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ARTICLE

Block Teaching of Chemistry Tutorial and Laboratory and the Effect on Competencies and Lesson Experience

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ABSTRACT

There is currently a lack of recent research on the advocated benefits of block teaching in higher education (HE) science, technology, engineering, and mathematics (STEM) laboratory courses. This study compares chemistry competencies in in-laboratory and post-laboratory summative assessments between traditional and block (or hybrid block) schedules. Students were from a freshman diploma course in chemical engineering at an institute of higher learning (IHL) in Singapore. In the first semester, all laboratory and tutorial lessons were blocked for three classes, and all students received the same instructional materials. In the second semester, the block schedule was converted into a hybrid block with a mix of independent and block lessons. This allowed for extended exploratory activities, while baseline learning continued for the other three traditional classes. In all subjects, there were no significant performance differences between schedules. A literature-based perception survey revealed deficits in students' thinking and affective engagement. The results were discussed in view of cursory findings from post-survey focus group discussions as input for future improvements in lesson design.

Keywords: Block teaching, chemistry, higher education, laboratory instruction, STEM.

INTRODUCTION

Hardly any STEM educator would discredit the contribution of laboratory instruction in training technical skills. Yet, the evidence to support this rhetorical argument remained flimsy. In a seminal review, Hofstein and Lunetta (1982) attempted to clarify the role of laboratory education, commenting that more needed to be done for the systematic inquiry and research into laboratory instruction efficacy. Twenty years later in 2004, the authors raised the same rhetoric, this time their perspectives enlarged by prevailing technological advances then. Hofstein and Lunetta (2004) urged STEM educators to capitalise on new research into laboratory assessment and knowledge construction theories, and on technology to "up the game". This was a call for laboratory instruction to remain relevant in the 21st century.

Fast forward another two decades to the 21st century. The persistence of Hofstein and Lunetta (1982) has spawned research and practice into areas such as inquiry-based laboratory, assessment of process skills, student and faculty perspectives of laboratory goals to summarise a few. Studies on laboratory assessment and pedagogy would not be discussed here. Rather, research in student and teacher goals (DeKorver & Towns, 2015; Domin, 2007; Galloway & Bretz, 2015; Parry, Walsh, Larsen, & Hogan, 2012; Russell & Weaver, 2008) revealed several fault lines of concern to the current study. Although Science educators think that laboratory work should groom skilled practitioners who could both think and do, learners do not necessarily subscribe to this axiom. Examples of this mismatch include learners' inability to connect laboratory work to theoretical knowledge (Russell & Weaver, 2008); a delay in making the theory-experiment connection only after the laboratory (Domin, 2007); a disengaged or "escapist mindset" to rush through the activities (DeKorver & Towns, 2015); an undue focus on using laboratory work to achieve good marks instead of learning skills (DeKorver & Towns, 2015), aptly phrased as an unintended "learning economy" by Parry *et al*. (pp.1, 2012). Therefore, unsurprisingly, laboratory work has failed to match up to expectations of meaningful learning (Galloway & Bretz, 2015).

THE SINGAPORE CONTEXT

In current times, constraints in government funding in the higher education (HE) sector challenge the value of investing in costly laboratory infrastructure (Gibbins & Perkin, 2013). At the same time, employers continue to expect institutes of higher learning (IHLs) to train skilled graduates. In Singapore, skills training has dominated the national agenda in the past four years, beginning in 2015. Under the SkillsFuture campaign, lifelong continuous learning and upskilling has created waves of curriculum change in IHLs to prepare graduates for an uncertain future workplace. Government ministries, HE providers and employers collaborated to establish a skills framework (SF) for more than 30 industry sectors (SkillsFuture.sg, n.d.). Each framework comprises details on career pathways, job descriptions, core skills (or critical work functions and key tasks), and generic skills ranging from entry to experienced job designations. Full-time and part-time certificate courses in the public HE sector offering training in these skill sets are also tagged to specific skills cluster in the framework. This would enable job-seekers and skills upgraders to find appropriate training opportunities. Focussing on the SF for the entry-level job role "laboratory technician/technologist" in the Energy and Chemicals sector, the most relevant sector and career track for this current study, it is clearly evident that the core domain skills are laboratory-centric (Skills Framework for Energy and Chemicals, n.d.)

BLOCK TEACHING IN SCIENCE: A LITERATURE REVIEW

One of the most obvious faultlines is the theory-experiment disconnect (Domin, 2007; Russell & Weaver, 2008). As science educators, our all too familiar encounter with HE laboratory curriculum is usually a package of laboratory tasks designed as a “cookbook” for expository learning. The main criticism is that with this approach, students simply rote-learn by following explicit procedures without much thought put in (Domin, 1999). As a result, they tend to focus on the wrong goals; instead of skills acquisition, they are engrossed in executing the right steps to get good marks. Another possible contributing reason to this divide is the traditional practice in IHLs of scheduling theory and practical lessons as separate, stand-alone learning experiences and spaces. The basics of cognitive science inform us that this weakens the associative relationship between theory and practical work. Indeed, educators have lamented that the space and time divide remains an unresolved issue in laboratory curriculum (Bailey, Kingsbury, Kulinowski, Paradis, & Schoonover, 2000; DiBiase & Wagner, 2002). On this basis, the research team went back to the basics to attempt to bridge theory with practical work by scheduling and integrating tutorial and laboratory activities into a common space and time, eventually leading us back to the practice of block teaching.

Block teaching, or intensive teaching began as a reform movement in secondary schools in the US from the late 1980s to the 1990s (Canady & Rettig, 1996, pp. 1- 28). The concept involves consolidating discrete lesson hours into longer teaching blocks. The advocated merits included more time for explorative and investigative activities, tighter integration of theory and hands-on work, less fragmented or patchy lesson experiences, deeper learning and more time for facilitators to build rapport with students. These claims seemed reasonably promising in addressing disengagement issues in practical courses.

Unfortunately, there is a shortage of recent research on the impact of block scheduling on student outcomes, not even in research that focusses on laboratory course outcomes and the associated student perceptions in Asian HE. Past research can be segmented into three main areas: students and staff perceptions of block teaching (Burton & Nesbit, 2002; Kucsera & Zimmaro, 2010; Veal & Flinders, 2001); characteristics of high quality block curriculum (Marshak, 1998; Queen, 2000; Scott, 2003) and a comparison of student outcomes between traditional, and block or hybrid schedules (Dexter, Tai, & Sadler, 2006; DiBiase & Wagner, 2002; Randler, Kranich, & Eisele, 2008).

On studies that compared outcomes and experiences between traditional and block or hybrid schedules, the results were ambivalent. In some cases, contrary to theoretical arguments, traditional schedules remained beneficial; or there were no distinct differences at all. In an analysis of 128 introductory college courses in biology, physics, and chemistry pooled from American universities and colleges, Dexter *et al*. (2006) analysed the effects of last high school (HS) schedule plans and experiences on first year college science performance. The results suggested that HS schedules (whether traditional or block) were weak predictors of college performance, even after controlling for confounding variables such as the last HS science or mathematics grade. More interestingly, a stronger college performance appeared to be associated with the traditional schedule. However, the difference between schedules was very small, less than a three-point deviation. Strategies such as peer tutoring, implemented even within traditional HS schedule, were also a significant predictor of college success.

DiBiase and Wagner (2002) attempted to bridge traditionally separate lectures and laboratory classes in a HE chemistry course taken by undergraduate majors. Participants’ performance and perception statistics were compared between the experimental and control sections. In the experimental group, participants met for a 3-hour block, twice weekly over two semesters. Lectures and practical lessons were scheduled back-to-back, beginning with 1.5 hours of lecture followed by 1.5 hours of experimental work. The teaching and learning activities between lectures and laboratory were matched closely. For example, laboratory tasks were intentionally aligned with the lecture concepts taught in the week, and participants get to analyse and discuss experimental data during the lecture session. The control group experienced the traditional schedules with disjointed timetables and experimental tasks. Taking into account prior differences in abilities, the authors reported a significant increase in student outcomes measured on assessment scores for the experimental group. There was also a significant difference in the perceptions of the extent of integration between theory-laboratory between the experimental and control participants, with the former indicating more favorable responses.

In another study, Randler *et al*. (2008) conducted a plant biology laboratory lesson in a traditional, spaced-out plan and under a block schedule. The block schedule was a 180-minute lesson while the traditional timetable comprised four 45-minute lessons, weekly. The same set of teaching resources and activities were planned for both schedules. Pre- and post-test evaluation of theoretical biology concepts showed that the traditional plan fared better. However, in a retention test administered seven days later, differences in schedule types disappeared.

The obvious advantage of block teaching is that it opens up more experiential learning opportunities. Very often, good quality block classes depend critically on skilful lesson delivery by the instructor, strong instructor-student rapport and thoughtful design of meaningful chunks of activities to allow “digestion” of concepts (Marshak, 1998; Queen, 2000; Scott, 2003). Therefore, instructors must master a repertoire of teaching strategies to create opportunities for continuous student engagement and learning over a prolonged lesson period. It is no longer sufficient to just employ the didactic lecture mode. Other members of the instructional team must also be committed to the process, with frequent opportunities to meet with colleagues and discuss the fine-tuning of instructional strategies (Queen, 2000). While these demands may also bring about valuable opportunities and challenges for professional development, it could also create stress and tensions in teachers (Veal & Flinders, 2001).

AIMS OF THE CURRENT STUDY

Given the relative dearth of recent studies exploring the efficacy of blocked teaching in science, mounting such a study in HE chemistry would serve both research and practice interests. The current study aims to fill this gap, with the overarching intent to examine the extent in which a traditional and a block plan of teaching chemistry content and laboratory would differentiate students' aptitudes and attitudes. Specifically, we want to investigate how

1) students' titration competence differs between a traditional, stand-alone schedule from a block or hybrid block chemistry schedule;
2) students' assessment outcomes, both in-laboratory and out-of-laboratory, differ between the two schedules;
3) students' expectations and experiences of chemistry laboratory differ between the two schedules.

METHOD

The data for this study was collected between April 2018 to March 2019, spanning two semesters with three foundation year chemistry courses in the IHL where the author taught. The study was funded by the Tertiary Education Research Fund (TRF), from the Ministry of Education (MOE), Singapore. Institutional Review Board (IRB) guidelines for educational research projects were observed and management approval was obtained.

Participants

Participants were freshmen who took the IHL's diploma course in chemical engineering, enrolled in April 2018. These students were required to read two compulsory chemistry courses in physical chemistry (PC1) and organic chemistry (OC) in the first semester. In the following semester (October 2018), the same cohort read another compulsory physical chemistry module (PC2). For this reason, the study was implemented in the chemical engineering cohort so that student outcomes and experiences under block and the traditional schedules could be collected and analysed over one academic year. Out of the six chemical engineering classes, three form classes were randomly selected by the scheduling team for blocked teaching and the other three for traditional schedules. The schedulers were not members of the research team nor were they subject instructors.

Students in all schedules were briefed about the study. Second year students who repeated the PC1 or OC modules and students admitted into the courses with special timetable planning needs were excluded for analysis purposes. Students with special timetable plan experienced disjointed scheduling. For example, they might attend a traditional-schedule tutorial, but laboratory lessons with a blocked class. This resulted in a total sample size of 145 students in the PC1 and OC modules. The block classes had 72 students, while the traditional classes had 73 students. In the PC2 semester, repeat students continued to be excluded. There were 73 students in the hybrid block schedules and 74 students in the traditional schedule, making it a total of 147 students. The sample pool for the various outcome measures (described in the section "Dependent Variables") had minor fluctuations mainly due to student dropouts and also missing data due to class absence when assessments were administered.

Schedules and learning activities

The design process of meshing the tutorial and laboratory activities was informed by Johnstone's levels chemistry competencies (Johnstone, 1982) and the learning cycle adopted by DiBiase and Wagner (2002). Johnstone's chemistry competencies are deeply entrenched in chemical education, with three levels of learning pitched at the molecular, symbolic, and macroscopic levels. The molecular realm focusses on the atomic or sub-atomic realm to explain macromolecular (real-world, experimental) observations. The symbolic realm represents the "lingo" of chemistry using symbols, equations, graphs, or equations. Three aspects of DiBiase and Wagner's (2002) learning cycle are most relevant to the current study: assessment, concept development, and exploration. Figure 1 shows how components of the learning cycle are embedded into Johnstone's framework to support learning between the three levels.

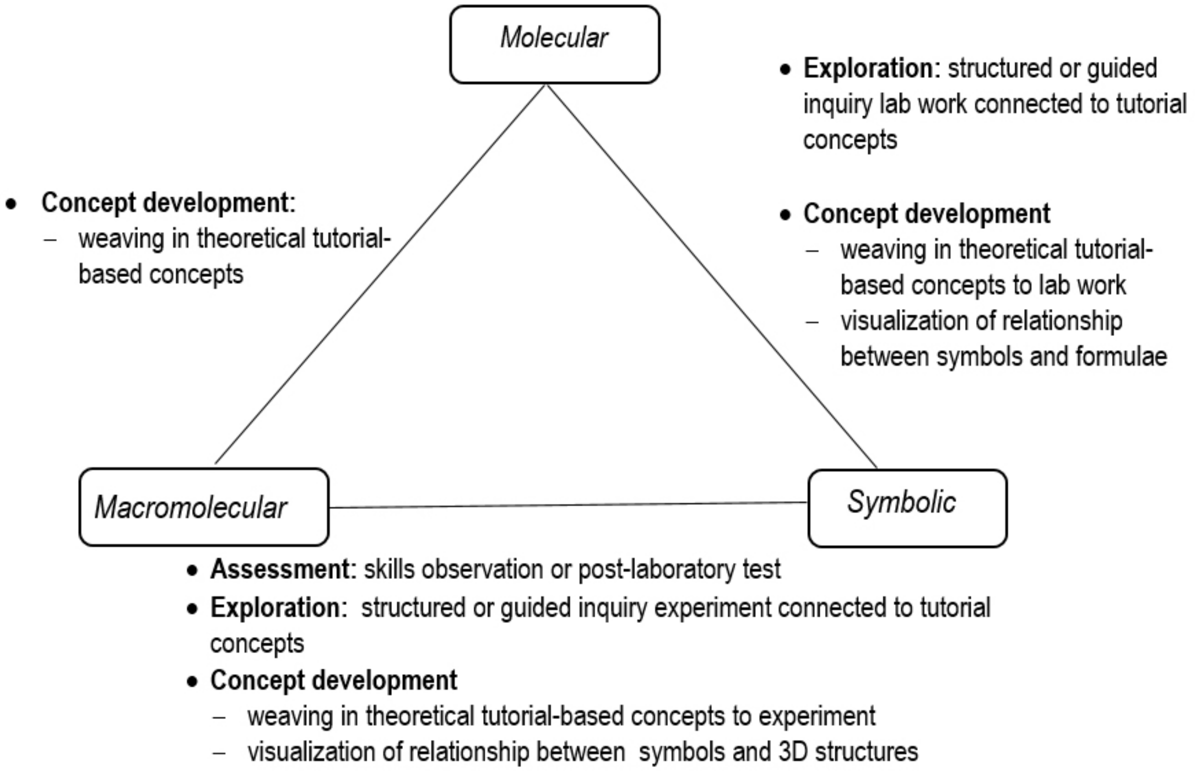
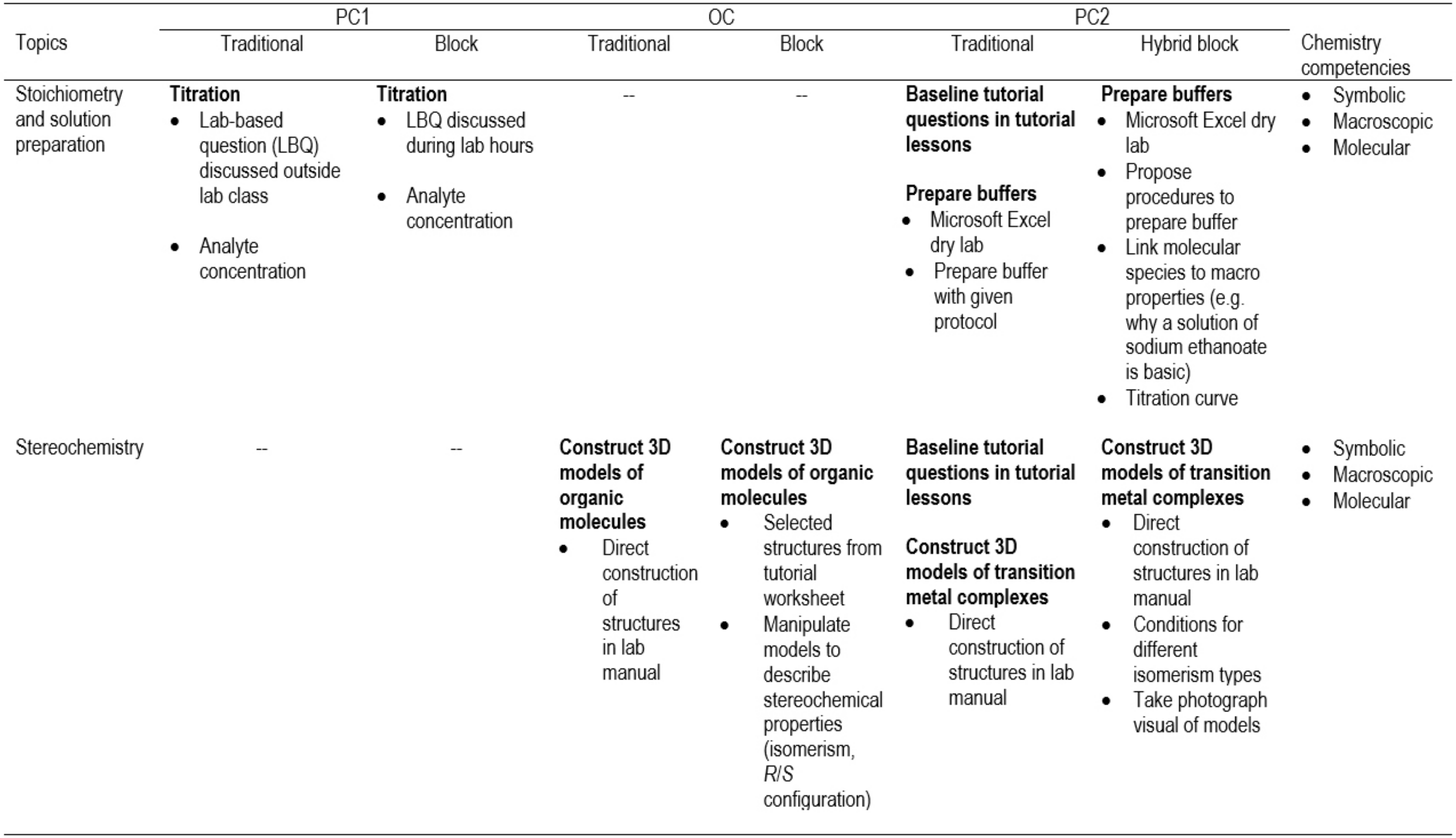


Figure 1. Johnstone's chemistry competencies (in italics) and components of learning cycles (in bold).

The author taught both the experimental and traditional-schedule classes, with two other instructors who each also taught one experimental and one traditional-schedule class each. Lesson plans were designed and distributed to all instructors. Appendix 1 shows representative tutorial, laboratory and assessment tasks in a biweekly schedule (Appendix 2). In the first semester, the block schedules toggled between PC1 and OC. Students in the block schedule experienced four hours of bi-weekly laboratory and tutorial sessions latched together, alternating between PC1 and OC each week. Students in the traditional schedule experienced the silo one-hour weekly PC1 or OC tutorial, and two hours of practical classes conducted bi-weekly alternating between PC1 and OC. The same set of tutorial and laboratory worksheets were deployed to both traditional and blocked classes for PC1 and OC. In the PC2 cycle, the earlier full block design in the PC1/OC phase was "unblocked" to allow for a mixture of standalone and block lessons (thus hybrid block) in PC2. This hybrid block was implemented to partly address tutors' concerns about students' attention levels, and also our observations that block teaching was not necessary for all topics.

Table 1 summarises representative tasks in the traditional and block (or hybrid block) schedules. Students worked in pairs for all laboratory tasks.

Table 1
Main lesson tasks and Johnstone's competency levels



	PC1		OC		PC2		
Topics	Traditional	Block	Traditional	Block	Traditional	Hybrid block	Chemistry competencies
Stoichiometry and solution preparation	**Titration** • Lab-based question (LBQ) discussed outside lab class • Analyte concentration	**Titration** • LBQ discussed during lab hours • Analyte concentration	--	--	**Baseline tutorial questions in tutorial lessons** **Prepare buffers** • Microsoft Excel dry lab • Prepare buffer with given protocol	**Prepare buffers** • Microsoft Excel dry lab • Propose procedures to prepare buffer • Link molecular species to macro properties (e.g. why a solution of sodium ethanoate is basic) • Titration curve	• Symbolic • Macroscopic • Molecular
Stereochemistry	--	--	**Construct 3D models of organic molecules** • Direct construction of structures in lab manual	**Construct 3D models of organic molecules** • Selected structures from tutorial worksheet • Manipulate models to describe stereochemical properties (isomerism, *R*/*S* configuration)	**Baseline tutorial questions in tutorial lessons** **Construct 3D models of transition metal complexes** • Direct construction of structures in lab manual	**Construct 3D models of transition metal complexes** • Direct construction of structures in lab manual • Conditions for different isomerism types • Take photograph visual of models	• Symbolic • Macroscopic • Molecular

The focal laboratory tasks were titration (PC1), buffer preparation (PC2), and stereochemistry modelling skills (OC and PC2). The topics, laboratory activities and assessments were designed to align with chemistry competences at the symbolic, experimental, and microscopic levels (Johnstone, 1982). In the PC1/OC semester, the laboratory-based question (LBQ) was incorporated into the tutorial worksheet. The LBQ typically invoked symbolic concepts relevant to the practical task, for example, stoichiometric formulae and calculations. Block classes could immediately tackle the laboratory work after the LBQ.

In PC2, slightly differentiated activities were deployed into the hybrid and traditional classes, owing to the change in scheduling design. Traditional classes continued to receive baseline materials comprising separate tasks for tutorial and practical classes. Hybrid block classes used a merged resource package incorporating the baseline objectives, which also afforded slightly extended exploration owing to longer class durations. For example, hybrid block classes were tasked to design the buffer preparation procedures from scratch, while those in the traditional classes were given the explicit steps. In the stereochemistry laboratory, molecular construction in the hybrid block classes progressed from relatively simple to complex structures (monodentate to bidentate ligands, 4-coordinated to 6-coordinated). Thus, students did not stop at just assembling models of transition metal complexes, but were prompted to think of the conditions required for various types of isomerism to exist. Since it was administratively infeasible for students to select a particular schedule, and impractical to fragmentise the hybrid block laboratory activities for the traditional-schedule classes, the teaching team exercised care to ensure that the baseline theory and concepts were taught to all students. In addition, all materials in the learning packages were made available to any student, whether from the block or traditional schedules, in the learning management system (LMS). Other topical lessons were delivered traditionally (baseline, independently-timed tutorial and practical classes).

Dependent variables (DVs)

Four quantitative variables were used to compare students' achievement and learning experiences between the schedules. They were: titration experimental variable (concentration of an unknown sodium hydroxide solution or [NaOH]; scores of laboratory tests administered during and after the laboratory class; mid-terms and semestral examination scores and pre- and post-scores from the Meaningful Learning in the Laboratory Instrument (MLLI), by Galloway and Bretz (2015). As part of the project, a series of focus group interviews were conducted after the semester to probe deeper into students' learning experiences in both schedules. For reasons of brevity, the full findings are not presented here; succinct references would be made where relevant to support the MLLI findings.

Experimental variable for titration class in PC1: sodium hydroxide concentration ([NaOH])

In PC1, the main laboratory task was a titration exercise to determine the concentration of an unknown sodium hydroxide (NaOH) solution. The dependent variable, the target analyte concentration, [NaOH], was computed from the raw data of a convenience sample of 50% of participants. This sample of participants also underwent a titration skills observation conducted by laboratory technicians and student teaching assistants (TAs). It was thought that sampling this dependent variable (DV) from a subset of participants who were skills-assessed (since they would put in more effort to perform the titration properly) would be more representative of the quality of titration skills. The raw data were recorded into a spreadsheet and stoichiometric computations were performed. To obtain the teacher's [NaOH], the titration was also repeated by the TAs under the author's and another instructor's supervision. For consistency, the teacher's titration was performed with the same batch of reagents used by all students. This DV was to provide data to test the first hypothesis.

In-class and out-of-class post-laboratory tests in PC1 and PC2

These were written open-book tests where students were allowed to refer to print materials such as lecture notes. In the titration and buffer preparation laboratory in PC1 and PC2, a post-laboratory test was administered for self-completion in the class. The titration and buffer post-laboratory tests were administered immediately after benchwork. These tests were meant to extend the main theoretical concepts encountered in the laboratory task to novel contexts. The intent was to assess students' ability to apply stoichiometric concepts (titration and buffer preparation) and propose solution preparation techniques for a modified version of the same experiment. These were graded by other instructors in the teaching team, or the author using a marking scheme. The maximum marks for the PC1 test was 11 points, while for PC2, it was 8 points.

For the OC laboratory, the post-laboratory test, which comprised nine multiple choice questions (MCQs), was administered electronically on the learning management system immediately after students completed the laboratory tasks. This was to allow students to view colored molecular models on-screen on their own laptops. This however, led to an unintended consequence in that students were observed to corroborate and discuss answers with each other. Online proctoring rules were harder to enforce under the open environment in the laboratory. Thus, due to the possibility of poor validity, the OC laboratory test results would not be reported here.

Another post-laboratory test administered in PC2 was a short essay, graded out of a maximum total of 10 points. It required students to describe as much as possible the stereochemistry of a novel and unseen transition metal (TM) complex. Due to time constraints, students were allowed to take the test home and submit the essay within a week after the laboratory class. The performance in the titration, buffer preparation and stereochemistry essay test serve as DVs to evaluate the second hypothesis.

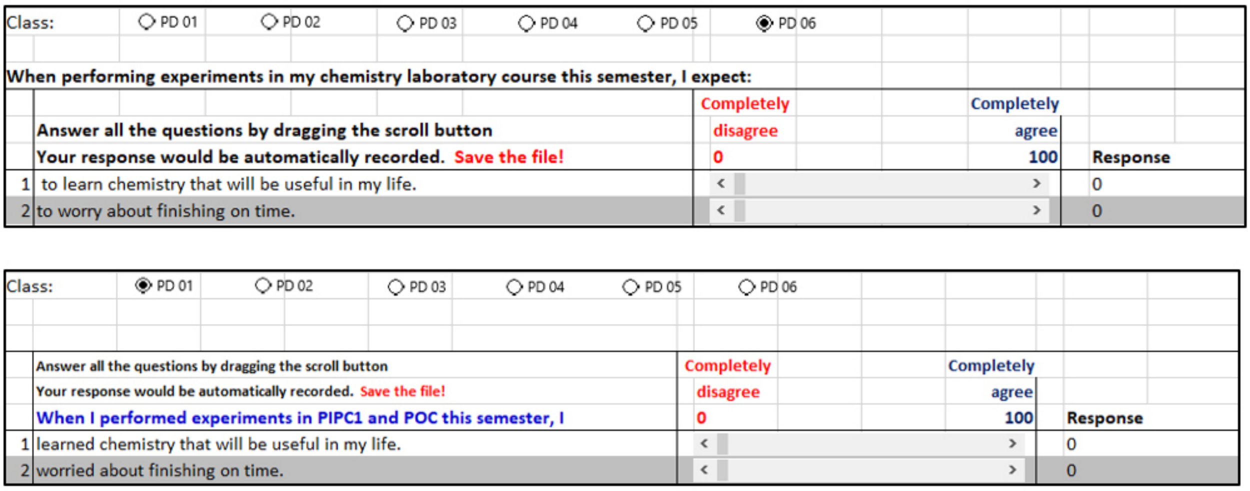
Mid-terms and semestral examinations

Similar to the laboratory tests, these DVs are to evaluate the second hypothesis. Mid-term assessments and end-of-semester examinations for each of the three subjects were administered according to institutional requirements and schedules. These were all written tests administered under proctored conditions. The marks for mid-terms and semestral examinations were analysed for possible delayed manifestations of student outcomes (Randler *et al*., 2008).

Student expectations and fulfilled experiences of laboratory

To investigate the third hypothesis, students' expectations and experiences before and after the laboratory curriculum were collected and compared between the traditional and block schedules. For this purpose, the Meaningful Learning in the Laboratory Instrument (or MLLI) designed by Galloway and Bretz (2015) was used. The MLLI was chosen because the cognitive (thinking) and affective experiences (feelings and emotions) are as important as the psychomotor domains of laboratory learning (Galloway & Bretz, 2015). The MLLI has been validated and its underlying structure characterised by the authors. Thus, the 31-item instrument is considered a reliable and reflective instrument to describe laboratory learning experiences. The affective subscale measures students' emotive experiences (for example, “I expect to worry about finishing on time”, or “I expect to be nervous about handling chemicals”) while the cognitive subscale relates to how students think during laboratory (for example, “I expect to learn problem-solving skills”). There are 16 cognitive items, 8 affective items, and 6 items classified as both cognitive and affective. One item is an indicator item used to sieve out participants who might not be reading the questions closely (for example, “Please select forty percent for this question”). The post-survey uses the same 31 items, but worded in the past tense (for example, “I felt disorganized”). 16 items were positively worded and 14 are negatively worded.

Figure 2 shows an example of the same item in the pre- and post-survey. The MLLI and subscale items are presented in Appendix 3.



Class: ○ PD 01 ○ PD 02 ○ PD 03 ○ PD 04 ○ PD 05 ● PD 06

When performing experiments in my chemistry laboratory course this semester, I expect:

		Completely disagree	Completely agree	
	Answer all the questions by dragging the scroll button Your response would be automatically recorded. Save the file!	0	100	Response
1	to learn chemistry that will be useful in my life.	<	>	0
2	to worry about finishing on time.	<	>	0

Class: ● PD 01 ○ PD 02 ○ PD 03 ○ PD 04 ○ PD 05 ○ PD 06

	Answer all the questions by dragging the scroll button Your response would be automatically recorded. Save the file!	Completely disagree	Completely agree	
	When I performed experiments in PIPC1 and POC this semester, I	0	100	Response
1	learned chemistry that will be useful in my life.	<	>	0
2	worried about finishing on time.	<	>	0

Figure 2. Screen shots of pre- and post-survey in the Excel forms.

The MLLI survey was constructed on an Excel form to retain the original feature of a sliding bar, instead of using the proprietary survey software as the authors did (Galloway & Bretz, 2015). In the beginning of each semester, the pre-survey form was uploaded onto the institution's LMS for students to download and upload the response file. The post-semester survey was made available about three weeks before the end of the semester. Nominal class participation marks were credited into the laboratory reports to encourage students to submit both a pre- and post-survey individually. After screening for outliers, the research team analysed a total of 33 valid pre- and post- responses in the PC1 and OC phase (22.7% response rate) and 83 in the PC2 phase (56.5% response rate).

Statistical analysis

All DVs were first checked for deviations from normality and outliers using SPSS. When the normality assumption is not met, outlier data was removed and the sample rechecked for normality. If the normality assumption is not met again, non-parametric tests were used. To compare differences in student and teacher values of [NaOH], a one-sample t-test was used. The Mann-Whitney U-test were used to compare differences in test marks, normalised to 100%. The treatment of the MLLI scores followed Galloway and Bretz's work (2015). Firstly, negatively worded items were reverse coded. Secondly, composite scores for the cognitive, affective, and cognitive/affective subscales were obtained from the average of items classified into these three subscales. A two-way repeated ANOVA was used with time (pre- and post-) as the within-subject factor, and schedule types as the between-subject factor. Three two-way repeated ANOVA analyses were performed for each of the subscales in the two semesters.

RESULTS

Differences in [NaOH]

Table 2 shows the mean [NaOH] obtained by the block and traditional classes. A one-sample t-test was performed to compare if there were significant differences between students and teacher for each schedule. A significant difference was found in the NaOH concentration ($t(28) = -3.43, p = .002$ for block; $t(33) = 11.6$, $p = .000$ for traditional) when compared to the teacher's value. Values of Cohen's d, calculated by dividing the mean difference between participants' and instructors' value by the standard deviation of the sample, are also shown.

An independent sample t-test was performed to evaluate schedule differences. Prior to this, homogeneity of variance was ascertained. There were no significant differences in variance ($F = 2.603$, $p > .05$). The mean [NaOH] reading differed significantly between the two schedules ($t(61) = -9.35$, $p = .000$). The effect size (η^2) is determined based on the procedure in Pallant (2007) for independent t-tests.

Table 2
Concentration of NaOH stock solution (in mol/L) by schedules, effect size and Cohen's d

	Block	Traditional	Instructor
n	29	34	3
Mean	0.582	0.629	0.596
SD	0.022	0.015	0.021
η^2 (between schedules)	0.589		-
Cohen's d	-0.637	1.985	-

Post-laboratory tests scores

Table 3 shows the performance of the three post-laboratory tests administered. Results of two-tailed Mann-Whitney analyses showed that there were no significant differences in performance levels between the two schedules.

Table 3
Descriptive statistics and mean ranks of laboratory tests performance by schedules

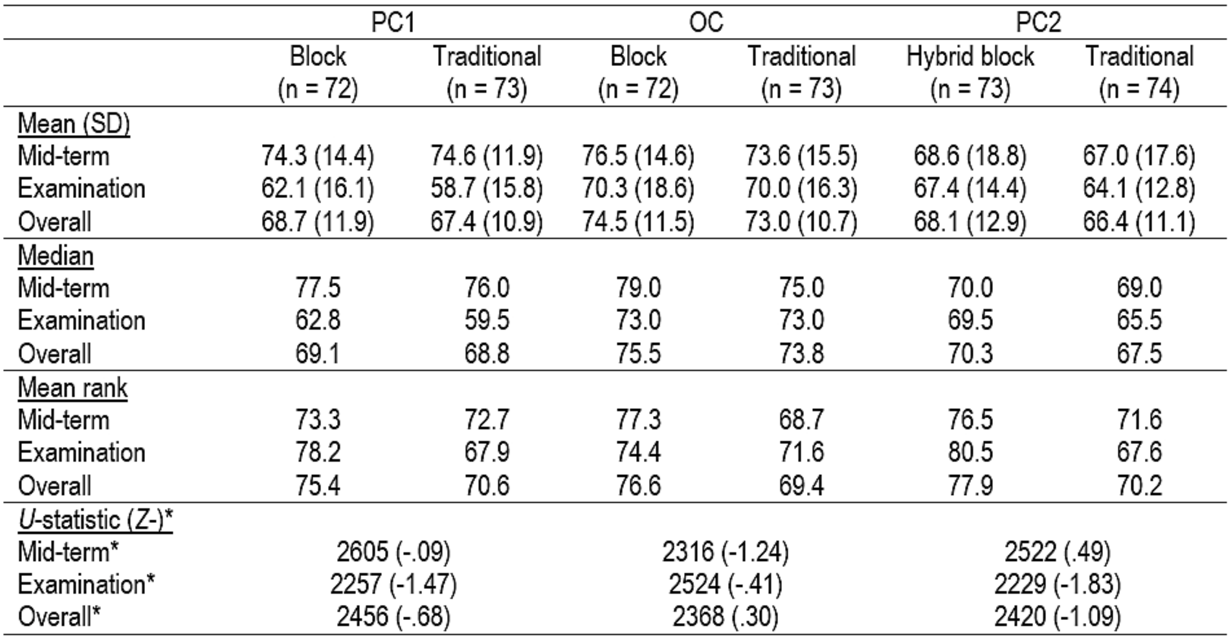
	Titration		Buffer preparation		TM Stereochemistry	
	Block (n = 69)	Traditional (n = 69)	Hybrid block (n = 72)	Traditional (n = 69)	Hybrid block (n = 58)	Traditional (n = 60)
M	51.8	46.2	52.2	50.6	66.3	68.8
SD	21.9	21.5	22.7	23.0	22.7	20.3
Md	45.5	45.5	56.3	56.3	65.0	70.0
Mean rank	74.5	64.5	72.0	69.9	57.4	61.6
U-statistic (Z-)*	2034 (-1.49)		2409 (-.311)		1616 (-.674)	

*p >.05

Mid-terms and semestral examinations

Table 4 shows the descriptive statistics and mean ranks of performance in the three subjects. All scores are computed on the basis of 100%. Results of two-tailed Mann-Whitney analyses showed that there were no significant differences in performance levels between the two schedules.

Table 4
Descriptive statistics and mean ranks of subject performance by schedules



	PC1		OC		PC2	
	Block (n = 72)	Traditional (n = 73)	Block (n = 72)	Traditional (n = 73)	Hybrid block (n = 73)	Traditional (n = 74)
Mean (SD)						
Mid-term	74.3 (14.4)	74.6 (11.9)	76.5 (14.6)	73.6 (15.5)	68.6 (18.8)	67.0 (17.6)
Examination	62.1 (16.1)	58.7 (15.8)	70.3 (18.6)	70.0 (16.3)	67.4 (14.4)	64.1 (12.8)
Overall	68.7 (11.9)	67.4 (10.9)	74.5 (11.5)	73.0 (10.7)	68.1 (12.9)	66.4 (11.1)
Median						
Mid-term	77.5	76.0	79.0	75.0	70.0	69.0
Examination	62.8	59.5	73.0	73.0	69.5	65.5
Overall	69.1	68.8	75.5	73.8	70.3	67.5
Mean rank						
Mid-term	73.3	72.7	77.3	68.7	76.5	71.6
Examination	78.2	67.9	74.4	71.6	80.5	67.6
Overall	75.4	70.6	76.6	69.4	77.9	70.2
U-statistic (*Z*-)*						
Mid-term*	2605 (-.09)		2316 (-1.24)		2522 (.49)	
Examination*	2257 (-1.47)		2524 (-.41)		2229 (-1.83)	
Overall*	2456 (-.68)		2368 (.30)		2420 (-1.09)	

*p >.05

MLLI

The Cronbach alpha reliability coefficients of the three MLLI subscales are presented in Table 5. The alpha coefficients measure how closely related the questions are in a particular subscale. It indicates if responses to a particular group of questions are made consistently. A negative coefficient indicates poor relationship between the items. Generally, a coefficient larger than 0.7 indicates acceptable internal consistency (Pallant, 2007).

The alpha coefficients ranged from a negative value of approximately -.09 to a high positive value of 0.80. The affective subscales are observed to have larger coefficients compared to the other two subscales. The cognitive and cognitive/affective subscales generally possess comparable coefficients but were lower than the affective subscales. The post- cognitive/affective subscale had a very low and negative coefficient in the PC1/OC phase rated by the traditional-schedule classes. The coefficients increased to about 0.5 in the next semester across all classes. The same subscale also violated the assumption of homogeneity of variance. The other two subscales in the PC1/OC semester and all subscales in PC2 semester met this assumption. As such, interpretation for the two-way ANOVA would not be presented for the cognitive/affective subscale in the PC1/OC semester.

The mean composite subscale scores are summarised in Table 6, with Table 7 displaying the two-way ANOVA results. In the PC1/OC semester, the cognitive and affective subscales did not produce any interaction effects. This allowed the main effects of time and schedule to be interpreted meaningfully. There was no significant difference between the two schedules for both subscales. There was a significant main effect of time for the cognitive subscale. Regardless of class schedules, cognitive subscale scores dropped significantly by the end of the semester. While ratings for the affective subscale appeared to increase slightly, the pre-post difference was not significant. The same overall trend was observed in the PC2 semester; there were no interaction effects, no difference between the schedules but composite scores decreased over time, regardless of schedules.

Table 5
Cronbach α coefficients of MLLI subscales

	Pre			Post		
	Cognitive	Affective	Cognitive/Affective	Cognitive	Affective	Cognitive/Affective
PC1/OC (n = 33)						
Traditional	0.53	0.65	0.28	0.50	0.79	-0.085
Block	0.78	0.82	0.66	0.46	0.82	0.71
Overall	0.72	0.75	0.53	0.50	0.83	0.55
PC2 (n = 83)						
Traditional	0.59	0.74	0.52	0.59	0.65	0.54
Hybrid block	0.71	0.78	0.59	0.68	0.72	0.54
Overall	0.66	0.76	0.55	0.64	0.69	0.55

Table 6
Composite average of MLLI subscales (standard deviation in brackets)

	Pre			Post		
	Cognitive	Affective	Cognitive/Affective	Cognitive	Affective	Cognitive/Affective
PC1/OC (n = 33)						
Traditional	65.7 (8.61)	63.7 (15.2)	58.0 (13.5)	60.4 (7.68)	53.1 (17.5)	51.8 (10.1)
Block	72.1 (12.2)	67.3 (19.0)	62.6 (18.7)	65.5 (9.13)	68.8 (19.8)	56.6 (20.1)
Overall	69.0 (11.0)	65.6 (17.1)	60.4 (16.3)	63.1 (8.72)	61.2 (20.1)	54.2 (16.0)
PC2 (n = 83)						
Traditional	64.6 (9.26)	68.9 (16.9)	62.6 (15.2)	59.7 (9.17)	64.6 (14.5)	61.2 (14.6)
Hybrid block	65.1 (11.8)	68.9 (17.7)	63.2 (16.2)	61.2 (11.0)	65.8 (16.6)	55.6 (16.2)
Overall	64.8 (10.5)	68.9 (17.2)	62.9 (15.6)	60.4 (10.0)	65.2 (15.4)	58.6 (15.6)

Table 7
Results from two-way repeated ANOVA

PC1/OC semester	Cognitive	Affective	Cognitive/Affective
Schedule	F(1,31) = 3.70, p = .064, partial η^2= 0.11	F(1,31) = 3.33, p = .078, partial η^2= 0.097	NA
Time	Wilks's λ = 0.66, F(1,31) = 15.8, p = .00, partial η^2= 0.34	Wilks's λ = 0.94, F(1,31) = 1.83, p = .19, partial η^2= 0.056	NA
Schedule*time	Wilks's λ= 0.99, F(1,31) = 0.20, p = .66, partial η^2= 0.006	Wilks's λ = 0.91, F(1,31) = 3.25, p = 0.081, partial η^2= 0.095	NA
PC2 semester			
Schedule	F(1,81) = 0.25, p = .62, partial η^2 = 0.003;	F(1,81) = 0.039, p = .84, partial η^2 = 0.00	F(1,81) = .75, p = .39, partial η^2 = 0.009
Time	Wilks's λ = 0.84, F(1,81) = 15.0, p = .00, partial η^2 = 0.16	Wilks's λ = 0.95, F(1,81) = 4.71, p = .03, partial η^2 = 0.055	Wilks's λ = 0.93, F(1,81) = 6.33, p = .014, partial η^2 = 0.072
Schedule*time	Wilks's λ = 1.00, F(1,81) = 0.24, p = .63, partial η^2 = 0.003	Wilks's λ = 1.00, F(1,81) = 0.13, p = .72, partial η^2 = 0.002	Wilks's λ = 0.97, F(1,81) = 2.96, p = .089, partial η^2 = 0.035

DISCUSSION

The fact that test performance (whether post-laboratory tests or follow-up assessments) did not produce any significant differences between schedules is consistent with some of the findings in the literature (Dexter *et al*., 2006; Randler *et al*., 2008). It was noted that in most of the assessments, the block or hybrid block classes performed slightly better than the traditional classes (except in the TM modelling post-laboratory test), but these differences did not reach statistical significance. In terms of titration results, the variance appeared to be comparable between the block and traditional classes. The one sample t-test flagged a significant difference when the analyte concentration of each schedule was independently evaluated against the instructor's reading. The independent sample t-test showed that the mean analyte concentration obtained by block and traditional participants were statistically different. From a practical standpoint related to the research aims, these data appeared to be inconclusive. This was because both groups were different, with a considerably large effect size of 0.59 (Cohen, 1988, p. 287), and *yet* each obtained a result *significantly different* from the instructor too. The block classes obtained a value (0.582 mol/L) that was intuitively closer to the instructor's (0.596 mol/L) than the traditional classes (0.629 mol/L). This was consistent with the magnitude of the effect size for the block and traditional classes. The difference in the mean analyte concentration obtained by the block classes and the instructor were less than one standard deviation. For the block classes, the difference was almost two standard deviations. The effect sizes are considered large (Cohen, 1988, p. 287) and thus unsurprisingly, manifested as statistically different from the instructor's value.

It is unclear at this point whether performance differences (or the lack of it) was in part due to prior differences in Chemistry abilities. In general, freshmen are admitted based on their performance in the Singapore General Certificate of Education (GCE) 'Ordinary' (O) Level examinations. The research team was not privy to the admissions data. This limitation could be addressed by implementing a baseline assessment at the start of the PC1/OC phase, as this is the entry point for the cohort. The overall subject performance in the PC1/OC phase could then serve as a baseline assessment for onward research in the PC2 phase. Another refinement was to increase the sampling pool to the whole of the PC1 participants, instead of just obtaining the [NaOH] DV from the skills-assessed sample.

The internal consistency of the MLLI subscales ranged from 0.53 to 0.83. This range is comparable to the variation reported by Galloway and Bretz (2015), who reported values from 0.60 to 0.82. The cognitive/affective subscales produced consistently lower coefficients, a finding that is also consistent with the authors' results. One explanation for the lower alpha values for the cognitive/affective subscale could be that students perceived thinking and feeling as separate domains. They do not integrate these two domains meaningfully, but view feelings and thinking processes in laboratory classes as distinct learning experiences (Galloway & Bretz, 2015). This is supported by the higher Cronbach values for the cognitive and affective subscales. Another observation is that the affective subscales consistently scored higher Cronbach alpha values. This could signal that students identified affective experiences during practical lessons in a more consistent and predictable manner than the other two subscales. The comments from the focus group discussions (FGD) also lend some qualitative support that students often like to describe emotion-laden experiences during laboratory classes. For example, students frequently attributed negative lesson experiences to lack of confidence, being nervous when handling complex equipment or worry about their inability to cope with the work. From Table 5, the pre- and post-difference in the alpha coefficients of the respective subscales ranged from 0.005 to 0.32 in the PC1/OC cycle (ignoring the cognitive/affective domain), and narrowed to 0.003 to 0.09 in the PC2 cycle. These range of differences are fairly consistent with those reported in Galloway and Bretz (2015). Most importantly, the differences in Cronbach coefficients between the pre- to post-test were smaller for the PC2 cycle, indicating less variation. This could be because the participants had experience answering the survey in the prior semester, and thus could provide more consistent scoring for the subscale.

In the PC1/OC phase, the slight increase in the affective subscale composite score in the block classes between the pre- and post-test did not reach significance in this cycle. Instead, there was a decrease in the rating of the cognitive subscale. The same result was obtained in the PC2 phase where scores in the three subscales dropped significantly over time. In both cycles, the largest effect size was seen in the cognitive subscale (η^2= 0.34 for PC1/OC and η^2= 0.16 for PC2). In simple terms, the effect size measures the amount of change in the subscale score contributed by time only, ignoring other extraneous effects. Therefore, about 34% and 16% of the dispersion in PC1/OC and PC2 cognitive ratings can be explained by the passage of time, magnitudes that are considered large (Cohen, 1988). Thus, regardless of schedules, laboratory experiences did not appear to stimulate deep thinking in students.

While the response rate in the MLLI survey was not particularly high (about 23% in PC1/OC and about 57% in PC2 phase), it is worth reflecting on why the subscale ratings did not differ significantly by schedules, but fell by the end of the semester. Firstly, students' concentration levels might wane under longer lesson durations, even though we changed the schedules from full block to hybrid block. This was also a feedback raised during the FGD. Poor concentration levels could adversely affect students' cognitive engagement. Secondly, there were insufficient opportunities for open-ended work in the hybrid block lessons. Comments shared during the FGD revealed that majority of students agreed that laboratory work facilitated visualisation and application of theoretical concepts, attributes that are "cognitive-like" in nature. None mentioned that they learnt problem solving or critical thinking skills. The buffer preparation laboratory was just one experience, insufficient to cultivate such skills. In fact, students from the hybrid block schedules articulated that having more unstructured tasks would wean students off from an over-reliance on instructors and the "step-by-step" style of laboratory work (Domin, 1999). These views present a qualitative dimension to students' experiences to supplement the MLLI data. Indeed, as suggested by the literature (Marshak, 1998; Queen, 2000; Scott, 2003), findings from the MLLI and FGD signalled the need to look into incorporating more experiential tasks to interest students mentally and emotionally. At this point, some initial ideas could include a "perspective-taking" activity in the OC stereochemistry task to help students think of different ways to view a molecule, or propose a titration protocol to determine the concentration of an unknown analyte, with extraneous glassware provided. Taking a leaf out from DiBiase and Wagner (2002), another approach would be to further tighten the integration between tutorial and laboratory work, such as revising tutorial concepts such that they are fully aligned with the practical tasks. Moving forward, more intensive discussions and ongoing conversations amongst the instructors would be necessary to align and improve future lesson designs.

CONCLUSIONS

In this project, a fully block and a hybrid block schedule of chemistry tutorial and laboratory classes was implemented over two semesters, and across three chemistry courses. Student outcomes, measured in terms of titration quality, laboratory quiz performance and summative assessment scores, did not differ by schedules. Laboratory experiences and perceptions were evaluated using the MLLI survey on three domains—cognitive, affective, and cognitive/affective. There were no significant differences in the three subscale ratings between schedules. However, ratings fell significantly pre- and post-semester, regardless of class schedules, indicating unmet expectations across the classes. The results appeared to signal the need for a variety of activities to entice deeper, open-ended experiential learning. These presented opportunities and challenges in instructor professional development and in future lesson design.

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APPENDIX 1. REPRESENTATIVE LESSON ACTIVITIES

APPENDIX 2. BIWEEKLY LESSON PLAN FOR BLOCK CLASSES IN PC1/OC AND PC2 PHASES, ILLUSTRATING THE WEEKS WHICH THE CORE INTEGRATION TOOK PLACE.

APPENDIX 3. MEANINGFUL LEARNING IN THE LABORATORY INSTRUMENT (MLLI) PRE- AND POST-SURVEY ITEMS. ■