.556	31.307	30.486

HOELTER

Model	HOELTER .05	HOELTER .01
Default model	209	215
Independence model	39	40

SRMR:



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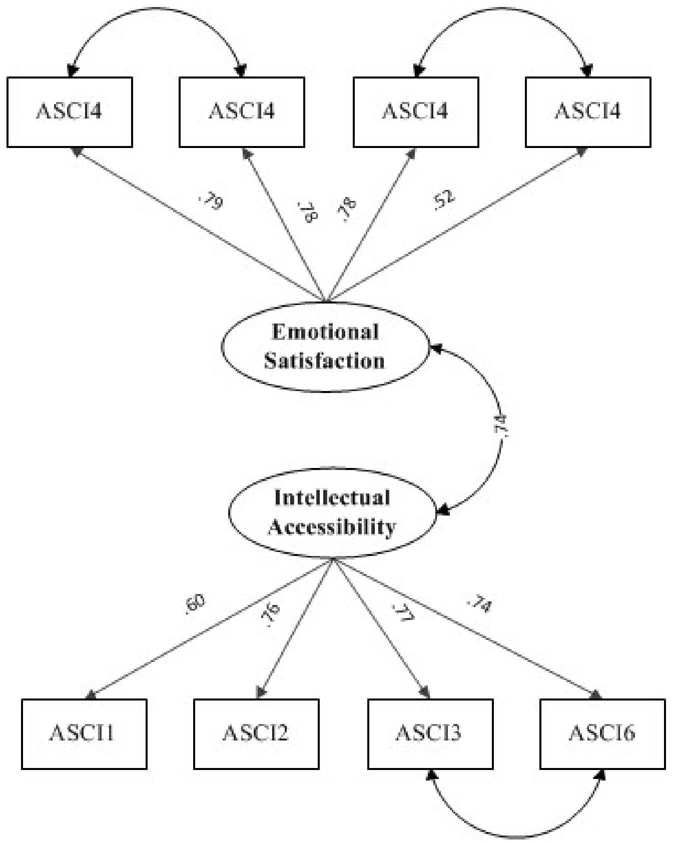
CFA: ASCIv2 Subscales



Structural Model: ASCI v2 factors

The structural model has eight items (ASCI1, ASCI2, ASCI3, ASCI4, ASCI5, ASCI6, ASCI7, and ASCI8) organised as two subscales – Emotional Satisfaction and Intellectual Accessibility.

The overall fitness of the two-factor structural model to the collected data was assessed against alternate fit indices such as chi-square ($\chi 2$), Comparative Fit Index, and the Standardized Root Mean Square Residual (SRMR).

The criteria of CFI value greater than 0.95 and SRMR value less than 0.05 were used to indicate a good model fit, while CFI > .9, and SRMR <.08 indicates an acceptable fit (Bentler, 1990; Hu & Bentler, 1995).

The fit indices of the model also revealed good model fit (CFI = .984; SRMR = .03; $\chi 2$ (11) = 26.58, p<0.005).

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Model Fit Summary

CMIN

Model	NPAR	CMIN	DF	P	CMIN/DF
Default model	33	26.575	11	.005	2.416
Saturated model	44	.000	0		
Independence model	16	1011.477	28	.000	36.124

Baseline Comparisons

Model	NFI Delta1	RFI rho1	IFI Delta2	TLI rho2	CFI
Default model	.974	.933	.984	.960	.984
Saturated model	1.000		1.000		1.000
Independence model	.000	.000	.000	.000	.000

Parsimony-Adjusted Measures

Model	PRATIO	PNFI	PCFI
Default model	.393	.383	.387
Saturated model	.000	.000	.000
Independence model	1.000	.000	.000

NCP

Model	NCP	LO 90	HI 90
Default model	15.575	4.155	34.671
Saturated model	.000	.000	.000
Independence model	983.477	883.237	1091.112

FMIN

Model	FMIN	F0	LO 90	HI 90
Default model	.091	.053	.014	.118
Saturated model	.000	.000	.000	.000
Independence model	3.452	3.357	3.014	3.724

RMSEA

Model	RMSEA	LO 90	HI 90	PCLOSE

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Model	RMSEA	LO 90	HI 90	PCLOSE
Default model	.070	.036	.104	.151
Independence model	.346	.328	.365	.000

AIC

Model	AIC	BCC	BIC	CAIC
Default model	92.575	94.666		
Saturated model	88.000	90.789		
Independence model	1043.477	1044.491		

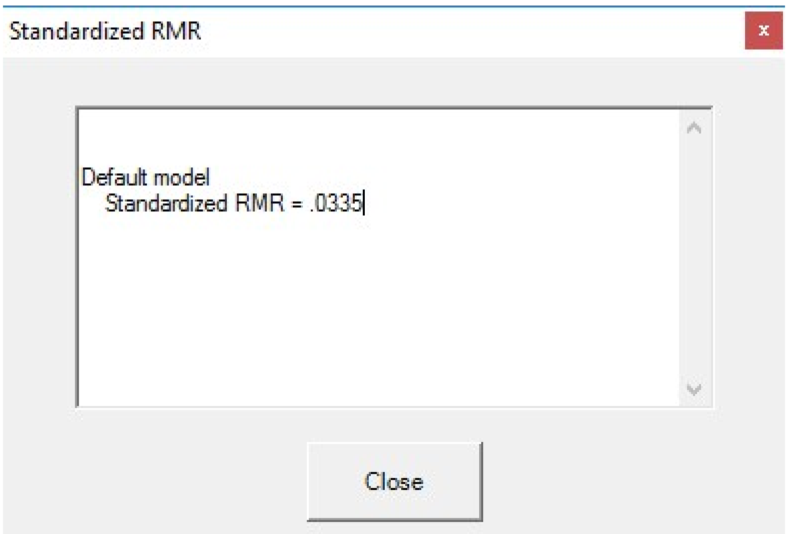
ECVI

Model	ECVI	LO 90	HI 90	MECVI
Default model	.316	.277	.381	.323
Saturated model	.300	.300	.300	.310
Independence model	3.561	3.219	3.929	3.565

HOELTER

Model	HOELTER .05	HOELTER .01
Default model	217	273
Independence model	12	14

SRMR:



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Appendix 3

Table 1: Categories of students' responses to items of ASCI v2 - Sem2, 2015, (n = 67)

ASCI v2 Items	Pre Test		Post Test		Ratios of students' responses (After Post Test)		Relative change in ratios
	Category 1 (1 to 3)	Category 2 (4 to 7)	Category 1 (1 to 3)	Category 2 (4 to 7)	Category 1	Category 2	
ASCI 1	31 (46.27)	36 (53.73)	23 (34.33)	44 (65.67)	0.74	1.22	0.48
ASCI 2	32 (47.76)	35 (52.24)	30 (44.78)	37 (55.22)	0.94	1.06	0.12
ASCI 3	29 (43.28)	38 (56.72)	24 (35.82)	43 (64.18)	0.83	1.13	0.30
ASCI 4	26 (38.81)	41 (61.19)	19 (28.36)	48 (71.64)	0.73	1.17	0.44
ASCI 5	19 (28.36)	48 (71.64)	21 (31.34)	46 (68.66)	1.11	0.96	-0.15
ASCI 6	40 (59.70)	27 (40.30)	38 (56.72)	29 (43.28)	0.95	1.07	0.12
ASCI 7	20 (29.85)	47 (70.15)	18 (26.87)	49 (73.13)	0.90	1.04	0.14
ASCI 8	11 (16.42)	56 (83.58)	16 (23.88)	51 (76.12)	1.45	0.91	-0.54

Percentage values are shown in parentheses

As shown in Table 1, the ratio between students' pre and post-test responses for ASCI v2 items in each category was computed. For example, in case of ASCI 1, the ratio between students' pre-test responses (31) and post-test responses (23) in Category 1 was 0.74, and similarly, the ratio value for pre-test responses (36) and post-test responses (44) in Category 2 (1.22) was also estimated.

The relative change in ratio values (as shown in the last column of Table 1) reflects the momentum in students' attitudes toward the study of chemistry in POGIL classes. This appeared to be consistent with results presented in the manuscript (see Table 4).

The relative change in ratios of students' responses to all ASCI v2 items is greater except for items #5 *(chemistry is satisfying ………. Frustrating),* and #8 (*chemistry is chaotic ……… organised*).

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Table 2: Categories of students' responses to items of ASCI v2 - Sem1, 2015, (n = 213)

ASCI v2 Items	Pre Test		Post Test		Ratios of Students' Responses (after Post-Test)		Relative Change in ratios
	Category 1 (1 to 3)	Category 2 (4 to 7)	Category 1 (1 to 3)	Category 2 (4 to 7)	Category 1	Category 2	
ASCI 1	77 (36.15)	136 (63.85)	66 (30.99)	147 (69.01)	0.86	1.08	0.22
ASCI 2	60 (28.17)	153 (71.83)	58 (27.23)	155 (72.77)	0.97	1.01	0.05
ASCI 3	59 (27.70)	154 (72.30)	48 (22.54)	165 (77.46)	0.81	1.07	0.26
ASCI 4	49 (23.00)	164 (77.00)	51 (23.94)	162 (76.06)	1.04	0.99	-0.05
ASCI 5	73 (34.27)	140 (65.73)	63 (29.58)	150 (70.42)	0.86	1.07	0.21
ASCI 6	91 (42.72)	122 (57.28)	83 (38.97)	130 (61.03)	0.91	1.07	0.15
ASCI 7	47 (22.07)	166 (77.93)	49 (23.00)	164 (77.00)	1.04	0.99	-0.05
ASCI 8	35 (16.43)	178 (83.57)	28 (13.15)	185 (86.85)	0.80	1.04	0.24

Percentage values are shown in parentheses

The relative change in ratios of students' responses to all ASCI v2 items is greater except for items #4 *(chemistry is comfortable ………. uncomfortable),* and #7 (*chemistry is pleasant ……… unpleasant*).