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Instructor's Use of Student-Generated Annotated Concept Sketches in Formative Assessment in General Science

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ABSTRACT

Student-generated annotated concept sketches provide an alternative approach for instructors to formatively assess students' understanding of environmental topics, such as photochemical smog and ozone layer depletion. The sketches are external representations of students' cognitive models. Results obtained from a group of 150 female students using an action research methodology, suggest that this method is effective in enhancing students' engagement and communication among peers. This further helps students to reinforce scientific theories and concepts. Furthermore, the data gathered also revealed alternative conceptions, misconceptions, and knowledge gaps in students' understanding and provides an opportunity for easy and immediate feedback. In this study, misconceptions define ideas that are in direct contrast with the accepted scientific conceptions, whereas alternative conceptions describe ideas that are incompatible but unconflicting with the accepted scientific conceptions. Students were actively engaged and showed the ability to express their knowledge in ways other than writing, which is especially useful in English Language Learner (ELL) friendly environments. Students were required to participate in the lecture by paying special attention to the source of pollution, environmental impact, and solutions to issues related to air pollution. The representational annotated concept sketches were completed individually or in groups of two to three students. Feedback was provided orally, and/or using a rubric designed to identify and highlight understanding, misconceptions, and knowledge gaps.

Keywords: Concept Sketches; Formative assessment; Active learning Strategies; Cognitive models; English Language Learner Friendly Environment

INTRODUCTION

Many undergraduate programmes require that students complete a general education component. Usually, general science is integral to the core-curriculum. General science education modules are aimed at fostering critical thinking and increasing students' global and local awareness of scientific issues (McConnell, Steer, & Owens, 2003; Solas & Wilson, 2015). However, students especially non-science majors, find it difficult to understand scientific material because of the inclusion of specialized jargon and abstract concepts (Ajaja, 2013). Within an English Language Learner (ELL) friendly environment, the complexities in terms of understanding increase, because the capacity of the mental working space of students

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reportedly reduce by up to 25%, owing to translation activities (Johnstone & Selepeng, 2001). Other studies, conducted from the point of view of teaching within the Arabic English Language Learning (AELL) classrooms, have outlined the difficulties faced by not only students but also native English-speaking faculty in the Middle East (Jewels & Albon, 2012; Wilson, Copeland-Solas, & Guthrie-Dixon, 2016). As such, countries that teach science in non-native languages should be aware of the implications of reduced critical thinking among language learners (Johnstone & Selepeng, 2001).

Within the general science classroom, it is imperative that instructors are able to gain insight into students' cognitive models to regulate and adapt their teaching to meet students' learning needs. Studies have shown that an effective formative assessment results in significant learning gains especially for low achievers (Black & Wiliam, 2010). Time constraints, language barriers, and lack of useful techniques result in a paucity of useful information to fulfill the exigencies of deep learning in classrooms.

Formative Assessment

Traditionally formative assessments are grouped into areas of questioning, providing assessment criteria (e.g., rubrics), feedback through written comments, peer and self-assessment, as well as summative assessment (Black & Wiliam, 2009). However, many of these methods are time consuming and burdensome for the teacher and do not fulfill the needs of deep learning, which is the main focus of formative assessment (assessment for learning). There is still a pressing need for assessment techniques which allow teachers to gain an insight into the cognitive models of learners to establish levels of comprehension, knowledge gaps, and misconceptions in learners. Information gained from such assessments would be extremely useful in increasing the learning levels of the students. According to David Ausubel, as reported by Wiliam (2011), understanding what a student knows, bears a significant influence on future learning as it provides the teacher with the tools to adapt the teaching methodology as per the student's needs. A few researchers have revealed that, despite similar instruction, students have different cognitive models for understanding concepts based on their prior learning experiences. Some researchers are even of the view that these existing cognitive models are mainly unaffected by instruction (Chandrasegaran, Treagust, & Mocerino, 2007; Howard, Brown, Chung, Jobson, & VanReken, 2013). It is therefore crucial that teachers understand these cognitive models to be able to affect change positively.

Drawing in Science Teaching and Learning

The merits of drawing to student learning in science have been well-documented (Ainsworth, Prain, & Tytler, 2011; Davidowitz, Chittleborough, & Murray, 2010; Johnson & Reynolds, 2005; Leopold & Leutner, 2012; Mason, Lowe, & Tornatora, 2013; Nyachwaya et al., 2011; Schwamborn, Mayer, Thillmann, Leopold, & Leutner, 2010; Van Meter, Aleksic, Schwartz, & Garner, 2006; Van Meter & Garner, 2005; Zhang & Linn, 2011). In their study, *Drawing to Learn in Science*, Ainsworth, Prain, & Tytler (2011) suggest that science teachers use student drawings inside classrooms to enhance student engagement, foster reasoning, and increase communication among themselves. Leopold and Leutner (2012) state that the drawings of students provide external representations of their cognitive models and therefore exposes the comprehension level of students. Johnson and Reynolds (2005) have successfully used student-drawings in geology to stimulate thinking and practice the selection of the main ideas. In chemistry, drawings have been used to provide instructors with external representations of students' cognitive models of chemical structures at the submicro level (Davidowitz et al., 2010; Kern, Wood, Roehrig, & Nyachwaya, 2010; Nyachwaya et al., 2011). From the sketches, instructors have been able to recognize students' prior understanding, knowledge gaps, and misconceptions, which were not obvious with traditional methods of using chemical symbols to represent reactions. It is also suggested that the discipline of having students create external representations of concepts forces them to actively arrive at main ideas, relevant connections, and the best ways to summarize and represent the information gained (Schwamborn et al., 2010). These claims have also been supported by Naylor and Keogh (2013). They proposed that concept cartoons are a valuable tool in helping learners to develop their ideas.

> Generally learners readily engage in discussion when Concept Cartoons are used, and as they attempt to justify their ideas, this exposes their views to the possibility of challenge by their peers. In looking for evidence and constructing suitable arguments to justify their ideas, learners often come to recognize for themselves that their understanding is limited and that there are more productive ways of understanding the situation. (p. 7)

These actions eliminate tendencies toward superficial learning though some researchers caution that if the mechanics of drawing are too demanding they may interfere with the capacity of learners to focus on generative activity, which in turn facilitates deep learning (Schwamborn et al., 2010).

This study describes the use of student-generated sketches as a formative assessment tool in environmental science. We describe how students, when using this strategy, provide teachers with external representations of cognitive models thereby allowing teachers to adapt their teaching methodology to improve student learning, which results in deep learning.

METHODOLOGY

Participants

The study used a convenience sample of N = 150 female students of a core-curriculum science course. The sample selected was based only on the classes assigned to the investigators. All students were Arabic English Language Learners. The sketches were collected over two semesters. Students either did individual sketches or were part of a group of two to three students. All students had previously taken a basic science course, which introduced them to the scientific process. Students were in their third semester or higher of their university programme.

Study Design and Data Collection

An action research methodology was the approach taken for this investigation. Action research can be defined as a process of inquiry conducted by individuals performing the action (Sagor, 2000). It focuses on instructors gaining a better understanding of their practice to inform how the practice itself can further be improved (Carr & Kemmis, 2005). The investigators mainly sought to assess how effective the use of concept sketches would be as a pedagogic strategy geared toward improving the learning experience of these language learners.

Students were taught lessons on topics related to air pollution including ozone layer depletion (OLD) and photochemical smog (PCS). At the start of each lesson, students were encouraged to note the names of air pollutants, sources of pollutants, effects on humans and the environment, and solutions to the environmental problems. Each topic was explained using a variety of methods: power point slides, anthropomorphism, videos, and animations. The explanations of the topics were repeated with emphasis being laid on the main ideas.

Students were then asked to brainstorm relevant ideas among themselves and jot down relevant information on how their ideas would be presented either individually or in groups. They were then asked to represent their understanding of the topic of study through a drawing. Drawings should include each of the main ideas emphasized and the significant relationships between the ideas. The students were also encouraged to discuss their sketches with other groups/individuals to foster communication and build each other's knowledge by listening and critiquing each other's work.

Sketches collected on photochemical smog included 36 group sketches and 54 individual sketches. A total of 68 individual sketches were collected for ozone layer depletion.

Data Analysis

The data was analyzed using a phenomenographic approach (Marton, 1986). Marton defines phenomenography as studies focused on qualitatively mapping the ways students perceive concepts differently within their environment (Marton, 1986). A qualitative study was conducted on the sketches produced by students on the environmental science topics. Sketches were assessed for representation of main ideas, correct portrayal of important relationships, conceptual errors and misconceptions, knowledge gaps, alternative conceptions, sketch and label details. Misconceptions was used to define ideas that are in direct contrast to the accepted scientific conceptions, whereas alternative conceptions describe ideas that are incompatible but are unconflicting with the accepted scientific conceptions(Abimbola & Baba, 1996). Feedback to students was given either orally and/or using a rubric, which was adapted from Johnson and Reynolds (2005). Four instructors from the science department examined and analyzed the sketches based on the rubric although no grades were assigned. Information gathered from the sketches were compared, whereever applicable, to that from other studies to analyze similar issues using other techniques, such as questionnaires and interviews (Cordero, 2000; Howard et al., 2013; Papadimitriou, 2004) .

Table 1. *Rubric for Concept Sketch*

Category	General Rubric		
Content	All essential concepts shown	Most concepts and relationships correctly shown	Essential concepts left out
	Important relationships portrayed correctly	Some aspects left out	Relationships not portrayed correctly
	No conceptual errors or evidence of misunderstanding	Minor conceptual errors or misunderstandings	Major conceptual errors or misunderstandings
Detail and Presentation	Sketch detailed and clearly drawn and labeled	Sketch lacking some detail	Sketch lacking detail or is illegible
		Not clearly drawn or labeled	Sketch is difficult to interpret

Content should include the following topics: causes, effects, important pollutants, solutions, and correct relationships between pollutants and processes.

RESULTS and DISCUSSION

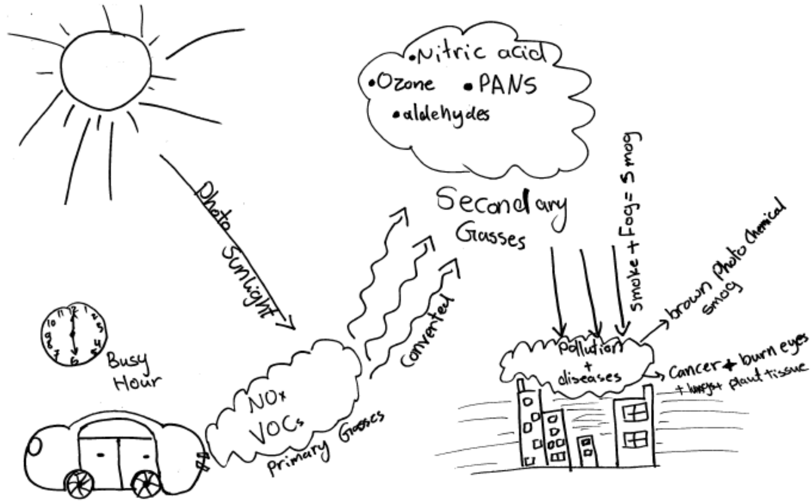
The general observations showed that students spent more time on the task during this activity than that spent on traditional worksheets; further, they seemed genuinely more engaged and motivated. Students could be seen comparing their sketches with each other and frequently amended their sketches wherein they believed that their key points were omitted. Students could be heard using scientific jargon when they were brainstorming with their peers and they were seen explaining their ideas to their peers, who needed further clarification.

Administration of the drawing technique and providing feedback to students was immediate and easy. Students appreciated the timely feedback and were very actively engaged in the process. It was heartening to see students engrossing themselves to an extent that they were even oblivious of the time as they worked on their sketches. The themes that emerged from the sketches were used as diagnostic tools to frame further instruction. The sketches of the students detailed out almost all the information on the concept thereby revealing the knowledge gaps, misconceptions, and alternative conceptions that were influenced by prior learning experiences. A quick assessment on the quality of the sketches revealed that more details were added when sketches were performed in groups versus those done individually. As was observed by Ozuro et al. and reported by Leopold and Leutner (2012), students submitting high quality sketches generally had higher levels of understanding. This was evident based on the higher test scores of these students.

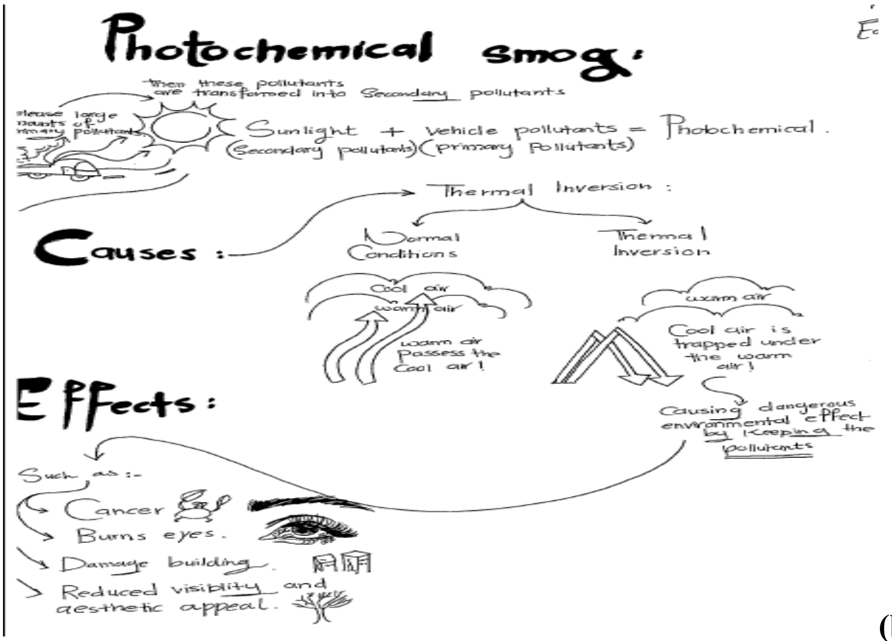
Emerging Themes from Sketches on the Formation of Photochemical Smog

A total of 90 sketches were assessed on photochemical smog (54 individual sketches and 36 group sketches). The sketches revealed that most students understood the principle behind the formation of smog and its effects on the environment (see Figure 1). Some students found it difficult to remember the names of primary and secondary pollutants. Other misunderstandings and knowledge gaps included incorrect relationships between primary and secondary pollutants; a belief that all primary pollutants, including carbon monoxide, resulted in the formation of photochemical smog, and that photochemical smog was destroying the ozone layer. It was interesting to see student sketches, including that on the ozone layer, in the drawing of photochemical smog, This is because, though ozone layer depletion is included in the syllabus, students were not yet given instruction on the topic. This confirms that students' preexisting knowledge inside the classroom and fit knowledge gained within the lesson into their prior cognitive schema, which may lead to incorrect cognitive models if not addressed (Osborne & Wittrock, 1985) We believe in this case that students confused tropospheric ozone, formed as a part of photochemical smog, with their prior knowledge on the destruction of stratospheric ozone.

A few sketches showed no relationships, pollutants, or effects; however, they showed only structures, such as buildings and cars. These sketches were usually produced by low achieving students and further revealed that their cognitive models missed relevant information on the concept. In a few instances, it was noticed that students who were very artistic spent too much effort and time on the quality of the artwork, rather than on the generative activity. This issue was mentioned by Schwambon et al. (2010), as they cautioned users of the technique that this could occur. Figures 1–4 provide examples of student sketches on photochemical smog and some information that could be gathered from each of these sketches.



(a)



(b)

Figure 1. Two examples of student-generated group sketches on photochemical smog

Findings

- The sketches shown in Figure 1 provide all details on the concept thereby providing the names of pollutants, their sources, and the health as well as environmental effects of PCS.

Figure 2. A student-generated sketch on PCS showing the misconception that carbon dioxide is involved in all problems related to air pollution

Findings

- This sketch reveals that the student understands that factories and vehicles lead to air pollution.
- The catalytic converter is called a filter on the car to indicate its “cleaning” effect on pollutant gases.
- The student understands the role of sunlight acting on oxides of nitrogen and hydrocarbons to form photochemical smog; however, he/she has failed to indicate the names of secondary pollutants.
- The student has used an increase in the number of trees to remedy the problem related to air pollution. Here, a knowledge of carbon dioxide as a pollutant is introduced; however, its involvement in photochemical smog is misplaced.

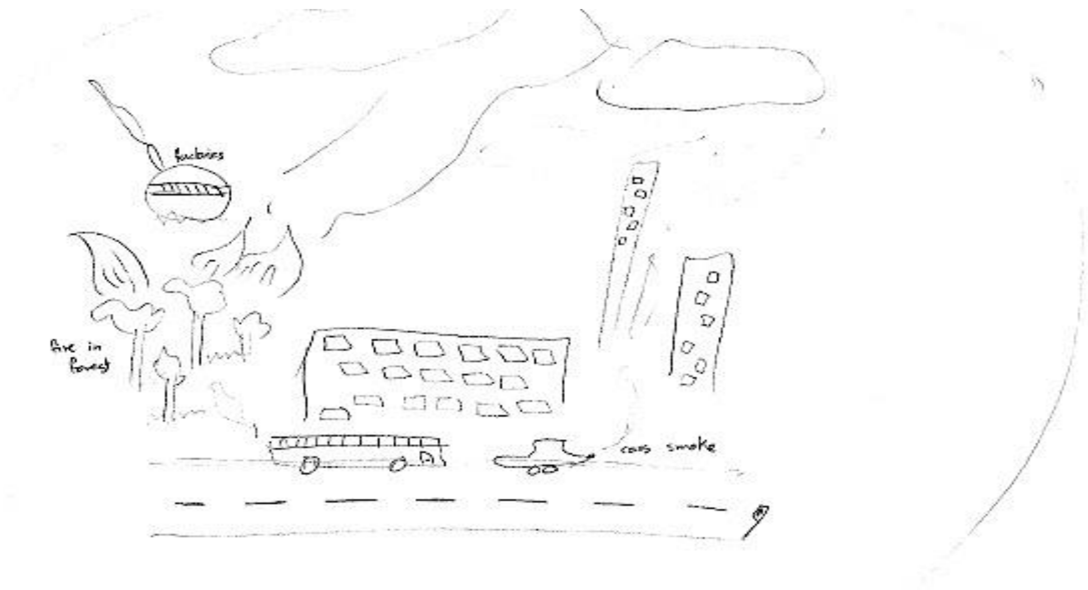


Figure 3. A student-generated sketch on PCS revealing knowledge gaps

Findings

- The student seems unsure of how exactly photochemical smog is formed; however, he/she knows that it is a form of air pollution.
- No specific pollutants are mentioned. However, motor vehicles, factories, and burning are identified as being the contributing factors to this problem.
- The effects of and solutions to solve the problem of photochemical smog are missing from the sketch.

Figure 4. A sketch showing the basic idea of PCS with some knowledge gaps

Findings

- The names of all pollutants are missing.
- The student has a general idea of the formation of photochemical smog (PCS)–and further understands the role of sunlight in the conversion of primary to secondary pollutants; further, he/she realizes that PCS is dangerous as it causes cancer.
- Vehicles have been identified as a source of primary pollution.

Group sketches were generally more detailed and showed fewer misconceptions and knowledge gaps. This is one advantage that resulted from students' learning from each other and supports social constructivism (Powell & Kalina, 2009). In these instances, students with different knowledge levels and strengths motivate and support each other (Solas & Wilson, 2015).

Emerging themes from sketches on Ozone Layer Depletion

A total of sixty-eight (68) individual sketches from female students, depicting ozone layer depletion, were analyzed. The concept of Ozone layer depletion is taught after the concept of photochemical smog is taught; therefore, students are already familiar with the formative assessment through the drawing task. In this course, the main emphasis is on the concept of chlorofluorocarbons (CFCs) being the primary ozone depleting pollutant; further, the effects of ozone layer depletion on human health, animal health, and physical environment are explored. The mechanistic details of ozone formation and destruction are not emphasized as this course is a general science curriculum module, and most students have minimal science backgrounds. The mechanism of formation and destruction of stratospheric ozone is however demonstrated through a short video to help with further clarification on the topic and satisfy the curiosity of those students who want to know more.

Several teaching methods and tools were utilized in explaining the OLD concept to students. These include caricaturing/cartooning (to show the difference between stratospheric and tropospheric ozone), drawing pictures, framing object lessons, videos, highlighting focal points, and providing cues at the start of the lesson.

An examination of the literature reveals that students commonly have alternative conceptions, misconceptions, and knowledge gaps about ozone layer depletion. A summary of issues identified from student's work, reported by other researchers, is provided in Table 2 (Howard et al., 2013; Papadimitriou, 2004). In particular, issues 8, 9, and 10, mentioned in

Table 2, were the most common misconceptions observed by the authors in the sketches that students generated.

Table 2. Misconceptions, alternative conceptions, and knowledge gaps regarding ozone layer depletion (Howard et al., 2013; Papadimitriou, 2004)

	Misconceptions, alternative conceptions, and knowledge gaps as seen from students' sketches	**Comments**
1	The concerns regarding ozone is due to its role as a greenhouse gas.	Its protective function in the atmosphere is not considered.
2	The students believed that stratospheric ozone was formed from oxides of nitrogen (NOx) and volatile organic compounds (VOCs).	This shows that students confuse between stratospheric and tropospheric ozone and the mechanism of the formation of each.
3	Ozone acts as a filter to remove harmful UV rays.	Alternative conceptions regarding the mechanism used to prevent harmful UV rays from reaching the earth.
4	The hole in the ozone makes the radiation vertical and therefore harmful.	This supposition stems from sunrays being more direct and therefore more potent.
5	The ozone layer is made of many compounds.	Other compounds excluding ozone form the ozone layer.
6	Pollutants dissolve the ozone layer.	Alternative conception of how stratospheric ozone is destroyed.
7	Ozone is contaminated by pollutants from the earth.	Alternative conception of how stratospheric ozone is destroyed.
8	Carbon dioxide is responsible for the depletion of ozone layer.	The students show confusion regarding the role of carbon dioxide in the process of environmental degradation.
9	Individual names for pollutants are omitted in favor of general terms such as aerosols, industry emissions, cars, and spray.	Some students have trouble recalling the names of pollutants, preferring instead to indicate the sources.
10	Cars and industry emissions are responsible for the depletion of the ozone layer.	The students are unclear regarding the roles of cars and industry emissions in air pollution.

An analysis of the sketches (see Figures 5–8) revealed that most students understood the position of the stratosphere in relation to the troposphere and earth. Though some students were not able to recall the name of the primary ozone depleting pollutant, most were able to recall CFCs as the agent of destruction for stratospheric ozone.

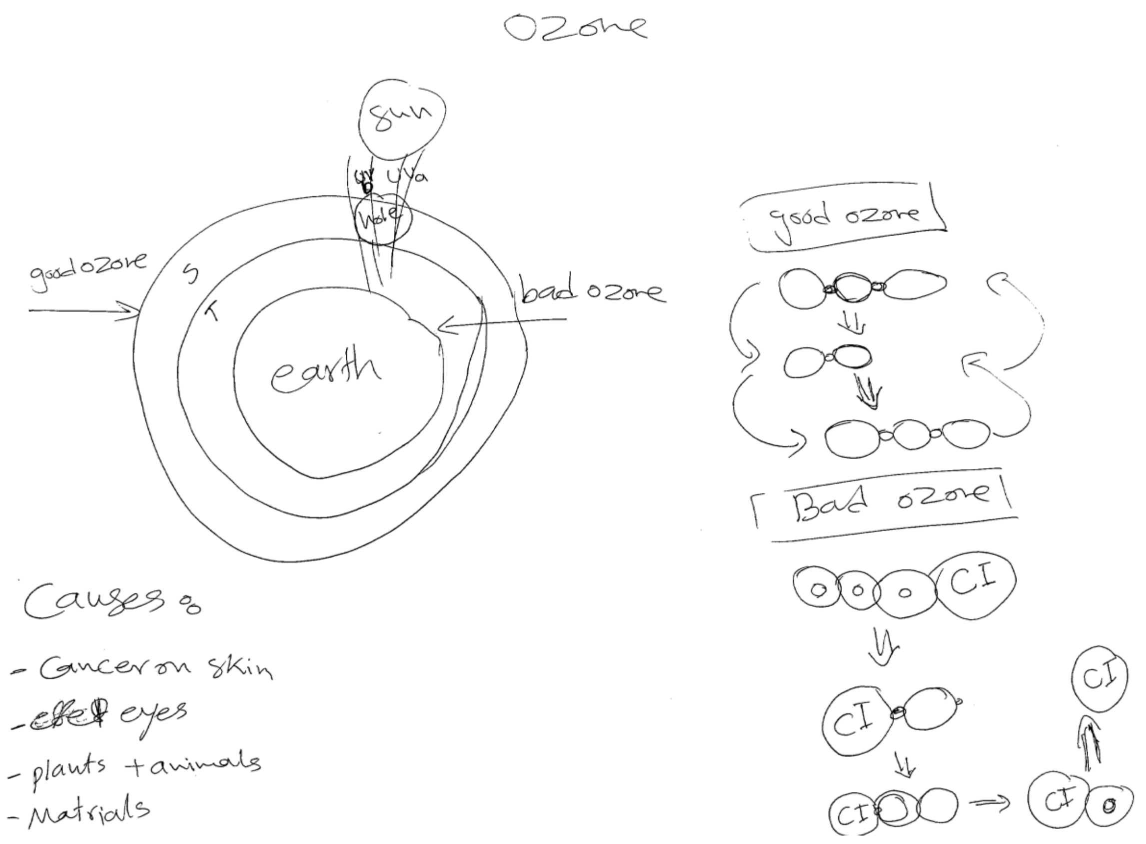


Figure 5. A sketch that reveals the misconception on why ozone is beneficial in the stratosphere and detrimental to the troposphere

Findings

- The sketch reveals an understanding of the positions of stratospheric ozone and tropospheric ozone relative to the earth's surface.
- One glaring misconception revealed is that ozone is "bad" because it reacts with the CFCs; however, it is good if it breaks and re-forms as ozone.
- The sketch indicates an awareness of problems, such as skin cancer, eye problems, associated with the ozone layer depletion.

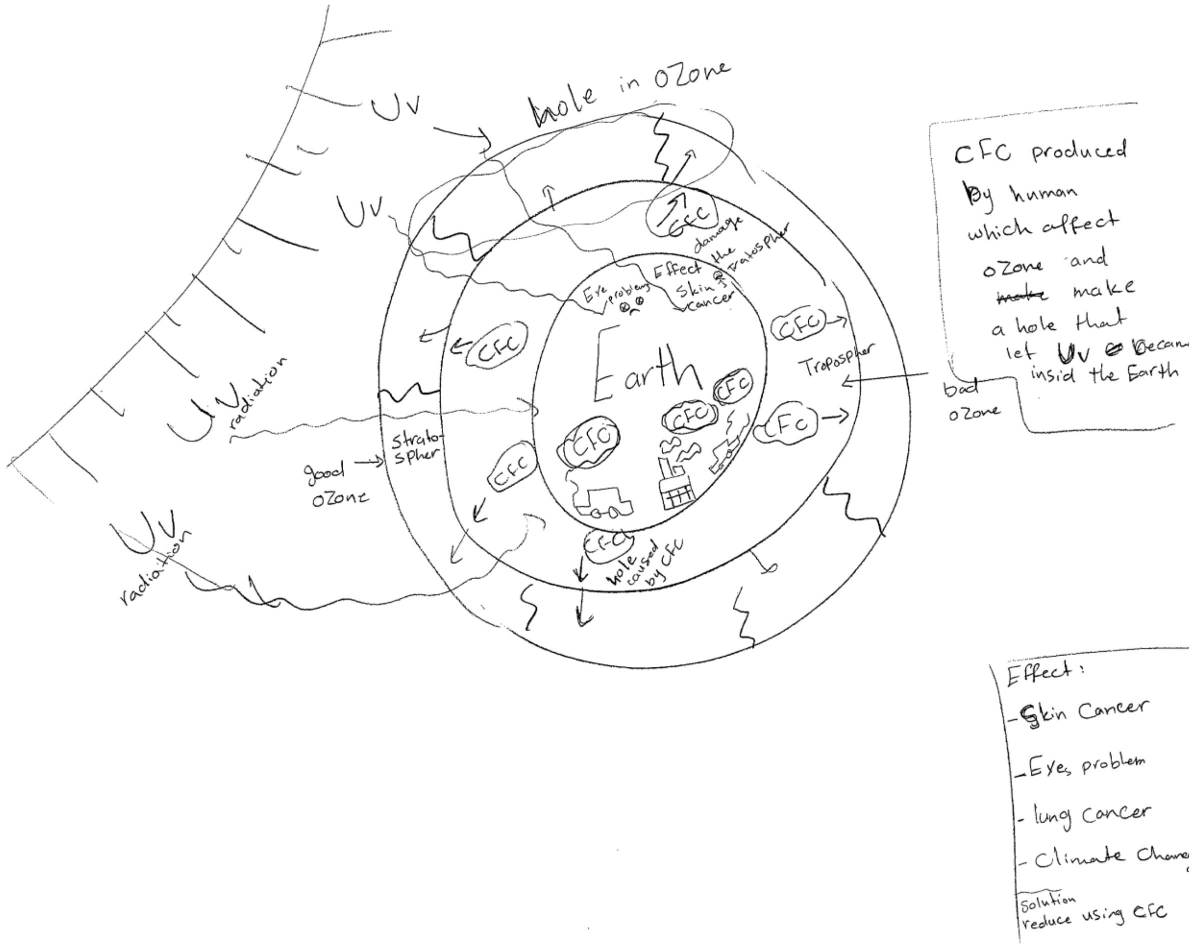


Figure 6. A student-generated sketch showing that motor vehicles and factories are incorrectly implicated in CFC production

Findings

- The above sketch reveals an understanding of CFCs as a manmade pollutant, the effect of CFCs on the ozone layer, and the harmful effects of UV radiation on the earth due to ozone layer depletion.
- It is easy to see that this student, as shown in this sample, has a deeper understanding of the concept than the one shown in Figure 5.

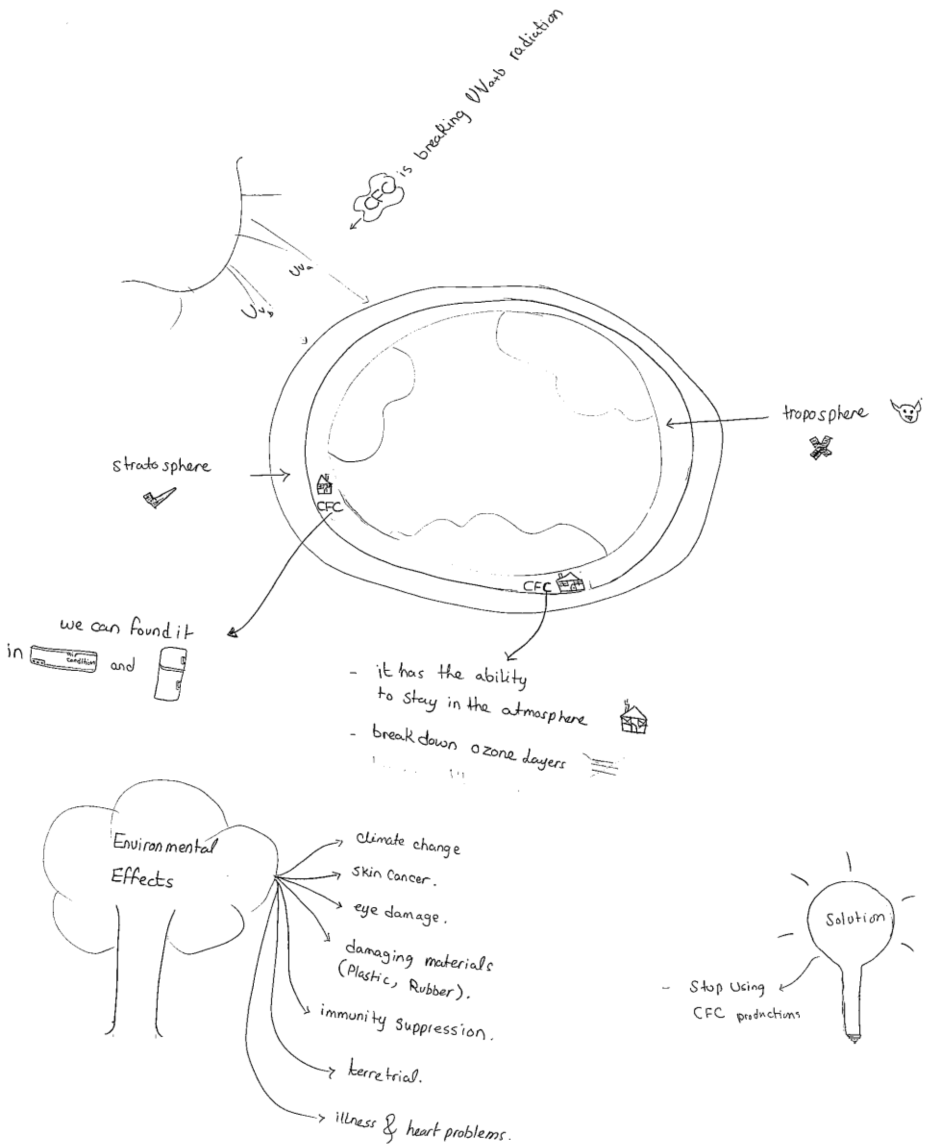


Figure 7. A student-generated drawing showing that CFC is "breaking UV radiation," illustrating a knowledge gap

Findings

- This sketch correctly implicates CFCs as a cause of ozone layer depletion. Here, the student gives the following message as a solution to the problem: stop producing CFC.
- The student lists several effects associated with OLD.
- No distinction is made between direct and indirect effects, which makes the instructor wonder if the student understood the distinction between the two or just wrote down every effect that had ever been mentioned in the class.

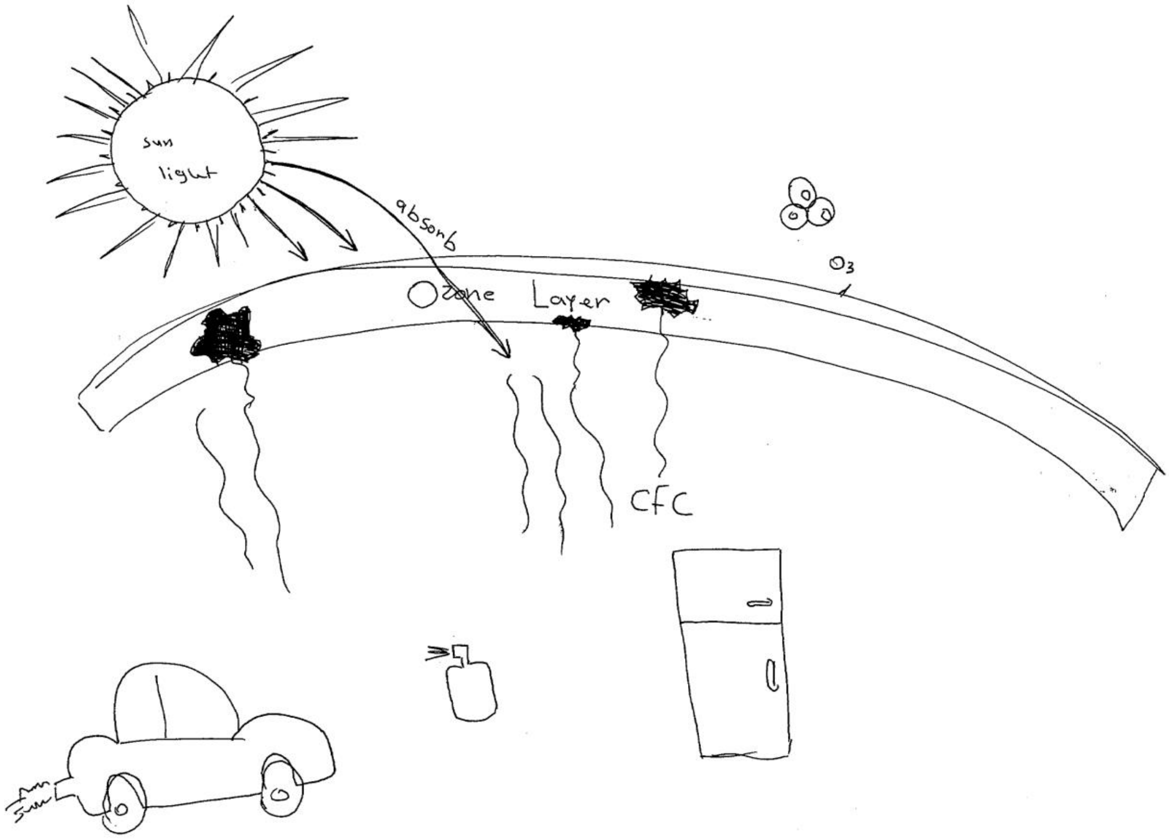


Figure 8. Motor vehicles are erroneously implicated in Ozone Layer Depletion

Finding

- This sketch reveals an understanding of the function of the ozone layer and the role of the CFCs in its depletion. However, the presence of an automobile indicates that the student believes that burning of fossil fuel is harmful to the ozone layer.

CONCLUSION

The results of the study show that student-generated annotated sketches are an excellent formative assessment tool. Formative assessments can be considered as activities that contribute to students' learning by providing information about their performance (Yorke, 2003) and those that inform student learning during the actual learning process (Bell & Cowie, 2001). This is a useful tool for both learners and educators. Having students create concept sketches allows them to make external representations of their cognitive schema thereby providing instructors with tools to assess and adjust their teaching accordingly. An effective formative assessment is crucial when teaching science to second language learners and this is considered to be an important aspect of an efficient teaching practice (Chickering & Gamson, 1987; ÇÝMER, 2007).

The literature documents reduction in the critical thinking skills and science academic achievements among Engilsh Language learners (ELLs) (Johnstone & Selepeng, 2001; Solas & Wilson, 2015). These inadequacies can only be addressed when instructors are aware of the cognitive abilities of students in a classroom situation. The ease of execution, opportunity for main idea selection and organization, prompt teacher evaluation of sketches, and revelatory glimpses of students' cognitive schema makes the technique useful and relevant inside an ELL classroom wherein students are more reliant on instructor feedback to determine their progress and the traditional methods of communication are inadequate due to language barriers.

It should also be noted that this study provides evidence that the use of sketches as a pedagogic strategy for teaching science may have significant implications in language learning environments. Activities such as sketching, facilitate the reduction of cognitive load and the ability to communicate knowledge without “filler” words, which was particularly useful for our students (Wilson et al., 2016). Another complementary aspect of using sketches in classroom situations was to give students freedom of individual expression and creativity. These features are highly beneficial in the context of our language learners as this strategy helps students to feel relaxed, creating a productive environment for the learning process. It also allows for diverse learning styles and creativity within the classroom (Eppler, 2006).

The study is also significant as the sketching technique is transferable to other pure science subjects, such as chemistry, physics, and biology. Although some researchers have used sketching to understand students’ cognitive models of particulate matter and chemical reactions (Kern et al., 2010; Nyachwaya et al., 2011), student sketches may also be quite revealing on other concepts, such as bonding in chemistry; this is a topic that has been shown to be a challenge for many students due to the abstract nature of the concept (Suat, Coþtu, & Alipaþa, 2010; Taber, 2011). For example, students may be asked to sketch what happens to water molecules when water boils. Sketches would reveal the understanding and misconceptions on intermolecular and intramolecular bonding (H-bonds vs covalent bonds). This information would not necessarily be revealed through traditional assessment. Teachers would then have a powerful tool to influence students’ cognitive models through the adaptation of classroom instruction as per the students’ needs.

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