Using "What if.." questions to teach science

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Abstract

With the widening knowledge base students will need to be more flexible in their learning habits. Traditionally, teaching school science often involves teacher-centred methods like lectures, experimental demonstration or guided inquiry. Plain knowledge dissemination will not adequately prepare students to cope with the changing world. Hence, schools need to train students to be reflective in their learning habits – that is, getting students to be observant, to generate relevant alternatives and to make sense of these ideas. This article discusses a well-documented reflective learning strategy - the use of "what if" questions, to help students extend their learning beyond curricular requirements. Students are introduced to a distillation set up and then asked to pose "what if" questions about it. Their questions and the corresponding peer responses are

a wealth of information for teachers to explore how science may be taught differently and with a greater impact on their students' learning experience.

Introduction

The present science curriculum includes a range of student learning outcomes covering laboratory and experimental science (MOE, 2007). Researchers and scholars had argued that the roles of experiments and practical work in schools should allow students to practice laboratory skills, learn the various investigative processes and acquire first hand experiences in dealing with materials and laboratory wares (Boud, Dunn and Hegarty-Hazel, 1986; Doran et al, 2002; Hegarty-Hazel, 1986; Josephsen, 2003; Woolnough, 1990). Besides these cognitive and psychomotor objectives of school laboratory courses, there are also suggestions that lessons should be made more attractive through more intellectually demanding courses and new teaching techniques that can motivate students to learn (Schmidt, 2000). This paper discusses a well-documented reflective learning strategy - the use of questions posed by students to help them extend their learning beyond curricular requirements (Chin and Chia, 2004; Walsh and Sattes, 2005). Specifically, it discusses the use of "what if" questions posed by students (Fogarty, 1994). Students are introduced to a distillation set up and then asked to pose "what if" questions about it. Their questions and the corresponding peer responses provide teachers with a good insight on how students contribute to knowledge building through self-created learning opportunities. The entire experience may also help to create a classroom teaching-learning culture in which the teacher takes on the role of the advanced learner among novice learners.

Conducting the lesson

Traditionally a lesson on experimental science would commence with teacher talk, student evaluation and then possibly, a confirmatory experimental experience in the laboratory. Inquiry-based lessons may tweak the lesson structure a bit, with the teacher starting a learning task by asking a question. For example,

"If you are stranded in the open sea on a small boat, how would you go about making some fresh water to drink from the sea water around you? (Assuming you have the essential laboratory wares with you.)"

The teacher may then follow up by facilitating a class discussion and end with the teacher summarizing and contextualizing the discussion to fit the curricular requirements.

Mortimer and Scott (2003) in their book, *Making Meaning in Secondary School Science*, suggested that students should engage in some form of dialogic activity if they are to develop an understanding of a science topic. In this respect, classroom talk, learning and meaning making would not make strange bedfellows but are essential features in the science classroom that would ensure students gain some impactful learning experiences.

The lesson, which the present discussion is based on, involved both the traditional classroom lesson delivery and the engagement of student dialogic process. It was conducted for a group of ten secondary three express students (equivalent to grade 8). The students, four girls and six boys, were selected by their Chemistry teacher to attend a remedial lesson on the topic of "*Separation Techniques*". They came from two different classes taught by the same teacher. The separation technique to be revised in the 40-minute lesson was on "Simple Distillation". The author of this paper was requested by their teacher to teach this remedial lesson. The author (referred to as the 'remedial teacher' in this paper) is also a qualified and experienced school science teacher of over 16 years. The proceedings of the lesson are summarized in Table 1.

Approximate Time frame	Learning/teaching events	Pedagogical approach
10 minutes	- Introduction - Importance of separation techniques in chemistry - Example of a technique: Simple Distillation	*Teacher talk*
10 minutes	- Activity: Students to pose questions - First attempt: Invitation to verbalise the questions (no students volunteered) - Second attempt: Invitation to write down the questions starting with the words "*What if..*" (Students were observed to be actively on task.)	*Reflective learning* strategy: Use of "*what if*" questions to get students to observe the learning task and generate responses (in this case posed questions)

20 minutes	- Activity: Teacher-facilitated the discussion on the what if questions posed and written by the students on slips of paper. - The slips of paper were collected and each student's written questions were projected on visualiser and openly discussed by the students with comments and evaluative remarks made by the teacher. Students were instructed not to write their names on the paper.	*Reflective learning strategy:* students engaged in meaning making (that is, attempting to answer, critique and perhaps re-phrase the questions so that some relationships can be established among the ideas generated).
5 minutes	- Summary: teacher summarised students' responses to the learning tasks - Conclusion: teacher concluded lesson with a review of the distillation method	*Teacher talk*

Table 1: Lesson Proceedings

After the formal greetings and a simple self-introduction, the remedial teacher proceeded to explain the importance of separation techniques in chemistry. He cited simple distillation as an important technique that allows us to obtain a pure solvent or liquid from a contaminated liquid sample (a solution or a suspension). A fully labelled diagram of the apparatus set up for simple distillation was projected on the screen with the help of a visualiser (Figure 1). Referring to the diagram on the screen, the remedial teacher then proceeded to explain how the simple distillation apparatus works. The students were attentive and some were busy taking notes. This segment of the lesson lasted about ten minutes and was totally delivered by teacher-talk.

At this juncture, students were invited to verbally ask any question about the apparatus set up. There was a short pause with no response from the students. The remedial teacher then requested that they pen their questions on blank pieces of paper. Again, there were some "thoughtful" actions (for examples, a boy had his chin propped by his hand on the table and a few girls showed contorted eyebrows, all presumably deep in their thoughts). Most of them stared blankly at the diagram projected on the screen. Again, no one wrote anything.

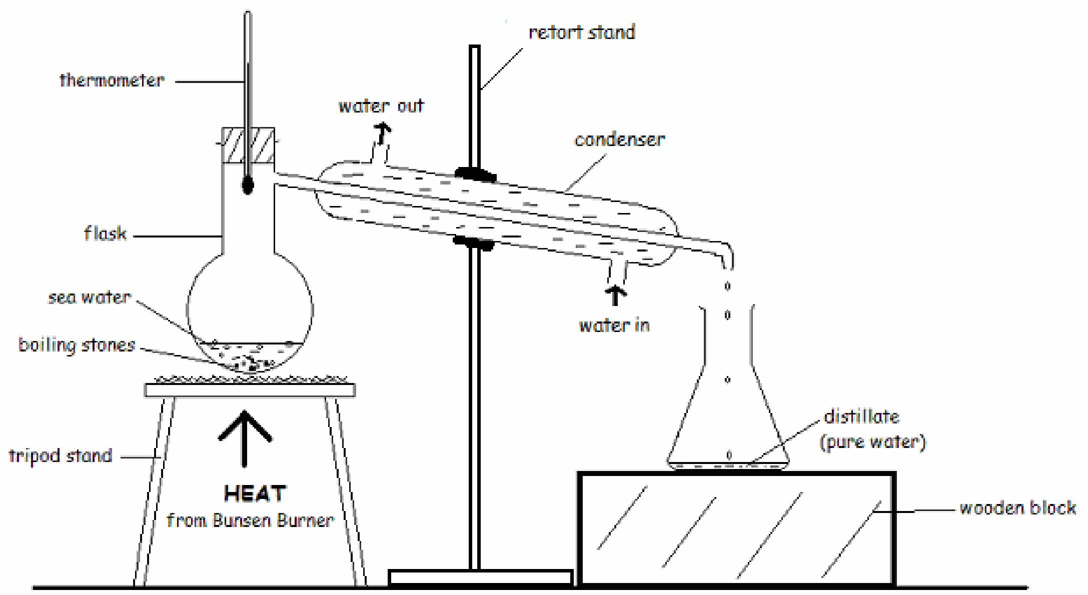

Figure 1. Diagram of a simple distillation set up for distilling seawater.

The remedial teacher then wrote the following words on the whiteboard – "*What if…*" and instructed students to begin posing their questions with these two words. He also added that they could ask anything about the apparatus set up, including the materials, products, reaction conditions or anything that interest them, so long as it was something related to the simple distillation process or apparatus set up. They could ask questions that they know the answers, or questions that they do not know the answers. *No examples* were given to the students other than these instructions.

It was observed that students began to pen their thoughts, writing down the questions and raising their heads periodically to refer to the diagram shown on the screen. It took about ten minutes before most of them became exhausted of ideas and a few started to curiously peek into their neighbours' work. The remedial teacher then collected the papers and began to flash them one by one on the visualiser. For each student's questions presented, the remedial teacher facilitated an almost spontaneous response from the floor. Students were observed to be chatty while a few showed amusements at their peers' questions. There was a lively contribution to the possibilities raised by the questions, including difficult and unfamiliar situations arising from questions like "*What if* there is no condenser there?" and "*What if* the Bunsen burner was replaced by a candle?" (Figure 2)

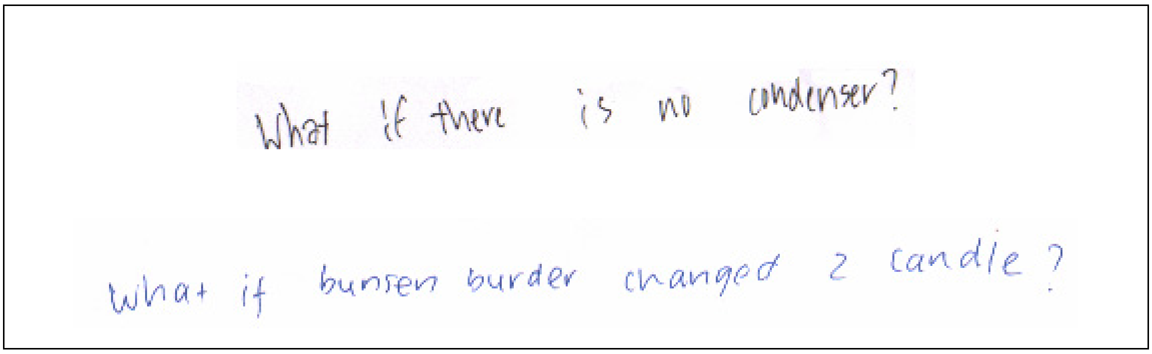

Figure 2. "*What if..*" questions can surface unfamiliar experimental situations

The "what if" questions and peer responses

The activity generated a list of 26 questions from the ten students (Table 2). These questions can be broadly classified into 11 different types of "*What if…*" questions pertaining to the topic on simple distillation of seawater.

	Conditions	**Broad Questions Asked**	**Frequency**
A	Missing materials	1. "*What if* there was no boiling stones in the flask?"	6
B	Change in set up of apparatus (including missing pieces)	2. "*What if* the positions of the water inlet and outlet of the condenser were switched?	2
		3 "*What if* there were no thermometer in the set up?"	1
		4. "*What if* there were no condenser?"	5
C	Change in choice of apparatus or materials	5. "*What if* candle(s) was/were used in place of the Bunsen burner?	2
		6. "*What if* hot water was used in the condenser instead of cold water?"	1
		7. "*What if* the flask is made up of a different material (other than pyrex glass)?"	1
		8. "*What if* there are other particles in the seawater?"	1

D	Change in physical or environmental conditions	9. "*What if* the room conditions were changed (higher or lower than standard)?"	4
		10. "*What if* a smaller (Bunsen) flame was used?"	2
E	Unexpected experimental results	11. "*What if* the water distillate was tested to be impure?"	1
		Total number of "*What if*" questions generated =	26

Table 2: Breakdown and frequency of the types of "*What if…*" questions posed by students.

(For the actual questions posed by students, please see Annex A)

Unfortunately, the lively discussion during the presentation of the students' "*What if..*" questions was not documented on paper on the spot or recorded in any media form. However, some typical examples of peer responses to the posed questions are summarized in Table 3. A few of the peer responses may not be technically sound and some may be incorrect. It is important to have these misconceptions addressed immediately, and on the spot, by the teacher. This was done each time the teacher identified a misconception during the discussion. Table 3 also shows some examples of students' misconceptions identified from their posed questions and peer responses.

"*What if..*" questions and typical peer responses
1. "*What if* there was no boiling stones in the flask?" *Typical peer responses*: a. "There will be no boiling in the water." (Misconception) b. "Boiling will spill out of the flask." (Possible, especially if "bumping" occurs and may cause the boiling liquid to spill out through the thermometer adaptor.) *What could happen and why it happened*: The boiling stones provide jagged surfaces for dissolved air to form small air bubbles. This will prevent the formation of a big air bubble at the bottom of the flask which would attempt to "break free", hence the "bumping"

phenomenon.
2. "*What if* the positions of the water inlet and outlet of the condenser were switched? *Typical peer responses*: a. "There will not be any liquid collected." (Misconception) b. "There will be less liquid collected." (Actual result) *What could happen and why it happened*: The direction of condensing medium (cold water) in the jacket of the condenser should be opposing the direction of the hot vapour entering the condenser through the tube. This way, there will always be a maximal temperature gradient between the hot vapour and cold condensing medium, resulting in a large amount of vapour condensing into the distillate. By switching their positions, the temperature gradient will be greatly reduced and somewhere midway or so in the condenser, the temperature difference between the vapour and the medium may not be significant enough to continue a good condensation process, hence the amount of distillate obtained will be reduced.
3 "*What if* there were no thermometer in the set up?" *Typical peer responses*: a. "I cannot do the experiment, because I cannot read the temperature." (Fair enough, but distillation can still continue without the thermometer in place.) b. "The distillation will be slower." (Misconception) *What could happen and why it happened*: The thermometer serves only as a monitoring instrument in this apparatus set up. It does not contribute to the distillation process. The distillation will still continue as usual, at the same rate, with or without the thermometer.

Table 3: Typical peer responses (verbal) to "*What if*…" questions posed by students

Discussion

The teacher-talk section lasted about ten minutes. Students took about another ten minutes to think about how to pose and write down the questions. This involved closely studying the diagram on the projector screen, generating possibilities on how the questions may be written, and making sense of the questions and possible responses if they know the answers. This was what one student did – she provided answers to her own questions. (See Annex A, last example)

The next twenty minutes were spent on facilitating peer responses to the questions. It is interesting to note that the students came from two classes and may not have known each other well. Although this is may be an assumption, what is amazing was that they were able to warm up to a total stranger, the remedial teacher, in just a couple of minutes. They were chatty and fully engrossed in contributing to possible answers to their peers' questions. There was laughter, an occasional argument and of course, delightful comments like "*Ah, we didn't know that!*" or "*Oh, now I see!*" (for example, when the teacher commented that theoretically, replacing the Bunsen burner with a candle would still lead to pure water being collected as the distillate, but in practice, this would be a slower and a less efficient process). They also expressed surprise that the thermometer is not an essential piece of apparatus in the set up.

The entire classroom learning experience threw up several interesting and noteworthy teaching-learning issues for science teachers.

(1) Modeling real life learning experiences.

Reflective learning strategies, like the use of "*what if*" questions, can be effectively applied to classroom situations. These learning experiences are, in effect, models of real life problem-solving and learning experiences (Associated Press, 2007; CNN, 2003; Straits Times, 2003). By posing "*what if*" questions on the distillation set up, students not only get to see the "problem" from different angles, they also have to generate different possibilities and interpret the situation in different ways.

(2) Engagement of dialogic activity.

Students were actively engaged in generating possibilities, defending their ideas, and developing deeper insights through social interactions with peers. There were a lot of opportunities for student-student and teacher-student communication. Plain knowledge dissemination and routine assessment tasks following a traditional lecture-demonstration lesson would at best result in students being able to understand the basic technical concepts and to apply the knowledge within a very limited scope (that is, within the curricular requirements).

(3) New knowledge and learning opportunities.

From the students' "*what if*" questions and the corresponding responses from the floor, including those from the teacher, new knowledge and challenges arose. Many of these were surfaced from the discussions and some could even be extended into mini projects or investigative activities in the laboratory. Although several learning situations arising from students' questions and responses (Tables 2 and 3) are not within the curricular requirements, new learning experiences gained from this lesson could help students transfer their observation and analytical skills to other learning situations in future.

The experience may be refreshing but several concerns have also been identified.

(1) Readiness of the teacher.

In facilitating the discussion, the teacher has to be knowledgeable on the topic and open to unfamiliar learning situations. She or he has to be ready to accept students' responses with some degree of plausibility and make connections between the students' questions and responses with the technical details involved in the topic. In the school context, it may be necessary to link the students' responses and ideas to what they are expected to learn from the prescribed curriculum (that is, from the syllabuses and textbooks). Although not every teacher is ready for such unpredictable learning-teaching situations, new learning situations like these could engage the teacher as a co-learner with the students, albeit an advanced one.

(2) Time constraints and proper closure for the lesson.

It is important to have a proper closure for the lesson. This means a good control over the time spent in the various stages of the lesson (from teacher talk to posing of question, peer responses and finally the summary). The teacher will need to tie up loose ends before summarizing the students' contributions and presenting the entire concept to them. If necessary, a separate lesson should be conducted to evaluate the students' understanding and abilities to apply newly acquired knowledge and skills. The concern here is that this remedial lesson was taught to a class of only ten students and it took about 40 minutes. To conduct a proper lesson of 60 to 70 minutes and to 40 students may not be as simple, especially when the more abstract science concepts and topics are being taught. Time constraint may hamper the facilitation of the students' discussion for it to be as effective.

(3) Follow-up learning opportunities.

With the teacher's experience, it would be possible to identify follow-up learning opportunities from this lesson. Some activities may be experimental, like letting students investigate by comparing the effectiveness of using a Bunsen burner and candles in a distillation set up. Other activities may involve evaluation of students' ability to analyse information. For example, students may be asked to comment on the effectiveness of the distillation process based on two sets of temperature data of water leaving the condenser's outlet - one set with water entering from the top of the condenser and another set from the bottom.

Although there is yet any research evidence to support the effectiveness of using 'what if' questions in a science lesson, observations from this lesson seem to suggest that students will show a high degree of motivation during and after such a lesson. They were actively on task, generating the questions, and discussing the responses during the peer response stage. At the end of the lesson, the students commented that the lesson was interesting. The teacher agreed but confessed that he had only prepared one diagram to teach the lesson while the rest of the teaching materials (the questions and responses) actually came from them. The students unanimously agreed in a choral reply, "That's why!" Their enthusiasm could therefore support the assertions from research on the use of students' questions, that students' motivation to learn is driven by their own questions, especially if they can ask the right questions and answer them (Chin and Chia, 2004).

Recommendations and Conclusion

The curricular statements that are used to assess students in some high-stake public examinations have all along dictated the teaching of science and other school subjects. However, unique to science are the elements of teaching through experiments and the high degree of creativity needed to solve problems. While it may be necessary to retain the lecture-demonstration style of lesson delivery, especially where basic experimental science topics are concern, teachers can try identifying opportunities for students to ask questions and insert short sessions within their assigned curricular schedules to let students have a go at posing and answering their own questions. This would help the students develop highly transferable skills of observing, generating and relating, and thus build a reflective learning culture in the classroom and laboratory. On the effectiveness of using "what if" questions, and in general, the use of student-generated questions of whatever form, research studies may best be done on specific topics and with groups of students of differing academic abilities. Teachers would agree that students' motivation to learn is an essential precursor to their achievement in school.

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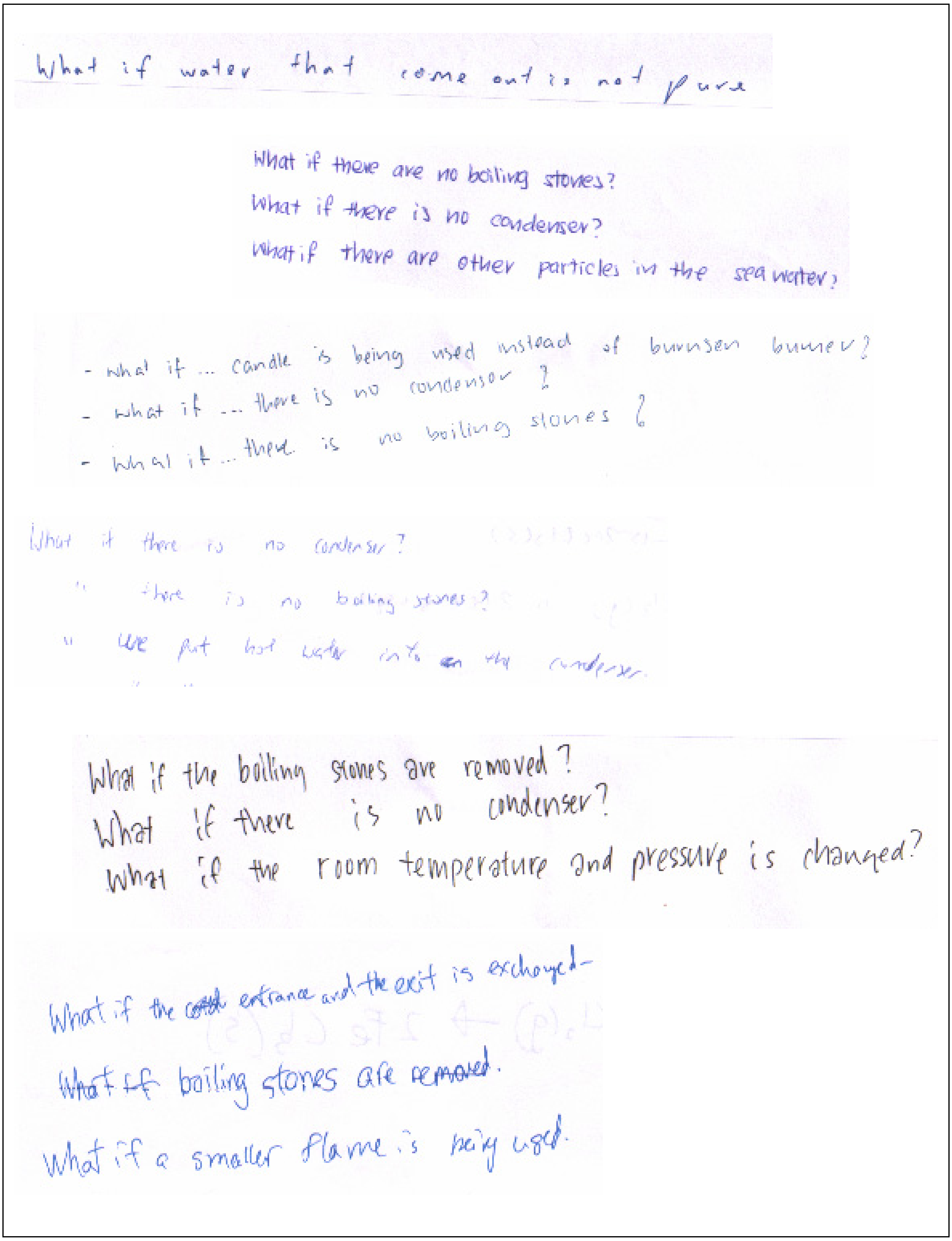
Annex A: Selected examples of "what if" questions posed by students



What if water that come out is not pure

What if there are no boiling stones?
What if there is no condenser?
What if there are other particles in the sea water?

- what if ... candle is being used instead of bunsen burner?
- what if ... there is no condensor ?
- what if ... there is no boiling stones ?

What if there is no condenser?
" there is no boiling stones?
" we put hot water into the condenser.

What if the boiling stones are removed?
What if there is no condenser?
What if the room temperature and pressure is changed?

What if the ~~cold~~ entrance and the exit is exchanged.
What if boiling stones are removed.
What if a smaller flame is being used.

What if the room temperature is not 25°C?

What if the flask is made up of different material?

" " The flame is not strong enough?

(1) What if there are no boiling stones?

Ans: ~~beco~~ the boiling will not smooth

(2) What if the water in and out are exchange?

Ans: The water will not be condensed.

(3) what if bunsen burder changed 2 candle?

Ans: the experiment will not be carried out. It takes very long.

About the author

TAN Kok Siang is a chemical education lecturer at the Natural Sciences and Science Education Academic Group, National Institute of Education, Nanyang Technological University, Singapore. He graduated from the National University of Singapore with a Bachelor of Science degree and holds a Masters of Science (Training) from the University of Leicester. Before becoming a teacher, he was a chemist in the pharmaceutical industry. In school, he taught science and was head of the science department in a secondary school before joining the NIE. He specializes in classroom and laboratory reflective pedagogy, school experimental science and chemical education. His main research areas are in student-designed chemistry experiments and reflective learning.