STUDENT-DESIGNED CHEMISTRY EXPERIMENTS

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Introduction

School science lessons have often been promoted as experiential processes involving students being given ample hands-on learning opportunities not only in the classroom, but also in the laboratory and in the field. In Chemistry lessons, most of the concepts are taught in a classroom or lecture-style setting while laboratory work is usually set aside for the verification of these taught concepts. The stakes at the national examinations are high for sixteen year-old Singaporean students taking the General Certificate of Education Examinations at the end of some ten years of schooling. The science practical assessment accounts for about a fifth of the total examination marks. The students are assessed on how closely they follow a given set of experimental instructions and their ability to perform the task at a one-off practical examination sitting including recording observations and making inferences. Hopefully they can also make some sense of their experimental observation and results to answer questions at the end of the question paper. The impending implementation of the School-based Practical Assessment (SPA) is an important move away from this traditional mode of "cook book" style laboratory instruction and assessment. Candidates will now be assessed over a period of two to three years on four important experimental skills, namely, (1) Using and organising techniques, apparatus and materials; (2) Observing, measuring and recording; (3) Handling experimental observations and data; and (4) Planning Investigations. Whatever the change is, many science curricula around the world still includes the laboratory as an important part of science instruction (Doran et al, 2002). What is changing, however, is the increasing involvement of the students' cognitive and psychomotor skills during science laboratory sessions in schools.

Towards Student-Centric Laboratory Instruction

There are indications of a shift towards a more student-centric performance assessment in the current Science syllabuses. The latest Chemistry Syllabus (code 5068) has a statement expecting students to produce a creative output from their attempt at the practical examination. This may be found in the assessment criteria for Paper 3 of the GCE Ordinary Level Chemistry Syllabus 5068, the practical component:

> "***Paper 3*** consisting of two compulsory questions. In one or both of the questions, candidates will be expected to suggest a modification or an extension, which does not need to be executed."
>
> - GCE O Level Syllabus 5068 Chemistry, pp4.

Now that candidates have to "suggest a modification or an extension", the direction is set for teachers to train students to make sense of the experimental tasks, scanning it for signs where they can start to create a "modification" to a procedure or make a different selection of materials for the experiment. The "extension" could also be a further verification of the experimental results either by repeating the procedures or designing a parallel set of procedures to re-confirm their experimental findings. These, in effect, are the starting points for Student-Designed Experiments.

Arce and Betancourt (1997) describe student-designed experiments as those that provide students with a learning cycle and a challenge to their prior factual knowledge. Such experimental tasks are crafted to engage students in self exploration, interpretation and application. Widstrand, Nordell and Ellis (2001) also describe such experiments in similar terms. They noted that these experiments characteristically provide the "opportunity for students to create their own research problem, investigate it quantitatively and communicate the results to technical and non-technical audiences" (pp. 1045).

It is not the objectives of this paper to discuss at length what do or do not constitute as a student-designed experiment. There is also no intention to debate on the different interpretations of an experiment and an investigation. However, it is important to note that laboratory work, in general, does provide the following opportunities to students and teachers: (1) an appropriate context for students to work on experimental problem tasks, (2) a practice of both cognitive and psychomotor skills and (3) an array of student artefacts, in the form of experimental products, data or procedures that teachers can use to assess the performance of students in laboratory instruction (Doran et al, 2002, Woolnough, 1990). It is often up to the teacher to craft the experimental task and provide it either as a procedure for the students to follow closely or an experience for them to explore and discover. To craft experimental tasks so that students have to engage in some form of design requires teachers to understand how ready are their students. Not knowing the state of readiness among the students could spell "disaster" as the task set could be perceived as difficult or stressful to the students. Worse, there may be no strategy to assess the students' work fairly.

This paper presents a simple research finding on a small sample of secondary three express Chemistry students (n = 112) in several Singapore schools tasked with designing an experimental set up for two given chemical reactions. The results are neither conclusive nor indicative of a confirmed trend of students' abilities. However, as a "dip-stick" research, it serves as a precursor to a more ambitious project to study into the thought processes of students as they design appropriate and acceptable experimental set-ups. Hopefully, by translating these thought processes into classroom and laboratory pedagogical strategies, teachers may then be armed with skills to train the masses towards a competency, if not a mastery, in experimental design. The next sections present the method and findings of this "dip-stick" research venture.

Method

As part of the larger research design, the present study involves a two-stage procedure. The first stage was a small trial on two very small groups of students of differing academic abilities. The trial involved 17 students attempting the experimental tasks (11 students from a secondary school, 6 students from two academically high performing schools). The tasks and the expected designs are presented in Annex 1. The second stage covers a larger group of students, n = 95) who have completed a year's instruction in secondary school chemistry. All students involved in this study are in secondary three express and taking Chemistry 5068 as an examination subject.

The students' responses to the experimental tasks were classified into acceptable (Correct) design and unacceptable (Incorrect) design. A third group of students includes all those who left the task sheet blank – an assumption of students having no idea where to start or a disinterest in the subject, which is less likely as these are Pure Chemistry students.

Results

Examples of acceptable designs (Correct) are shown in Annex 2 while those that are unacceptable (Incorrect) are shown in Annex 3.

The first stage of the study showed the viability of the tasks in discriminating students of different academic abilities. The group of students from a top-performing school could mostly produce at least some acceptable designs, while the group of students from an academically weak class in an average-performing school showed great difficulties in attempting the tasks. The data collected in the first stage, to test the viability of experimental task involved only a few teacher-selected students. Table 1a and Table 1b show the distribution of the students' outputs.

Reaction	A Correct	A Incorrect
B Correct	1	0
B Incorrect	5	0

Table 1a. First Stage (academically able students, n = 6)

Reaction	A Correct	A Incorrect
B Correct	0	0
B Incorrect	1	10

Table 1b. First Stage (academically weak students, n = 11)

The second stage was done on 95 students from two average-performing schools. Unfortunately, the top performing school that was to provide the academically better students could not be accessed before the time this presentation was made. This was due to the tight year-end school schedule and a request by the teachers to postpone the arrangement for the study to the next academic year. Thus, the results presented are for this group of 95 students from two neighbourhood schools (School X and School Y). Table 2 shows the distribution of the students' responses from school X while Table 3 is for those from school Y.

Reaction	A Correct	A Incorrect
B Correct	7	0

B Incorrect	5	8

Table 2. Second Stage (School X, n = 35, Blank Response = 15)

Reaction	A Correct	A Incorrect
B Correct	5	2
B Incorrect	18	25

Table 3. Second Stage (School Y, n = 60, Blank Response = 10)

Table 4 below collates the results obtained from both schools.

Reaction	A Correct*	A Incorrect
B Correct	12 (12.6%)	2 (2.1%)
B Incorrect	23 (24.2%)	33 (34.7%)

* "Correct" includes those set ups that are "appropriate"

Table 4.
Second Stage (Combined, Schools X and Y, n = 95, Blank Response = 25 or 26.4%)

Preliminary Findings

The data collected by themselves are revealing in as far as these groups of students are concerned. Given the constraints of this initial study, there is no definitive trend or conclusion that can be generalized from these data but they do serve to start the process for a larger collection of data and an extension of the study by creating an appropriate list of experimental tasks for the subjects to attempt. Such a list will be generated at perhaps the third or fourth stage of this study. Also, it has to be noted that a separate study profiling the students' learning and thinking preferences using the Chemistry Learning and Thinking Instrument (the CLTI, first reported in ERAS2002 Conference by Tan and Goh, 2002, and at the ICASE World Conference 2003 by Tan and Goh 2003) was also conducted in parallel with the current study.

From the simple analysis of the raw figures, it can be seen that a good proportion (38.9%) of the average-performing students in the study can produce some kind of acceptable experimental design. The overall results may be presented in Table 5 below.

Range of Ability to Design an Experimental Set-up	Percentage
Able to design an appropriate experimental set up.	12.6%
Able to design some kind of experimental set up.	26.3%
Tried hard to design some kind of experimental set up.	34.7%
No idea to start with.	26.4%

Table 5.
Some Preliminary Trends on Students' Abilities to Design an Experimental Set-up

Conclusion

Work is still in progress and this research project is holding on to some interesting promise of results that could help Chemistry teachers understand their students' thinking, especially in the creative use of ideas in experimental design. The findings, though preliminary and inconclusive, can help boost the confidence among teachers who may be wondering if their students can get started designing their own experiments. If any good may come out of this study, it could be the result of a set of pedagogical strategies Chemistry teachers can use to train students to think and generate ideas in designing experimental set ups.

References

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Annex 1 –
The Experimental Tasks and the Expected Experimental Set-ups

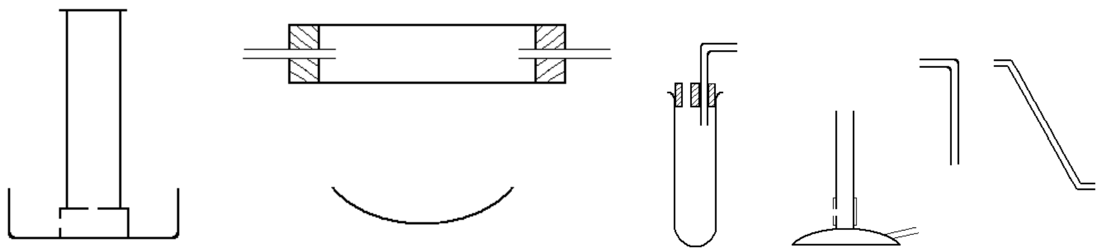
PREPARATION OF IRON (III) CHLORIDE

Background : Iron (III) chloride may be prepared using gaseous chlorine in two different reactions :

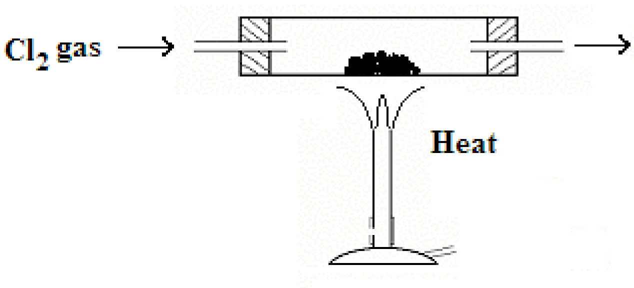
(A) $2Fe_{(s)} + 3Cl_{2(g)} \rightarrow 2FeCl_{3(s)}$

(B) $2FeCl_{2(aq)} + Cl_{2(g)} \rightarrow 2FeCl_{3(aq)}$

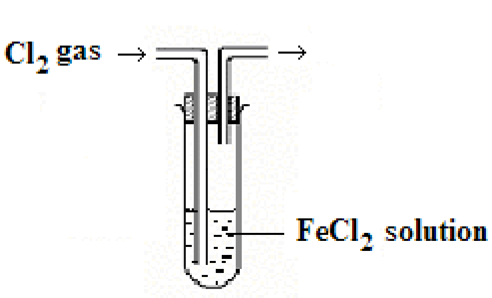
Task: Using the apparatus illustrated below (*not drawn to scale*), or any other apparatus of your choice, design separate experimental set ups for reaction (A) and reaction (B). You may modify or extend the set up in any way you feel appropriate.



Draw your experimental set-up for Reaction A in the space below: (Expected set up)

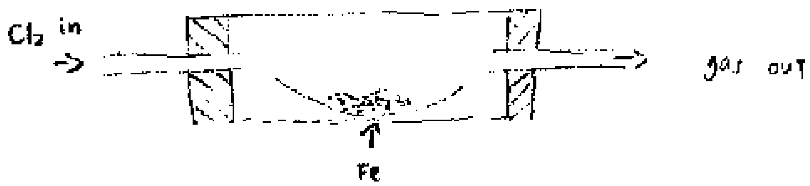


Draw your experimental set-up for Reaction B in the space below: (Expected set up)

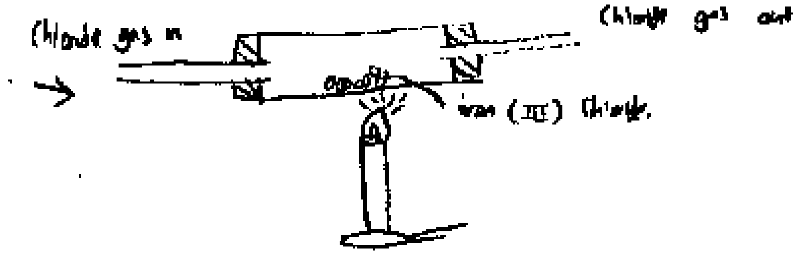


Annex 2 – Students' Experimental Set-ups (Appropriate / Correct)

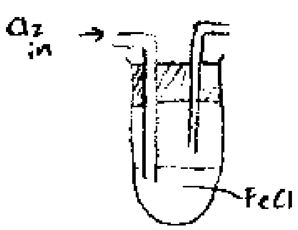
Example 1 – Appropriate order of apparatus set up for Reaction A. (Heat source missing)



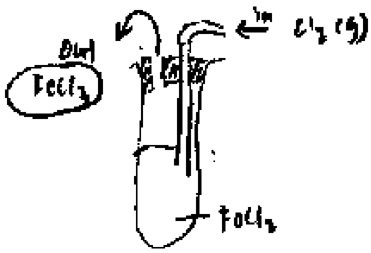
Example 2- Correct apparatus set up for Reaction A. (Ignore spelling mistake)



Example 3 – Appropriate apparatus set up for Reaction B (although formula for iron (II) chloride is incorrect)

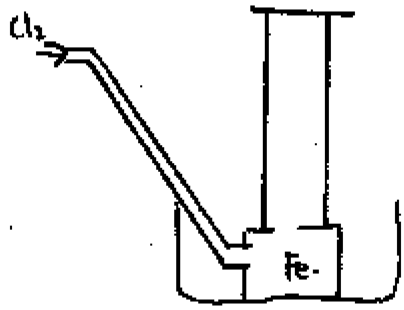


Example 4 – Appropriate apparatus set up for Reaction B (although there is a missing outlet tube through the left hole of the stopper.)

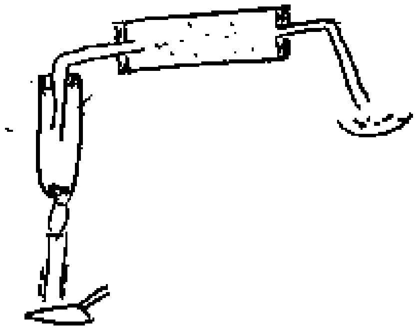


Annex 3 – Students' Experimental Set-ups (Inappropriate / Incorrect)

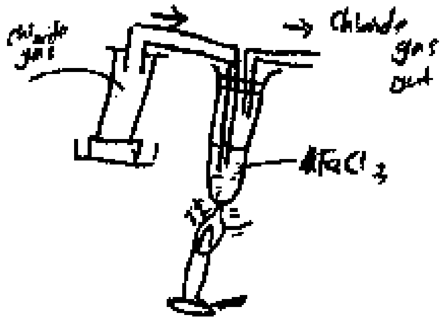
Example 5– Inappropriate choice of apparatus for Reaction A.



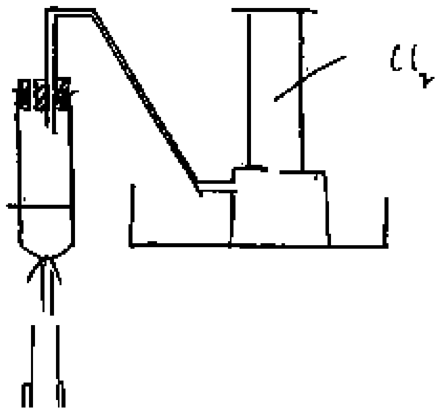
Example 6 – Incorrect choice and order of apparatus for Reaction A.



Example 7 – Inappropriate choice of apparatus (gas jar and Bunsen burner) but correct order of apparatus on the right hand side for Reaction B.



Example 8 – Inappropriate choice of apparatus and incorrect set up for Reaction B.



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