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Process Oriented Guided Inquiry Learning: Empirical evidence from student outcomes addressing the quality of instruction in chemistry

The quality of instruction

For many decades, science educators and science teachers have been concerned about the quality of instruction and instructional resources to enhance the outcomes of learning (Bodner, 1992; Cooper, 2010; Day & Houk, 1970). A consequence of concerns about the Space Race and the launch of Sputnik, in the late 1950s and early 1960, led to the development of new textbooks, laboratory manuals and related support material for teachers at the upper secondary level such a Chem Study and PSSC Physics in the USA (Rutherford, 1997). In England, the Nuffield textbooks, teachers' guides and laboratory equipment were produced for secondary school students aged 11-15 years based on concerns about out-of-date science content, especially physics, and the need for better science teaching to improve the quality of British industry (Stevens, 1978). Since these developments 50-60 years ago, there have been curriculum changes in many countries in attempts to improve the quality of instruction and hence improve students' learning outcomes. This activity has accelerated since the implementation of the TIMSS and PISA and the inevitable international comparisons. However, to demonstrate the relationship between the use of instructional materials and outcomes such as student achievement is not a simple issue and as demonstrated in physics classrooms by Fischer, Labudde, Neumann, and Viiri (2014) a much deeper analysis is needed than has been the case to now.

Overall research about the quality of instruction recommends that student learning outcomes can be optimised by (a) organising and presenting the learning task(s) to enable students to learn as efficiently as possible and (b) teachers' instructional behaviour should include cues, reinforcement, feedback and corrections (Kaendler, Wiedmann, Rummel, & Spada, 2015; Webb, 2008).

POGIL and the design of instruction

We argue that the features of Process Oriented Guided Inquiry Learning - POGIL are a good example of quality instructional design. POGIL is informed by social constructivist theory (Vygotsky, 1978) which outlines the role of social interaction in cognitive development. POGIL practitioners such as Cole et al. (2012) view that knowledge is constructed as a result of the learners' social interactions that include sharing, comparing and debating. In these small self-managed groups of three to four students, roles are assigned as manager, recorder, presenter and reflector (Straumanis, 2010). Philosophically, POGIL connects the nature of learning process and expected outcomes, is student-centered focussing on small group learning and the simultaneous development of content knowledge and process skills. Furthermore, the POGIL workshops and published materials provide a foundation to enable instructors to more confidently engage as a facilitator, changing their teaching practices from traditional lecture to more active student engagement. The activities are designed based on a highly structured learning cycle paradigm (Karplus & Butts, 1977) and contain critical thinking questions that help students develop information processing skills besides disciplinary content knowledge as shown in Figure 1.

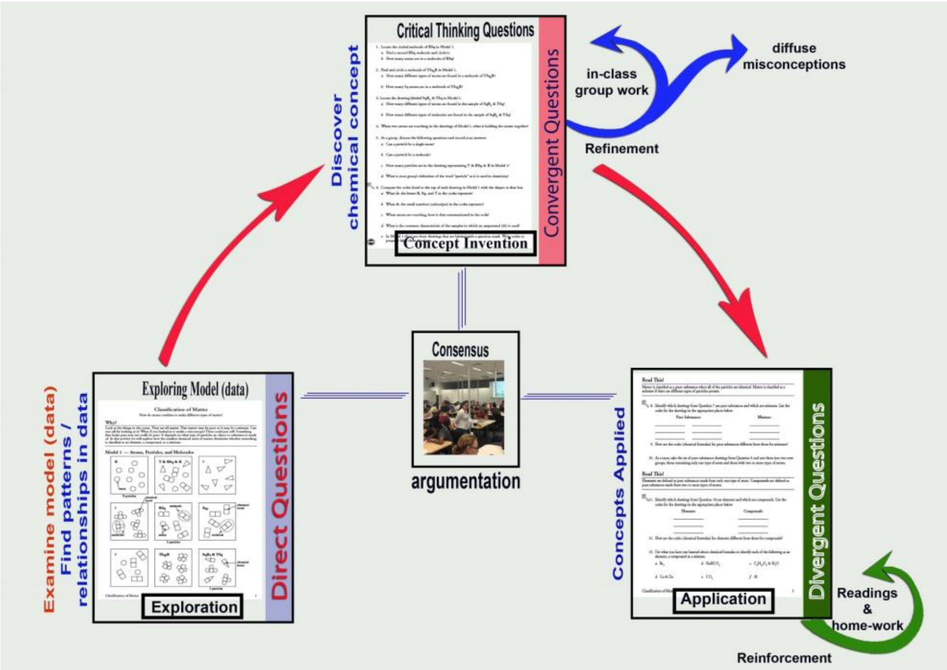

Figure 1: Introduction to Process Oriented Guided Inquiry Learning

Previous research using POGIL

Originally initiated in first year undergraduate non-major chemistry classes by Moog et al. (2009); POGIL gained familiarity across STEM disciplines in terms of an alternative pedagogical approach to traditional teaching and also as a domain for scholarly activity by chemistry educators. Consequently, the implementation of POGIL spread to organic chemistry (Bailey, Minderhout, & Loertscher, 2012; medicinal chemistry (Brown, 2010); as well as other disciplines. Numerous studies have reported the pedagogical implications of POGIL on students' academic achievement (Straumanis & Simons, 2008), conceptual understanding (Minderhout & Loertscher, 2007), and their attitudes and science learning experience in post-secondary education settings (Vishnumolakala, Southam, Treagust, Mocerino, & Qureshi, 2017).

POGIL in the context of educational Reforms

In recent years chemistry educators in Australian universities and institutes in Qatar have changed the curriculum, particularly in first year chemistry from lecture emphasis to laboratory emphasis with an increased use of POGIL adapted teaching. The intention behind such a paradigm shift was to integrate industry-oriented transferable skills and students' personal attributes with disciplinary skills and knowledge. In order to provide increased education opportunities for high school graduates, the government of Qatar created Education City that includes several campuses from top international universities from the USA and Canada. One of these universities is Cornell University which set up a Medical School – Weill Cornell Medicine - in Qatar. To bridge high school graduates to into the medical degree, a Foundation Chemistry course is delivered utilising POGIL instructional approach over two semesters. POGIL workshops (each 1-hour duration) are held three times a week and, sometimes, complementary lectures are embedded into POGIL sessions to further assist students in understanding the concepts. The students' laboratory work is also structured according to the content covered in POGIL classes.

With similar interests in teaching POGIL in undergraduate classes, the researchers at Curtin and Weill Cornell Medicine in Qatar (see names in the Acknowledgement) were successful in obtaining research funding from the Qatar National Research Fund. The three published studies briefly discussed here are based on these collaborations.

Study # 1 – Studying the affective domain in modified POGIL undergraduate chemistry classes (Vishnumolakala, Southam, Treagust, Mocerino & Qureshi, 2017).
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 Australian undergraduate non-major chemistry students from two cohorts in a modified Process-Oriented Guided Inquiry Learning (POGIL) classes.

The research questions that guided this research were concerned with instrument reliability, students' attitudes, levels of efficacy and learning experiences before and after the introductory POGIL-intervention chemistry course. Attitude toward the Study of Chemistry (ASCI) (Xu, Villafanea, & Lewis, 2013) and Chemistry Attitudes and Experiences Questionnaire (CAEQ) (Dalgety, Coll, & Jones, 2003) were administered to understand and gauge students' affective outcomes before and after he semester's POGIL-oriented teaching. The ASCI measures two subscales of Intellectual Accessibility and Emotional Satisfaction on a semantic differential scales such as Chemistry is: *Easy ……. Difficult*. The CAEQ measures five subscales including self-efficacy, Lecture Learning Experience, and Workshop Learning Experience on Likert scales.

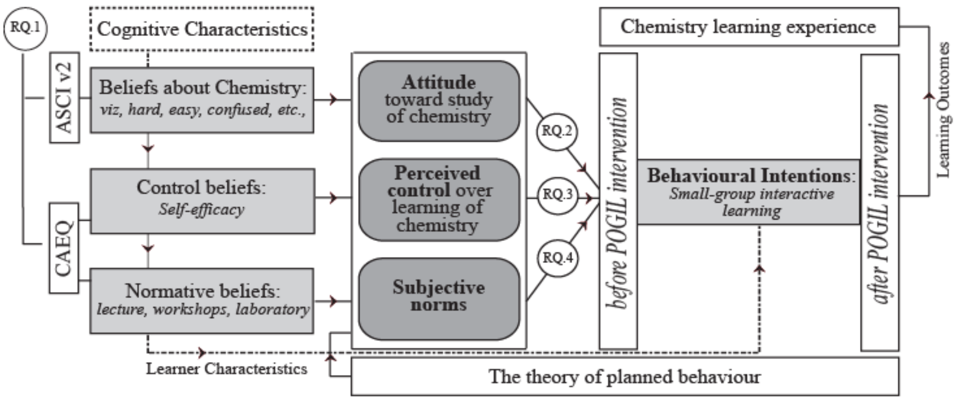

Figure 2: Theoretical framework and research design for Study #1

The instruments were reliable with all subscales having Cronbach alpha values over .70. Differences in attitudes toward the study of chemistry showed highly statistically significant difference between pre and post-tests ($p < 0.0001$) and high effect sizes (Cohen's d = .47 and .33). The post-test mean scores for all items of subscales of CAEQ on students' experience in lectures, workshops and laboratories 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.

In brief, this study showed that student-centred pedagogical practices that are alternative to traditional classroom discourses can provide positive affective experiences to students who are new to the disciplinary area or who undertake courses with limited discipline-related prior knowledge.

Study #2: Qatari Chemistry Foundation students' achievement, perceived learning gains and self-efficacy (Qureshi, Vishnumolakala, Southam, & Treagust, 2016)
In this case study, we present the impact of pedagogic reform in a higher education setting in Qatar. POGIL fits well with Qatar's educational reforms that focused on research-based pedagogies that involve inquiry learning. The purpose of this study was to explore the impact of inquiry-based learning in a foundation chemistry course at Weill-Cornell College over two semesters (Fall and Spring). The study utilized quantitative data obtained from normalized content tests published by the American Chemical Society and the CAEQ self-efficacy scale and a Learning Gains questionnaire. Qualitative data from open-ended student questionnaires were analyzed to cross-validate findings from the study.

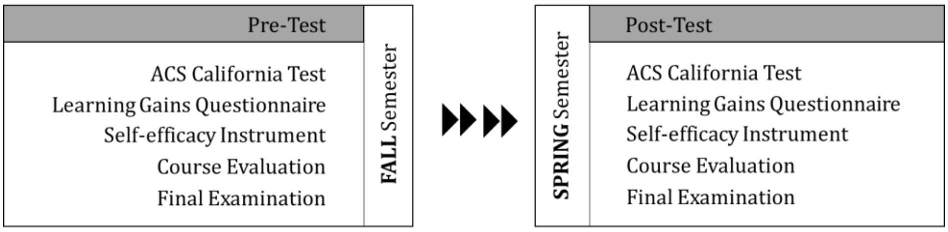

Figure 3: Research design and instruments used in Study #2

Positive effects of POGIL during fall (semester 1) and spring (semester 2) semesters were evidenced by a) improved mean scores and medium to large effect sizes for content test results, perceived learning gains, and self-efficacy levels, and b) a positive correlation between the measures of perceived learning gains and self-efficacy. Students self-reported increased self-efficacy, interest, and better understanding of concepts using the POGIL method. Comparing fall and spring semesters, student reluctance and negative perceptions of the POGIL approach gradually diminished. Students were able to adapt easily to POGIL – a method of teaching that they had not experienced before but which was compatible with the high context culture in which they live.

In summary, POGIL was able to make positive difference in students' chemistry achievement and their perceived learning gains and self-efficacy and students were generally comfortable with POGIL instruction and their perceptions of its positive effects became more evident during the second semester of the course.

Study #3 POGIL in Qatar Grade 10 high school chemistry classes (Treagust, Qureshi, Vishnumolakala, Ojeil, Mocerino, & Southam, in review).
POGIL was implemented over two semesters in four selected Arabic independent schools involving 154 Grade 10 students and six science teachers. The mixed-methods, experimental and pre- and post-test research design measured students' perceptions of their learning using the Arabic version of the 'What is Happening in this Class? – WIHIC' (Afari, Aldridge, Fraser, & Khine, 2013) instrument which was administered to both POGIL and Non-POGIL groups before (pre-test) and after (post-test) POGIL instruction.

Over two semesters during 2016–2017, POGIL groups received instruction through Arabic translated POGIL activity worksheets written by the research team in accordance with the Grade 10 curriculum standards prescribed by the Ministry of Education (MOE) in Qatar. Non-POGIL groups were taught the same curriculum to the same standards but were not exposed to POGIL-style interactions and did not use POGIL activity worksheets.

The selection of WIHIC instrument in this study was based on its robustness, suitability to inquiry-based instruction (Wolf & Fraser, 2008) and the availability of a validated Arabic version previously used in the Gulf region (Afari et al., 2013). Each of the six teachers taught one Grade 10 class with POGIL and related materials and a Grade 10 class with the traditional instructional approach. Teachers' implementation of POGIL lessons was observed by experienced university-based POGIL practitioners and researchers. Teachers were invited to participate in the semi-structured interviews to reflect upon their experiences with the POGIL implementation. The text from classroom observations and teachers' semi-structured interviews was coded by researchers and later analysed using QSR NVivo software.

The Cronbach's alpha values for the subscales of pre- and post-test WIHIC were above the acceptable threshold of 0.70 indicating that the data collected from the students is highly reliable for making any inferences. As shown in Table 1, the post-test mean scores of WIHIC subscales for POGIL groups were higher than those from Non-POGIL groups. The effect sizes - represented as Cohen's d value (Cohen, 1988) varied for POGIL classes ranged from 0.14 (small) to 71 (large).

Table 1. Descriptive Statistics, effect size for differences between Post-test POGIL and Non-POGIL groups

WIHIC Subscale	POGIL (n = 83) Total Mean (SD)	NON-POGIL (n = 71) Total Mean (SD)	Effect Size Cohen's d
Student Cohesiveness	34.03 (4.14)	32.02 (4.76)	0.45
Teacher Support	30.50 (7.28)	29.53 (6.78)	0.14
Involvement	30.48 (5.45)	27.53 (6.03)	0.51
Cooperation	31.98 (5.28)	28.17 (5.45)	0.71
Equity	32.44 (6.27)	30.47 (7.51)	0.28
Personal Relevance	31.22 (5.72)	28.63 (5.87)	0.43
Enjoyment of Chemistry Lessons	31.09 (7.38)	26.98 (6.63)	0.59
Academic Efficiency	30.71 (6.53)	29.81 (6.98)	0.55

In brief, the results indicate that POGIL helped Grade 10 students to improve their perceptions of chemistry learning more tha the non-POGIL students. The teachers were enthusiastic about their POGIL implementation.

Summary: POGIL and the quality of instruction

This paper has described three studies using a POGIL materials and an approach for teaching and learning chemistry that have accommodated recognised quality criteria of instruction by the learning tasks being well organised and presented and instructors providing support, reinforcement and feedback.

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