

Longitudinal impact of process-oriented guided inquiry learning on the attitudes, self-efficacy and experiences of pre-medical chemistry students

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ABSTRACT

A follow-up study was conducted with foundation-year chemistry students who were taught in an inquiry- and role-based, small-group active learning environment in order to evaluate their attitudes, experiences and self-efficacy during pre-medical chemistry courses. The study adopted a mixed-methods research design that involved both experimental and comparison groups. Using the CAEQ (Chemistry Attitudes and Experiences Questionnaire) and the ASCI v2 (Attitude toward the Study of Chemistry Inventory), the findings of this study indicated that inquiry-based chemistry learning experience improves the students' *intellectual accessibility* and *emotional satisfaction* as well as develops their self-efficacy levels while pursuing intensive pre-medical courses in chemistry. The results of the qualitative data analyses using a course experience questionnaire indicated that the process-oriented guided inquiry learning (POGIL) experience helped the students succeed in rigorous pre-medical chemistry courses and gained some process skills required in the medical programme as listed by the AAMC (American Association of Medical Colleges).

Keywords: POGIL, active learning, chemistry education, guided inquiry learning, science education, teacher education, Qatar

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1. BACKGROUND

Process-oriented guided inquiry learning (POGIL)¹ refers to the students' acquisition of content knowledge through a guided inquiry learning for developing their process skills.² This method requires that students, with assigned roles between them, work in small groups (of three or four)³ in large lecture theatres or workshops/tutorials where the instructors will help them to actively discuss and explore the concepts using highly structured learning materials developed from a learning cycle paradigm.^{4,5} In these teaching and learning contexts, instructors act as facilitators rather than lecturers. Lectures alone are insufficient for teaching students how best to learn; therefore, it requires a different approach to delivering the curriculum content. Furthermore, there is an increased expectation that processes and other transferrable skills should be an integral part of science pedagogy⁶ so that they help students to adapt themselves to more complex concepts. Moreover, the need for student engagement expands with increasing cognitive load. This study emphasises that students must share ideas early at the foundational level in order to promote the development of process and other transferrable skills.

Originally initiated in first-year undergraduate non-major chemistry classes by Moog et al.,⁷ POGIL gained popularity across STEM (Science, Technology, Engineering and Mathematics) disciplines as an alternative pedagogical approach to traditional teaching as well as a domain for scholarly activity by chemistry educators. Consequently, the implementation of POGIL spread to organic chemistry,^{8–11} anatomy and physiology,¹² medicinal chemistry,¹³ engineering,¹⁴ environmental health¹⁵ and foreign languages.¹⁶

Theoretically, POGIL follows a constructivist model which researchers believe is based on the principle that knowledge is constructed in the mind of the learner.¹⁷ Some researchers¹⁸ have contextualised POGIL into *social constructivism*, as the learning involves role-based, small-group interactions. Philosophically, POGIL integrates 'cognitive and social processes in students' expansion of their knowledge through the process of reflecting on and sharing their own experiences and others' experiences or ideas'.¹⁹

In medical education, POGIL is often believed to be a replica of problem-based learning (PBL). In their article focusing on differentiating characteristics of active learning pedagogies in science, Eberlein et al.¹⁸ viewed POGIL as an in-class activity intended to acquire some of the characteristics of PBL. The major difference between these two group-based self-learning strategies is the conscious development of targeted learning skills by students. POGIL offers a role-based learning environment facilitated by instructors.

The key themes of most of these studies were students' cognitive and/or affective characteristics in POGIL classrooms over a short term, spanning for a semester or two. However, there is little or no evidence of long-term beneficial impacts of student-centred active learning on their attitudes, self-efficacy and experiences as they advance to undergraduate chemistry courses. The following three reasons could be attributed to the lack of opportunities for longitudinal studies involving students' attitudes, self-efficacy beliefs and experiences in college-level or undergraduate chemistry courses: (1) requirement of general chemistry as one of the core units of the first-year undergraduate curriculum in STEM disciplines; (2) less chances for non-major chemistry students enrolled in STEM disciplines to continue chemistry courses after their first-year study; and (3) non-availability of opportunities to link the characteristics of students and curricula with the POGIL criteria.

When conducted systematically, longitudinal studies offer more than just a historical perspective to researchers.²⁰ Tytler²¹ argued that most evaluations of teaching and learning interventions take place in a short term, and that there is a need for innovating pedagogical practices in order to trace their benefits. Thus, the identified positive outcomes of POGIL using subsequent cohorts may facilitate instructors to conduct POGIL classes more efficiently and confidently. Similarly, this study focused on determining the benefits of teaching former foundation-year chemistry students using the POGIL approach.

In order to measure the impact of teaching, pedagogical researchers often carry out short-term studies. Based on the results of longitudinal studies on science education research conducted from 1964 to 1986, Arzi²² inferred that in-depth, long-term studies may contribute to knowledge generation in well-defined contexts. Long-term studies on inquiry-based science instructions are very few or often confined to out-of-class science activities. For example, Gibson and Chase²³ examined the long-term impact of a two-week inquiry-based science camp over two years on the attitudes of middle school students towards science. Similarly, Chen et al.²⁴ studied the impact of a three-semester-long,

after-school, inquiry-based science intervention on students' affective perceptions of learning science. However, this study distinguishes itself from other studies reported in the literature in that it followed up several student cohorts enrolled in pre-medical chemistry courses and those who had entered the first-year medical programme spanning a three-year period.

2. WEILL CORNELL MEDICINE IN QATAR

Established in 2001 as a branch campus of Weill Cornell Medicine in New York (WCM-NY), Weill Cornell Medicine in Qatar (WCM-Q) commenced its academic programmes in 2002. WCM-Q offers an integrated programme of foundation studies, namely pre-medical and medical studies, leading to the Cornell University MD degree. Furthermore, it offers medical education in the following three stages: (1) the Foundation Program, which is mainly designed for Qatari nationals to improve their science, mathematics and English skills; (2) the pre-medical component, which is a two-year programme (referred to as Pre-med 1 and Pre-med 2) that covers mathematics, English-writing seminars and science courses; and (3) a four-year medical programme (MD), which has a unified curriculum across the two campuses of WCM-NY. The medical curriculum includes both basic and clinical sciences. The challenging and rigorous nature of this curriculum is evident from the students at both campuses of WCM-NY attaining consistently high passing rates on the USMLE (United States Medical Licensing Examination).²⁵

2.1. Foundation Program

The one-year intensive foundation programme at WCM-Q provides local students with a pathway to the six-year medical programme. The foundation curriculum, which includes English, Biology, Chemistry, Mathematics and Physics, was taught for more than two semesters.

POGIL was introduced in the foundation program in 2011 after the instructor's completion of appropriate training at inquiry based learning workshops and feeling comfortable about adopting this pedagogy. The content of the POGIL activity sheets was aligned with the pre-medical curriculum. The commitment and belief of the instructors to implementing such strategies is very important for students to 'buy into' this style of learning because they are culturally used to a didactic learning environment and may thus show resistance to new styles of learning. However, a significant feature of POGIL is its similarities to PBL in the medical programme, whose process skills are similar to those listed by the AAMC (American Association of Medical Colleges).²⁶ These pedagogies encourage students to discuss and analyse the course content as well as other learning goals. It also enhances their problem-solving skills in tutorial sessions. Recently, the pre-medical programme has introduced team-based learning (TBL) and flipped class learning. All of these inquiry-based learning approaches are similar in that students work in small groups and discuss the course content.

A chemistry faculty member, who is also one of the co-authors of this study, incorporated more inquiry-based learning following experience gained from POGIL workshops. The availability of resources for the Foundation Program in chemistry and the relevance of role-based students' group work to the cultural context of Qatar have been the main driving factors for selecting POGIL as the pedagogy implemented by the faculty member since 2011. All teaching and POGIL materials are in English in which the students are competent. However, Arabic is the first language of all students who have graduated from local government independent high schools and international schools that offer traditional didactic teaching with typically little or no student-centred learning.

Typical implementation of POGIL²⁷ was performed for the foundation chemistry class, which was the experimental group in this study. Students undertook a POGIL activity from published sources^{28,29} facilitated by a faculty member and a teaching assistant in a two or three 50-minute workshop format supported by lectures and laboratories. The students worked in groups that were randomly assigned and changed each semester. On average, there were 12 to 24 students per year group, of whom approximately 90% progressed to the pre-medical programme.

The comparison group comprised students who gained direct entry to the pre-medical programme. These students were from both local schools of Qatar and international schools in the region. They did not have similar secondary schooling practices such as inquiry-based learning to those in the experimental group. There were between 42 and 50 students (including the Foundation Program students who progressed) per year group in the pre-medical programme. This pre-medical programme adopted inquiry-based strategies, including TBL in biology and PBL in physics recitations. The control

and experimental groups shared similar experiences during their pre-medical programme, which means that these variables are poorly controlled and may therefore influence or limit the findings.

3. METHODS

3.1. Research design

This study used a mixed-methods research design³⁰ that included both experimental and comparison groups. The following research questions guided this longitudinal research:

1. How does students' POGIL experience gained in foundation chemistry contribute to their study of pre-medical chemistry courses during 2015–17?
2. How do former foundation-year chemistry students perceive the benefits of POGIL experience in their pre-medical chemistry courses and/or first-year medical courses?

3.1.1. Sample

Two categories of students were admitted into the Pre-med 1 course: (1) *internal students* (referred to as the experimental group) and (2) *external students* (referred to as the comparison group). The internal students comprise those who graduated from the foundation-year programme at WCM-Q. In comparison, the external students were direct-entry high school graduates who progressed to the pre-medical programme after fulfilling all the required admission criteria. In other words, the internal students were familiar with POGIL-style learning, whereas the external students had no experience with POGIL lessons. Most of the students in the Pre-med 1 programme sequentially progressed to Pre-med 2 and the core medical programme. A follow-up study was conducted on the students enrolled in Pre-med 1 programme from foundation years 2014 to 2017. As shown in Figure 1, the experimental group refers to the students who completed the POGIL foundation chemistry course, and the comparison group refers to the direct-entry students with no POGIL experience. The details of the cohort sizes are presented in Table 1.

The former foundation-year chemistry students were interviewed to obtain their perceptions of learning chemistry and the usefulness of POGIL experience in learning the pre-medical chemistry course content. The students enrolled in the first-year medical programme (Med 1), as shown in Figure 1, were not included in quantitative data collection because chemistry was not included in the first-year medical curriculum. These qualitative data were obtained from this cohort to understand the impact of their POGIL experience on process skills and their transferability to the medical programme, especially in line with PBL.

3.1.2. Instruments

Quantitative data were collected using two assessment tools: (1) *Attitude toward the Study of Chemistry Inventory* (ASCI v2) and (2) *Chemistry Attitudes and Experiences Questionnaire* (CAEQ).

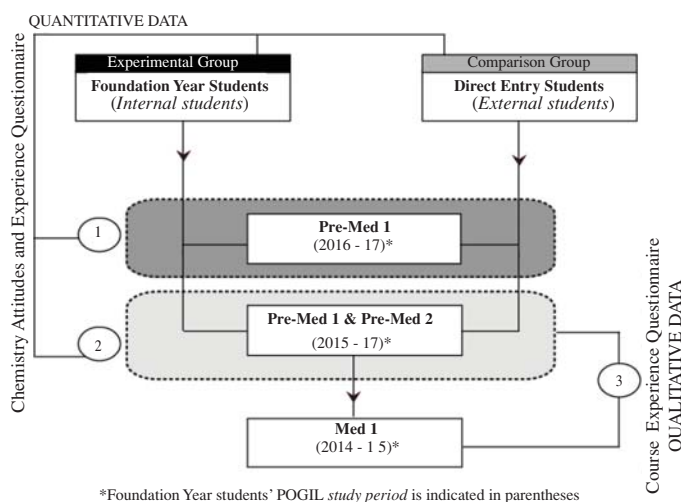


Figure 1. Data points and research design used in the longitudinal study.

Table 1. Participants of the longitudinal research study.

Data point	Cohort	Experimental group (n)	Comparison group (n)
2	Pre-med 1 and Pre-med 2	19	16
1	Pre-med 1	8	9

The ASCI v2 was developed and validated by Xu and Lewis³¹ to measure the students' attitudes towards the study of chemistry. The CAEQ was developed and validated by Coll et al.³² to measure the attitudes of first-year undergraduate chemistry students towards the study of chemistry, its self-efficacy and college-level learning experiences. Both of these instruments have 7-point Likert score items organised into different scales. On the one hand, the ASCI v2 contains two scales: intellectual accessibility and emotional satisfaction. On the other hand, the CAEQ contains five scales: self-efficacy, lecture learning experience, workshop learning experience, laboratory class learning experience and demonstrator learning experience. Some of the ASCI v2 and CAEQ items are provided in the Supplementary file: Appendix A.

Qualitative data were collected from Pre-med 1, Pre-med 2 and Med 1 students using the course experience questionnaire (CEQ), which was developed and validated by Ramsden and Entwistle³³ to explore the students' perceived teaching quality in tertiary-level courses. The qualitative component of the CEQ was used and further modified to suit the research context. The electronic versions of questionnaires designed with Qualtrics software were distributed to both the experimental and comparison groups. The students' attitudes, perceptions and experiences of learning chemistry and the influence of POGIL experience on pre-medical chemistry learning during 2015–17 were investigated by one-way multivariate analysis of variance (MANOVA). Student groups (internal and external) and year levels (2015 and 2016) were considered as independent categorical variables, and the subscales of the ASCI v2 and CAEQ were chosen as dependent variables. A preliminary assumption test was conducted to verify the normality, linearity, univariate and multivariate outliers, homogeneity of variance–covariance matrices and multicollinearity, with no serious violations indicated. The qualitative data were thematically analysed using QSR NVivo version 11.

4. RESULTS

4.1. Quantitative results

To address the two aforementioned research questions, we first calculated Cronbach's alpha values for the ASCI v2 and CAEQ subscales to assess the reliability of the data obtained from these survey instruments. Table 2 presents the values of internal consistency reliability of the survey instruments and the reliability of data used in this study.

To answer the first research question, the students' responses to the ASCI v2 and CAEQ were analysed. The quantitative data of the experimental and comparison groups in the Pre-med 1 and Pre-med 2 programmes during 2015–17 were analysed, the results of which are summarised in Tables 2 and 3. Descriptive statistics for the ASCI v2 and CAEQ subscales obtained from the 2015 and 2016 cohorts are presented in Table 2. The students' perception towards attitudes, efficacy and experiences from the experimental and comparison groups were found to be almost consistent in 2015 and 2016 except for intellectual accessibility and lecture learning experience. Furthermore, the presence or absence of a statistically significant interaction between the student groups and the year of study (2015–16/2016–17) was used to determine the differences or similarities between the internal and external students in terms of their attitudes, efficacy and experiences of learning pre-medical chemistry courses. The results of two-way MANOVA are presented in Table 3. Both the *F* value and the partial eta squared (η^2) value (representing the amount of variance accounted for) are provided for each dependent variable.

As indicated in Table 3, there were no significant mean differences in the subscales of the ASCI v2 and CAEQ between the *internal* (experimental) and *external* (comparison) groups except for *intellectual accessibility* and *lecture learning experience*. The *intellectual accessibility* subscale of the ASCI v2 measures the students' perceived levels of difficulty in chemistry. The *intellectual accessibility* of the former foundation-year students who had POGIL experience was statistically significantly higher than that of the non-POGIL direct-entry students. This shows that POGIL experience is beneficial for

Table 2. Descriptive statistics for the subscales of the ASCI v2 and CAEQ.

ASCI/CAEQ subscale	2015						2016					
	Experimental (n = 19)			Comparison (n = 16)			Experimental (n = 8)			Comparison (n = 9)		
	Mean	Std. Dev.	Cronbach's alpha	Mean	Std. Dev.	Cronbach's alpha	Mean	Std. Dev.	Cronbach's alpha	Mean	Std. Dev.	Cronbach's alpha
Intellectual accessibility (4 items)	4.76	0.86	0.85	3.42	0.85	0.67	4.75	0.35	0.85	3.50	1.53	0.85
Emotional satisfaction (4 items)	4.61	0.90	1.24	4.54	1.24	0.85	5.63	0.44	0.85	4.47	1.38	0.81
Self-efficacy (16 items)	5.57	0.56	0.96	5.26	0.96	0.93	5.28	1.36	0.93	5.45	0.63	0.82
Lecture learning exp. (9 items)	5.11	0.94	0.87	6.09	0.87	0.94	5.57	1.03	0.94	6.26	0.73	0.87
Workshop learning exp. (9 items)	5.40	0.87	0.61	5.46	0.61	0.65	5.21	1.53	0.65	5.49	0.71	0.73
Laboratory learning exp. (9 items)	5.64	0.77	0.90	5.63	0.90	0.88	5.76	1.01	0.88	5.62	0.79	0.88
Demonstrator learning exp. (4 items)	5.51	0.84	1.13	5.21	1.13	0.86	5.32	1.57	0.86	4.92	1.56	0.88

Table 3. Two-way MANOVA for group and year differences in each subscale of the ASCI v2 and CAEQ.

Scale	Group		Year		Group × year interaction	
	F	Eta ²	F	Eta ²	F	Eta ²
Intellectual accessibility	9.72*	0.17	1.64	0.03	1.07	0.02
Emotional satisfaction	2.21	0.04	3.24	0.06	4.08	0.08
Self-efficacy	0.01	0.00	0.00	0.00	0.58	0.01
Lecture learning experience	9.92*	0.17	1.45	0.03	0.31	0.00
Workshop learning experience	0.77	0.02	0.00	0.00	0.02	0.00
Laboratory learning experience	0.09	0.00	0.05	0.00	0.07	0.00
Demonstrator learning experience	1.02	0.02	0.47	0.01	0.02	0.00

* $p < 0.05$

improving the former foundation-year students' intellectual attitudes towards the study of pre-medical chemistry courses.

As indicated in Tables 2 and 3, there was a significant difference in the mean scores for the *lecture learning experience* subscale of the CAEQ between the two groups, with the comparison group preferring lectures in pre-medical courses compared with the experimental group. However, among the pre-medical cohorts of 2016–17, there was no statistically significant difference in the mean scores of the CAEQ between the experimental and comparison groups.

Similarly, there were no significant differences in the mean scores for the CAEQ subscales between the experimental and comparison groups. This indicates that POGIL improved the attitudes towards the study of chemistry and the experiences of the foundation-year students as well as those of the external students whose learning was primarily based on lectures.

The longitudinal impact of the internal students' POGIL experience was further investigated by observing the interaction effects between the group and the year using a two-way MANOVA. The group × year-level interaction was examined to determine the differences between the internal and external students during 2015–17 in terms of their attitudes, efficacy levels and experiences of learning pre-medical chemistry courses. As indicated in Table 3, the group × year interaction was not statistically significant for all the subscales. In addition, the combined dependent variables ($F(7, 43) = 1.16$ ($p = 0.347$), Wilk's lambda = 0.82 and eta² = 0.16) also yielded a non-significant result. Therefore, the non-significant MANOVA results for the ASCI v2 and CAEQ subscales indicate that the internal students were similar to their peers in the external group in terms of attitudes, self-efficacy levels and experiences of learning pre-medical chemistry courses. In other words, the foundation-year chemistry students' participation in POGIL lessons may have helped them to continue their positive attitudes towards learning pre-medical chemistry courses.

The impact of the students' POGIL experience of their pre-medical chemistry learning was further evidenced from the eta² values, as indicated in Table 3. Based on these values, the group-level differences in intellectual accessibility (0.17) and lecture learning experience (0.17) revealed an important aspect, that is, a 17% variance in the intellectual accessibility and lecture learning experience of the internal students. However, for the group × year interaction, there was a remarkably small effect for the ASCI v2 subscales.

4.2. Qualitative results

To answer the second research question, the students' responses to the open-ended items of the CEQ were coded and categorised as follows: (1) POGIL style in other subjects; (2) conceptual understanding in other pre-medical courses including pre-medical chemistry; (3) development of information processing skills; (4) gaining confidence and (5) implementation of POGIL.

4.2.1. POGIL style in other subjects

This category was used to identify pre-medical disciplinary experiences where small-group student-centred learning existed, and to determine whether the experimental group's POGIL experience was helpful in these courses. The Pre-med 1, Pre-med 2 and Med 1 students reported that team-based, small-group interactive approaches were followed in biological science and organic chemistry classes. For example:

Biology. Team-based learning. I was better at working with a team (PM1_1); First-Year Biology. It helped me develop study habits. (PM1_4)

In the following excerpt, PM2_4 recognises the practice of role-based team interaction skills developed from foundation-year chemistry POGIL classes during the pre-medical biology course:

In Biology lab, for example, where we often did work and analysis in groups. POGIL has prepared me well to be able to act as a leader, helper, writer or any kind of group role that my group needs.

The Med 1 students reported that small-group learning was followed in pre-medical organic chemistry classes where the students practiced their problem-solving skills that they had developed from their foundation chemistry courses. For example:

During organic chemistry recitation, I worked with group solving organic chemistry questions, which I found very similar to chemistry POGIL sessions. (Med 1_4)

The above-listed excerpts indicate that students continued to practice and appreciate the skills gained from the foundation-year chemistry POGIL classes during their pre-medical courses.

4.2.2. Conceptual understanding in other pre-medical courses including pre-medical chemistry

The students' responses to the open-ended item of the CEQ were categorised to determine the usefulness of POGIL experience in understanding concepts in pre-medical courses.

The students reported that the skills gained from cooperative small-group active discussion and peer interaction in foundation-year chemistry classes were helpful in understanding the concepts in pre-medical courses. For example:

Yeah, sometimes students explain things in a way I can better understand and remember (PM1_1); Yes, because small groups allow each individual to talk more (PM2_1); Yes, because sharing thoughts/ideas with other members of group facilitate the learning experience and emphasized understanding certain concepts (Med1_1); Yes, it helped me a lot, because the smaller the number, the more effort is going to be put through each individual trying to solve a case or a question which amplifies our learning experience. (Med 1_4)

In response to the usefulness of POGIL experience in pre-medical chemistry courses, the students reported that they could retain and apply the desired conceptual knowledge of chemistry in new learning contexts:

When we try hard to learn something, we hardly forget about it. This is how POGIL helped us (PM2_1);

[POGIL] helped me tackle problems that are not straightforward. This is because I learned the reasoning that chemistry fundamentals are behind (PM2_4);

4.2.3. Development of information processing skills

The students' development of information processing skills was considered to be one of the characteristic features of POGIL interactions. This category was used to explore how students from the experimental group in their pre-medical and medical courses applied their information processing skills to succeed further academically:

Discussing the information and making decisions based on that (PM1_1);

I developed my logical thinking habit in a sense that I learned to be logical in my way through questions (PM1_4);

All skills above were developed while doing group activities because they are all involved to make successful progress for each of us as students. (Med1_4)

The above excerpts obtained from former foundation-year students indicate that the development and application of their information processing skills was a continually evolving process initiated from the POGIL class environment.

4.2.4. Gaining confidence

This category stemmed from the coding of the students' responses from the experimental group to the usefulness of small-group, in-class activities in improving their confidence in current pre-medical courses.

The students reported that they felt comfortable and had gained a sense of *can do* attitude. For example:

It made me feel like I can understand chemistry independently (PM1_1);

I get to be more comfortable in explaining ideas that I understand to group members (PM1_3);

We have to share ideas with our group team, having to do that to deliver an idea improves one's confidence (PM1_4);

Very much, especially when it helped me realize that I am able to explain concepts some of my peers have trouble in (PM2_4);

Because it improves social skills and allows you to put yourself out and share thoughts (Med1_1);

Presenting your ideas and answers that you are not sure of . . . helps in making you more of a confident person (Med1_4);

I gained confidence as whenever I used to share my idea and my way of thinking and it turns out to be right, I gained confidence in solving other questions by myself. I would also help other students because I was confident of myself (Med1_2).

From the above responses, it is evident that the students' active interaction in small groups, their content-specific peer discussion and reconciliation of ideas/information could have led to the development of confidence in pre-medical courses.

4.2.5. Implementation of POGIL

This category was used to identify the students' perceptions about the implementation of POGIL in their foundation-year chemistry classes and its impact on the development of essential study skills required for further study in pre-medical chemistry. It also included the comments about this implementation from pre-medical faculty members. The following excerpts from the students in the experimental group indicate that the initial orientation offered by the instructor during POGIL instructions was helpful in the development and use of students' affective characteristics beyond foundation chemistry:

In the first class, the instructor explained to us how the POGIL program works, and how it is going to help us develop skills and knowledge. The instructor explained how team work with switched groups would make us become better adapted team members. Moreover, the instructor wanted each and every one of us to switch roles on our groups regularly. This switching between roles helped us to master every role in a group setting. (Med1_5)

Indeed, after the year of foundation level chemistry we had I assure you that we were not the same again. I remember how the shy people in our class have developed confidence that would encourage them to present in other classes and be more socially active. As for me, I learned that helping people is the way to success; every concept I explained to my group members is the same concept that is still in my mind. Another benefit of the instructor's classes, I miss as a medical student, is the amount of fun that we had. (Med1_6)

The following excerpt is a feedback from a pre-medical faculty about the instructor:

I was introduced to inquiry-based teaching methodologies in the 1990s; I was a skeptic. But, seeing the strong foundational underpinnings in chemical concepts that her former students possess have changed my attitude toward POGIL. In addition, POGIL has imparted to her students a strong sense of personal responsibility in learning. Students leave her class knowing how to constructively contribute to a team. They're better students across the academic spectrum.

Perhaps even more important is her willingness to coax her Foundation Chemistry students out of their comfort zone in order to become self-reliant, independent learners.

5. DISCUSSION

The present study highlighted the long-term impact of POGIL on students' attitudes towards the study of chemistry and their experiences of learning pre-medical chemistry. Only a few longitudinal studies²² have focused on students' affective characteristics³⁴ in science education, and efforts have been made to identify similar studies from the literature in order to compare the results.

Since the research has emphasised on the usefulness of POGIL experienced by the internal students upon entering pre-medical education, a follow-up study was conducted on the academic progress of pre-medical cohorts over two years to determine whether the experimental group is *on a par* with the comparison group in pre-medical years with respect to their learning experience in chemistry. More importantly, the students from the experimental group continued to demonstrate *intellectual accessibility* and *emotional satisfaction* in their pre-medical years. In their longitudinal study based on an inquiry-based instruction, Chen et al.²⁴ reported a similar trend in students' affective perceptions of learning science. They found that student-centred and inquiry-based *hands-on* and *mind-on* activity orientation was effective in improving students' attitudes towards and interests in learning science. Another interesting trend, as evidenced from MANOVA, is that students who had experienced POGIL were less comfortable with traditional lecture methods during their later years of study. Such a positive impact of an inquiry-based instruction has been recognised when students progressed from their preparatory programme to pre-medical chemistry courses.

The learning experiences of former foundation-year chemistry students in chemistry lectures, workshops and laboratory classes during their pre-medical years were found to be consistent with those of the comparison group. Therefore, this indicates that POGIL adequately prepares the internal students for intensive and academically challenging pre-medical chemistry education. The outcomes from the qualitative data analyses reinforce the quantitative findings that students are comfortable and confident in learning pre-medical chemistry as a result of their POGIL experience gained from foundation-year chemistry classes. These findings are in agreement with a previous study conducted by Jones et al.,³⁵ who found that students' perception of learning science increased as they progressed hierarchically in the education system.

Students appreciated the development and use of higher-order thinking skills, namely critical and analytical thinking, as a result of POGIL discussions in foundation-year chemistry classes. The promotion of critical thinking and other process skills such as problem solving, team management and communication skills during POGIL interactions demonstrated that the discipline-based purposeful teaching of desired skills is appropriate to the pre-medical curriculum as an advancement of students from their foundation-year level. Barak et al.³⁶ emphasised such a goal of teaching for transferring essential capabilities among students across disciplines and domains. Furthermore, the affective characteristics developed from POGIL instructions seemed to align with core competencies that were identified as essential for students by medical education providers.²⁶ Referring to the contemporary medical education and the use of innovative instructional approaches, Gregory et al.³⁷ described the need for developing key competencies in students in their *early* medical education programmes.

As pointed out by Lee and Anderson,³⁸ factors such as student engagement, achievement and teachers' commitment significantly influence the academic success of students. In this study, the perceptions of students about the instructor's implementation of POGIL reveal not only the suitability of the POGIL learning environment in the foundation-year chemistry course for actively engaging students but also the instructor's commitment to achieving this.

6. CONCLUSIONS

The results of this study indicate that POGIL has a long-term impact on the attitudes, self-efficacy and learning experiences of chemistry students. With a greater dependence on the beneficial quality of affective characteristics gained from POGIL interactions in foundation-year chemistry classes, pre-medical students continue to build their academic interest in advanced chemistry classes.

The findings of this study are based on a small sample size, and there was no control over students' *attrition* from participation in the longitudinal study. Therefore, the generalizability of these findings may be limited. Despite these limitations, the findings of this study provide additional evidence on the long-term benefits of POGIL in pre-medical education in Qatar.

Competing interests

There are no competing interests.

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Appendix 1

Attitude and self-efficacy survey

INSTRUCTIONS

This survey has three parts on four pages. 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.

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	<input type="radio"/> 1 <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 <input type="radio"/> 6 <input type="radio"/> 7		hard
complicated	<input type="radio"/> 1 <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 <input type="radio"/> 6 <input type="radio"/> 7		simple
confusing	<input type="radio"/> 1 <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 <input type="radio"/> 6 <input type="radio"/> 7		clear
comfortable	<input type="radio"/> 1 <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 <input type="radio"/> 6 <input type="radio"/> 7		uncomfortable
		middle	
satisfying	<input type="radio"/> 1 <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 <input type="radio"/> 6 <input type="radio"/> 7		frustrating
challenging	<input type="radio"/> 1 <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 <input type="radio"/> 6 <input type="radio"/> 7		not challenging
pleasant	<input type="radio"/> 1 <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 <input type="radio"/> 6 <input type="radio"/> 7		unpleasant
chaotic	<input type="radio"/> 1 <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 <input type="radio"/> 6 <input type="radio"/> 7		organised
		middle	

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)

PART 3: CLASSROOM EXPERIENCES

Please answer these questions about your **laboratory** 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)

	Strongly disagree	neutral	Strongly agree
Please answer these questions about your workshop classes			
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			
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)
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.