# A SCAFFOLDING STRATEGY FOR HELPING LOWER SECONDARY SCIENCE STUDENTS CONSTRUCT SCIENTIFIC EXPLANATIONS FOR EXPERIMENTAL BASED QUESTIONS IN SCIENCE

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## ABSTRACT

The study of Science in essence involves the explanation of phenomena by inferring the reasons for occurrences and justifying the significance of the observed event (Nagel, 1961; McNeil & Krajcik, 2008). This raises a challenge for the educator: How can we equip students with the requisite knowledge, skills, and dispositions for answering science questions? This research study responds to this challenge by doing five things. First, it adopts an action strategy with reference to Feldman's approach to art criticism- DINE (whereby "D" is describe, "IN" is interpret, "E" is evaluate). Students adopt this action strategy to construct arguments and explanations needed for phenomena posed on them. Second, it incorporates a bite-size classroom-teaching to equip students with the pre-requisite knowledge. During teaching, an educator teaches directly on a "need-to-know" basis and with focus on context that can help students move forward in their inquiry with DINE. Third, it introduces a set of focal lessons for students to work on. Each focal lesson comprises a set of step-by-step instructions and tasks to be carried out by students. Each task takes into consideration the appropriate zone of proximal development (ZPD) whereby the level of potential development is determined through problem solving in collaboration with fellow students (Vygotsky, 1978). Fourth, it provides the justifications for our integrated use of DINE, Bite-Size Teaching, and Focal Lesson as a collective whole via the Connective Approach as described in the work of Strawson (1992), Tay (2003), and Tay et al (2010). Lastly, it demonstrates the cycles that one goes through when embarking on an action research journey.

Keywords: action research; scaffolding strategy; connective approach; zone of proximal development

## INTRODUCTION

We are a team of Biology and Lower Secondary Science teachers of a public secondary school with a student population of about 1120, comprising of students from three different streams (in decreasing order of academic capabilities), namely, the Express stream, Normal (Academic) stream, and Normal (Technical) stream. In Singapore, students are streamed in secondary schools based on their performance in a primary school leaving examination. The Express course is a four-year course leading to the GCE 'O' Level examination. The Normal (Academic) course students will take a GCE 'N' level examination at the end of their 4$^{th}$ year of study for entry to either a polytechnic foundation course or the 5$^{th}$ year of study in their

secondary school to prepare for the GCE 'O' Level examination. The Normal (Technical) curriculum prepares students for a vocational education at the end of four years in secondary school. Students may be laterally transferred between courses in secondary school based on their academic performance and assessment of their abilities by their school leaders and teachers.

Since 2012, the school has adopted a modular approach for teaching Lower Secondary Science for Secondary 1 and Secondary 2 Express course students. Students will take Biology and Science Skill modules in the Secondary 1 Science course, and do Chemistry and Physics modules in the Secondary 2 Science course. The general science curriculum is rearranged into the respective modules with reference to the selected Science textbook- Lower Secondary Science Matters (2nd Edition) by Marshall Cavendish Education. The rationale for introducing the modular approach to the teaching of Lower Secondary Science in the Express course includes: (1) It allows teachers to have ample time to focus in-depth on chapters with additional hands on and practical lessons; (2) it allows teachers trained in their subject discipline to skilfully deliver the subject. Most teachers are trained in at most two sciences. In the conventional curriculum approach, the Chemistry and Physics trained teachers have to teach Biology too. However, with the modular approach, these teachers with relevant knowledge can deliver the respective subjects more effectively; (3) students will be better informed of the disciplines of Biology, Chemistry and Physics when they have to select their GCE 'O' Level subject combination course at the end of Secondary 2.

With this new arrangement in school, we intended to use our additional time freed from the conventional curriculum approach and decided to embark on this Action Research (AR) journey with a view to implement a new teaching strategy that can empower our students in answering experimental based questions in Science.

As pointed out by Dick (2001) and Reason & Bradbury (2001) as well as reflected by the experiences described in this Action Research study, Action Research achieves change through its participative approach and enables this research study to be conducted by being responsive to an issue of concern. As we proceed with the Action Research journey, we adjusted our teaching approach by taking into account our growing understanding of a Scaffolding Strategy to help our students learn Science.

## ACTION RESEARCH CYCLE ONE: IMMERSING IN OUR PROBLEM SITUATION

Lower Secondary Express students (Secondary 1 and Secondary 2) find it challenging to interpret given data (**Fig. 1.1** and **Fig. 1.2**), which is frequently found in Secondary Science pen and paper assessments. Generally, Lower Secondary Science students have a few challenges in answering data-based questions: (1) Inability to describe the data provided (**Fig. 1.1**), (2) Inability to understand the intention of the data, and (3) Inability to link scientific concepts to given data (**Fig. 1.2**). However, there is an increasing emphasis on experimental data based questions in GCE 'O' Level examinations due to a shift in the education landscape to inculcate creative and critical thinking skills (**Fig. 1.3**) to prepare students for the 21st Century.

For the first challenge (**Fig. 1.1**), our students tend to generalise loosely and prematurely in their written answers. Most students fail to put in effort to describe the pattern(s) offered by the data in a given question (Sandoval, 2003). Instead of using the data provided, students often rely on their personal views, textbook knowledge and beliefs to draw conclusions (Hogan & Maglienti, 2001). For instance, as depicted in **Fig 1.1**, the student answered by using '*affects*' to describe the effect of increasing water temperature on the amount of solute that can be dissolved in the water without clear mention of what exactly the effect was.

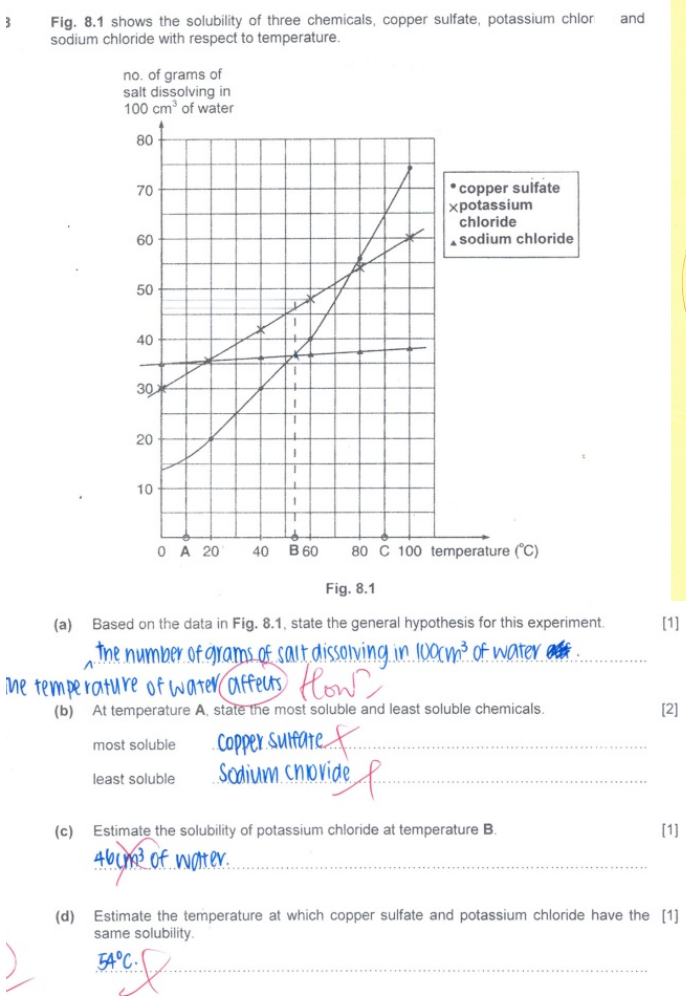



**Fig. 1.1**

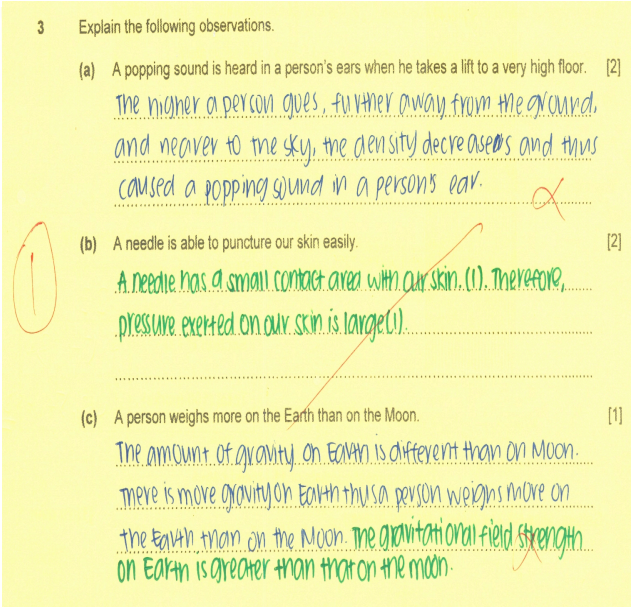



**Fig. 1.2**

**Fig. 1.3** 21st Century Skills (MOE framework) www.moe.gov.sg

In the case of the second challenge, our students are unable to understand the intention of the question. As illustrated in **Fig 1.2**, the student was neither able to provide a reasoning nor make a reference to a taught theory in class. As pointed out by Chinn & Brewer (2001), our

students' understanding of content knowledge and data evidence in question impacts on whether they are able to provide appropriate evidence for a particular task. Students are also likely to ignore data that contradicts the theoretical knowledge they already know, and they are more likely to take data into account if they can visualise the concept behind the data pattern. Therefore, the need for stronger content knowledge and exposure to data patterns may help students improve their understanding for the underlying intention of a given science question.

With regards to the third challenge, our students are often confounded by the term 'explain' and tend to miss the linking to concepts they have learnt in class. As pointed out by Bell & Linn (2000), our students have difficulty in providing reasons on why they have chosen certain data evidence in their written explanations. For example, in **Fig. 1.2**, the student wrote a set of explanations that were either disconnected or irrelevant to the given questions. For instance, the student failed to link the question to the *concept of air pressure* in the inner and outer ear. Research findings show that even when students are able to describe and link their inference to data-evidence, they are less likely to articulate the scientific principles behind that connection (McNeill et. al., 2003). The situation is worse when they do not understand the intent of the given science question in the first place.

In the past, we have tried to explain the answering of experimental based questions on a question-by-question basis. This may have led to some students memorising answers to specific questions and hence, being unable to realise that there is a certain form of thinking involved in answering experimental based questions. There are studies indicating that the ability to craft scientific explanations does not come naturally to most individuals; instead, it is mostly assimilated through practice (Osborne et. al., 2004). Therefore, students should be explicitly taught the skill on how to craft accurate scientific explanations and this should be practised in lessons regularly through exposure to experimental based questions.

After a few rounds of brainstorming sessions among ourselves, we concluded at the end of this action research cycles with the following research question:

*How can a scaffolding instructional strategy be used to improve students' construction of scientific explanations for experimental based questions?*

We then proceeded to the next action research cycle to determine the key ingredients to implement such a scaffolding instructional strategy.

## ACTION RESEARCH CYCLE TWO: CONDUCT LITERATURE REVIEW

A core facet of science is the ability to construct explanations from interpreting evidences or texts and assessing claims (Driver et. al., 2000). The ability to derive proper scientific explanations encompasses the goal of inquiry learning because it involves understanding the phenomena and convincing others of the same understanding (Sandoval & Reiser, 2004). Students' engagement in construction of scientific explanation may promote a positive outlook on science as well as increase their understanding of scientific content (Bell & Linn, 2000; Zohar & Nemet, 2002). **Therefore we realised that in order to help our students construct**

**explanations, we need to put in place an action strategy that can be adopted by our students.**

Although the mastery of scientific explanation is crucial for classroom science, it is frequently overlooked by educators in the classroom (Driver et. al., 2000). Consequently, most science students have difficulty explaining and justifying their claims when presented with evidences (Sadler, 2004). Hence, there is a need to explicitly teach students about crafting scientific explanations in order to help them gain a better understanding of science. **This has prompted us the need to teach pre-requisite knowledge to our students.**

Scaffolding, as described by Wood, Bruner and Ross (1976), consists of an adult manipulating the elements of task that are beyond the learner's ability, so that the learner is able to focus on and achieve competence in the fundamentals within his capacity. A number of researchers (Stone, 1993; Brown & Palincsar, 1987) have made the connection that scaffolding allows learners to reach a higher level of understanding of task within their zone of proximal development. According to the famed Vygotsky's theory (1978), the zone of proximal development (ZPD) defines the area where a learner is able to solve problems independently and attain a potential level of problem solving capabilities with guidance. In order for a scaffold to serve its function well, it should reside within the learner's zone of proximal development. If the scaffold provides too much assistance, the learner will not be challenged to inquire more. Hence, the scaffold should provide just enough assistance so that the learner will be able to progress independently and achieve a higher level of understanding (Vygotsky, 1978).

Besides, scaffolding can be used to make abstract processes visible for learners. For instance, a teacher can provide suggestions through modelling strategies (Brown & Palincsar, 1987) as well as prompts and questions to help learners understand the processes involved in learning (Jackson et. al., 1998).

As part of the scaffolding process, teachers also play an important role in supporting students in construction of scientific explanations and inquiry practices. Bransford et. al. (2000) cited some strategies that teachers can model after in order to improve students' abilities in scientific explanation such as making the framework explicit, modeling explanations, and assessing and providing feedback to students. In making the framework explicit, teachers cannot assume that students understand what a scientific explanation entails. There is a need to explicitly discuss what each component of an explanation requires (McNeill & Krajcik, 2008). In modeling and critiquing explanations, teachers can bring out strong and weak explanations so that students are able to understand what exactly is needed in scientific discourse (McNeill & Krajcik, 2008). In their research, McNeill and Krajcik (2008) also stressed the importance for teachers to provide explicit and specific feedback on the various components of explanation so that students can develop a deeper understanding of articulating an explanation and content. **Therefore, the need to consider zone of proximal development, to make abstract process visible, and to support students for constructing scientific explanation, has prompted us to design focal lessons with step-by-step instructions**.

**A Scaffolding Strategy for helping students construct scientific explanations**

In summary, the above literature suggest that the to-be-derived Scaffolding Strategy or program must entail three aspects, namely,

- First Aspect: an action strategy for helping students construct scientific explanations
- Second Aspect: a lesson for teaching pre-requisite knowledge to students
- Third Aspect: a Scaffolding Lesson with tasks that take proximal development into consideration

## ACTION RESEARCH CYCLE THREE: DERIVATION OF OUR SCAFFOLDING STRATEGY

### First Aspect: Developing the appropriate instructional strategy for crafting scientific explanations

Prior to our research study, the art curriculum in Singapore has already adopted Feldman's method of art criticism (1967) as a simple four-step method for evaluating a work of art. It comprises the followings:

*I. Description: listing what an art object seems to include*
*II. Formal Analysis: describing the relationship among the things that were listed*
*III. Interpretation: deciding what all your earlier observation means*
*IV. Judgement: deciding the value of an art object*

We noticed the similarities behind the Feldman thinking model of art criticism and constructing scientific explanations. Hence, we decided to adapt Feldman's model instead of using it directly, with a view to make it more accessible to lower secondary students for learning science. Besides, we also intentionally reduced the complexity of experimental based questions for students with a view that students can collaborate among themselves in deriving valid scientific explanation (Wood et al, 1976).

As a result, we created an instructional model (DINE) consisting of three elements for thinking:

*I.* ***D****escribe - State what you have observed*
*For example: What general trends does the graph show? What are the highest and lowest points on the graph? What changes were seen in the set-up?*

*II.* ***In****terpret - What does your observation mean?*
*For example: Explain the relationship between the variables.*
*How does the dependent variable (y axis) vary with the independent variable (x axis)? How does one variable affect the other variables to cause changes?*

*III.* ***E****valuate - How does your observation relate to theory/scientific concepts?*
*For example: Justify the decision, or explain the concept using theories you have learnt*
*Why does the graph show such a trend? Why do the changes happen in the setup? Are the results expected according to concept?*

**A Scaffolding Strategy for helping students construct scientific explanations**

To affirm if students have improved in terms of thinking critically to solve data based questions, the team adapted 10 multiple choice questions extracted from The International Competitions and Assessments for Schools (ICAS) Science papers administered by the University of New South Wales (UNSW) from years 2000, 2001, 2002, 2003 and 2007 (Appendix A). In this research study, we administered this test before the explicit teaching of DINE in the classroom to understand their pre-analytical ability for data based questions, and administered the same test after the DINE implementation period to check for improvement in their post-analytical ability. The administration of the test was conducted by shading the OTAS mark sheet and the duration for the pre-test and post-test was set at 20 minutes each.

**Second Aspect: Preparation of bite-size notes for teaching pre-requisite knowledge to students.**

Student epistemology influences the learning experiences students have and impacts student learning (Hogan & Maglienti, 2001). As such, we took into consideration the prior knowledge of our target students who had just graduated from primary school and incorporated additional information on a "need-to-know" basis, with focus on context that can help students move forward in their inquiry during the scaffolding lesson. For example, pre–requisite knowledge for Focal lesson 1 include: the concept of osmosis, relevant practical skills, laboratory safety procedures and use of an online platform like Google documents for collaboration. The concept of osmosis and relevant examples were taught to students through use of guiding slides (**Fig. 3.1**) leading up to Focal lesson 1.

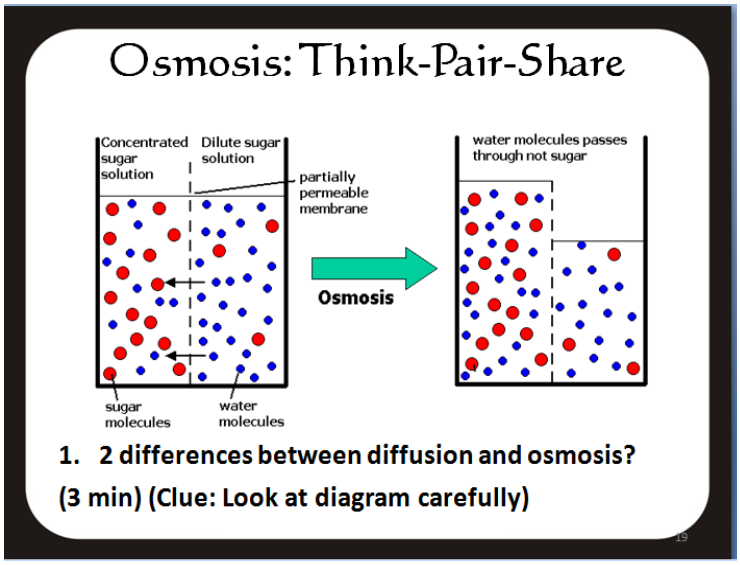



**Fig. 3.1**

Practical skills and laboratory safety were taught prior to Focal lesson 1. Students also had varying exposure to online learning and collaboration from their primary school. The teachers built on this prior exposure to online learning by briefly showing students how to access the Google spreadsheet.

**Third Aspect: Selection of focal lessons and materials to implement the use of DINE**

In order to fit into the allocated timetable for Science, we decided to introduce three focal lessons, namely, one for Biology, one for Science Skills, and the third one for Biology and Science Skills collectively. Apart from the identified focal lessons, the team also identified daily exercise questions in the theory workbook and practical book (Marshall Cavendish Education, Science Matters Volume A and B, Lower Secondary Science) for teachers to incorporate DINE into construction of scientific explanations (Appendix B). We were mindful that the tasks in the focal lessons were pitched at the right level for the students - Tasks that are too difficult are outside the students' ZPD and tasks that are too easy will leave the students unmotivated.

For example, in Focal lesson 3, we brought students to the school eco-garden to build interest and engage the students. Prior to Focal lesson 3, students were taught chapters on photosynthesis, respiration and transport in plants in classroom lessons. Students were tasked to observe things around them in the eco-garden and write down any question they gather based on their observations (Appendix I). Each task took into account the students' pre-requisite knowledge and was structured in a manner to induce them to inquire beyond their prior knowledge. Through this, the students formed their own hypotheses and planned experiments within their ZPD. This process was simplified by breaking a task into smaller subtasks (Appendix I and Appendix J). We also intentionally structured our intended manner for hypothesis formation and the planning of simple experiments in prior bite-size lessons, with a view that the students could imitate our modelled behaviour and eventually internalise in the third focal lesson.

In addition, we also incorporated two additional features for our research study, namely, the fourth and fifth aspects.

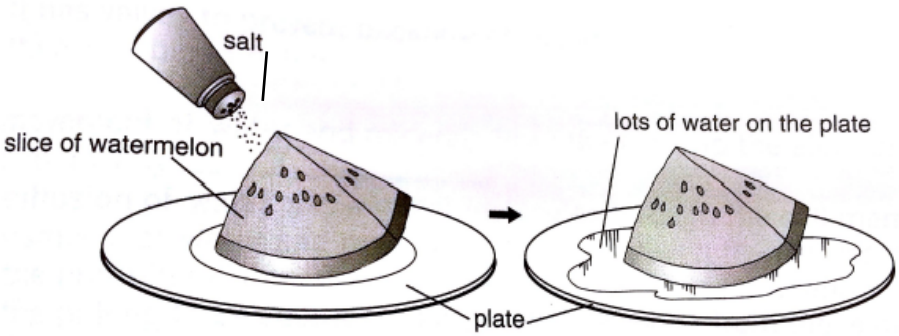
**Fourth Aspect: Adaptation of UNSW DINE questions for pre-UNSW DINE test and post-UNSW DINE test.**

As mentioned above, we adapted 10 multiple choice questions from The International Competitions and Assessments for Schools (ICAS) Science papers administered by the University of New South Wales (UNSW) from selected years. The ICAS questions were chosen because the questions assess students' skills in the key scientific areas of interpreting data, applying data and higher order skills. The skills assessed ICAS Science papers are listed out in the ICAS Science assessment framework (http://www.eaa.unsw.edu.au/forms/pdf/icas/subjects/science-framework.pdf). We based our choice of questions on a spread of data based question types- inference, line graphs, pie charts, bar charts, tabular data (Appendix C). It is important to note that in our research study, we did not conduct any pre-knowledge lessons to students for these extracted UNSW questions. This fourth aspect was introduced with a view to find out whether equipping students with DINE alone is sufficient to improve their analytical skill.

**Fifth Aspect: Developing Domain pre-test and post-test**

Pen and paper assessment tests based on domain knowledge were developed and administered to students before the administration of DINE instructional strategy and after the administration of DINE instructional strategy respectively. These assessments included data based questions in both multiple choice questions and structured questions (**Fig. 3.2**). Through this, we wanted to assess how the preparation and teaching of domain knowledge impact the DINE instructional strategy adopted in this research study.

*Some table salt was sprinkled on a slice of watermelon and was left untouched for 20 minutes.*




*After 20 minutes, a pool of water was found around the water watermelon. Explain what has happened that led to this pool of water.* *[2]*

**Fig. 3.2**

## ACTION RESEARCH CYCLE FOUR: OUR INTERVENTION

The three focal lessons were carried out accordingly in chronological order and administered to all four Secondary 1 Express Stream classes comprising of forty students each, over a period of eight months.

**Stage 1**: Conduct UNSW DINE pre-test (Appendix A) before DINE is taught to students

**Stage 2**: Conduct Domain pre-test before DINE is taught to students

**Stage 3**: Students were taught explicitly the use of DINE prior to focal lessons in the following format: Describe- What do you observe?, Interpret- What does your observation mean?, Evaluate- How is your observation related to theory/ scientific concepts?

**Stage 4**: Conduct of Focal lesson 1 (Appendix D)

**Stage 5**: Conduct of Focal lesson 2 (Appendix F)

**Stage 6**: Conduct of Focal lesson 3 (Appendix G, Appendix H)

**Stage 7**: Conduct Domain post-test after implementation of DINE focal lessons

**Stage 8**: Conduct UNSW DINE post-test (Appendix A)

The activities from Stage 4 to Stage 5 are described in detail in the remaining parts of this chapter.

**Stage 4: Focal lesson 1 (Biology practical)**

In the selected Biology practical on Diffusion and Osmosis (Appendix D), students were tasked to carry out the experiment and obtain their own tabular data through the practical session. Via Google document, students worked in groups of four and used DINE to answer the two questions posed in the practical session.

Step 1: Students participated in the practical session and collected the tabular data on their own (**Fig. 4.1**). Practical skills and laboratory safety were taught prior to this focal lesson.

| | **Initial length /cm** | **Final length /cm** | **Difference in length /cm** | **Texture and appearance** |
|---|---|---|---|---|
| Strip in water | 6.0 | 6.8 | +0.8 | rough, hard |
| Strip in 20% sucrose solution | 6.0 | 5.4 | - 0.6 | smooth, soft |
| Strip in 10% sucrose solution | 6.0 | 5.6 | -0.4 | smooth, soft |
| Strip in 5% sucrose solution | 6.0 | 5.9 | -0.1 | smooth, soft |
| Strip in 1% sucrose solution | 6.0 | 6.3 | +0.3 | rough, hard |
| Strip in 0.5% sucrose solution | 6.0 | 6.5 | +0.5 | rough, hard |

**Fig. 4.1**

Step 2: After completing the practical and clearing up the laboratory benches, students worked collaboratively in groups of 4 and used DINE to answer the two questions at the end of the practical exercise: *Explain what happens to the potato strip when placed in distilled water?* and *Explain what happens to the potato strip when placed in 20% sucrose solution?*. They answered the questions in a Google document that was created and shared among classmates. The Google document allowed students to collaborate and share answers with a view to help each other develop a better understanding of construction of scientific explanation.

Step 3: Each student was allocated one part of explanation done by another group to critique; i.e. Student A critiqued on the 'Describe' statement done by Group 1, Student B in turn would critique on the 'Interpret' statement done by Group 1. Some students were observed to have gone on to critique the entire explanation (D, IN, E parts) done by a group (Appendix E). Some students were observed to be able to provide better feedback for the groups with poorer

scientific explanations; however, it was also observed that some students were unable to identify the misconceptions by the group and proceed to concur with the misconception (Appendix E).

Step 4: Teacher does a general feedback for the class on how DINE can be useful to help in construction of scientific explanation.

**Stage 5: Focal lesson 2 (Science Skill workbook exercise)**

In the Science Skill module, teachers selected a question from the Science workbook (Appendix F), question 5 (a). The question was centred on the concept of 'particulate model of matter' and the effect of adding or removing thermal energy from a system. The question selected did not focus on data management through tables and graphs but it had the observation and inference component to it. We intended students to view the DINE instructional strategy to be applicable for use across most question types apart from questions with a high concentration of data management.

Step 1: Students attempted the workbook question 5(a) on their own using the DINE instructional strategy.

Step 2: Teacher walked about the class to check students' work at random and went through the question as a whole using the DINE approach.

**Stage 6: Focal lesson 3 (Biology + Science Skill eco-garden lesson)**

The third focal lesson, it was carried out in 2 separate lesson periods- (Focal lesson 3 Part 1) exploration of school eco-garden and generating inquiry questions (Appendix G) and (Focal lesson 3 Part 2) using DINE strategy to construct scientific explanations to the students' inquiry questions (Appendix H).

Step 1: In Focal lesson 3 (Part 1), students worked in groups of four. Groupings were arranged by the teacher. They were brought down to the eco-garden to observe the biodiversity there and came up with their own inquiry questions and hypotheses (Appendix G) using the worksheet provided (Appendix I). In groups, they designed a simple experiment to test out their hypotheses and included the type of data they were collecting. At the end of the Focal lesson 3 (Part 1), the teacher collected the worksheets (Appendix I).

Step 2: The teacher looked at each experiment and hypothesis selected by each group and came up with fictitious data in tabular form for the groups to analyse. The fictitious data was customised to the hypotheses and experiments of each group (**Fig. 4.2**). This fictitious data generation was performed between Focal lesson 3 Part 1 and Focal lesson 3 Part 2.

| | with support | | | without support | | |
|---|---|---|---|---|---|---|
| week | 1 | 2 | 3 | 1 | 2 | 3 |
| height of plant | 15 | 25 | 37 | 15 | 18 | 19 |

| | | | | | | |
|---|---|---|---|---|---|---|
| (cm) | | | | | | |

**Fig. 4.2**

Step 3: In Focal lesson 3 (Part 2), the teacher returned to the classroom with fictitious data generated for each group (Appendix H). Using the guided worksheet (Appendix J), students worked in their own groups and used DINE instructional strategy to construct scientific explanations for their hypotheses. During the session, each group had to use the data provided to Describe, *What are the highest and lowest readings?*, Interpret, *What do these readings signify? Is the trend of the data increasing, decreasing or constant and what does it mean?* and Evaluate, *Give a conclusion to your hypothesis, stating whether it was possibly true or possibly false, and why*. The teacher collected the worksheets and assessed students' ability to construct scientific explanations using DINE instructional strategy. It was observed that students constructed better scientific explanations when they were provided with a structured approach and guiding questions (Appendix K).

## ACTION RESEARCH CYCLE FIVE: DATA COLLECTION AND INTERPRETATION

### Quantitative analysis of UNSW DINE pre- test and post- test

A multiple choice question test of ten questions selected from UNSW past papers was carried out as a pre-test and post-test to assess the effectiveness of DINE strategy in helping students to structure their scientific explanations and hence, inquiry thought processes (Appendix A). Marks were allocated based on 1 mark per correct answer, with a maximum scoring of 10 marks.

We conducted a paired sample t-test to examine whether there is a significant improvement in the mean marks of post-test compared to the mean marks of pre-test of all the four classes (**Table 5.1**).

**Table 5.1**

| class | pre-test mean (out of 10) | post-test mean (out of 10) |
|---|---|---|
| **P** | 6.5 | 6.8 |
| **Q** | 6.1 | 6.7 |
| **R** | 5.6 | 6.1 |
| **S** | 6.5 | 6.6 |

Only for **class Q**, the absolute value of the t stat was smaller than the t critical two tail and the probability that the null hypothesis is true is smaller than alpha (p=0.0012). For **class P**, **R** and **S**, there was no significant statistical difference between the mean of pre-test and post-test mark scores.

The UNSW DINE pre-test and post-test developed assesses students' ability to analyse data based questions without the need for domain knowledge. With these findings, we can postulate that measurement of the DINE strategy alone is insignificant. In accordance with Vygotsky's theory (1978), scaffolding is most effective if applied within the learner's zone of proximal development. In other words, equipping students with just DINE approach alone is not sufficient for students to learn Science in our school context.

**Quantitative analysis of Domain pre-test and post-test with DINE approach taught to students**

We conducted a paired sample t-test to understand if there is a significant improvement in students structuring scientific explanations using DINE, in assessment tests which require domain knowledge. These content based assessment tests were conducted before the implementation of DINE (pre-test) and after the implementation of DINE (post-test).

**Table 5.2**

| | domain pre-test | domain post-test |
|---|---|---|
| **mean percentage mark for all Sec 1E students (%)** | 65.2 | 67.1 |

The null hypothesis ($H_0$) is that DINE instructional strategy has no impact in improving students' understanding and construction of scientific explanations in content based scientific concepts. With regards to the test results listed in Table 5.2, the p value obtained for a one-tail t test is 0.027 ($p < 0.05$), and the null hypothesis can be rejected. Therefore, we can conclude that DINE has a significant impact on students' ability to construct scientific explanations if scaffolding occurs within their zone of proximal development.

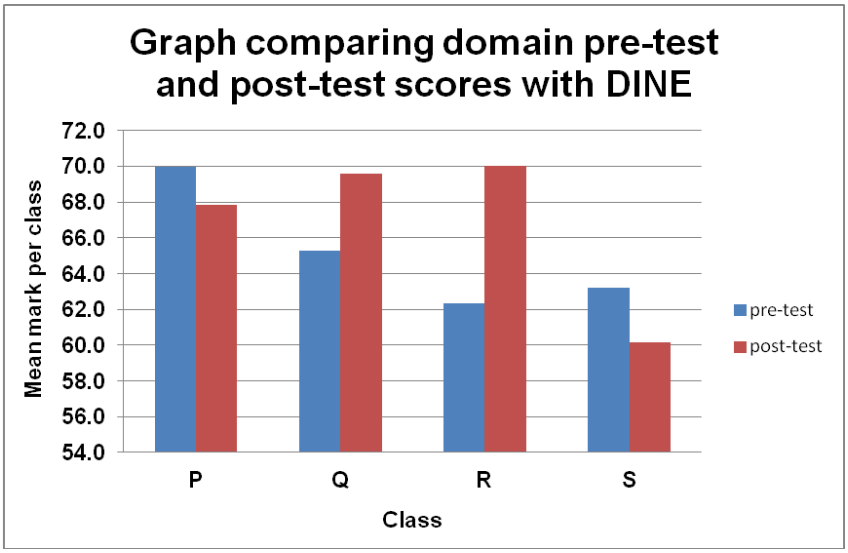


**Fig. 5.3**

Comparing the individual classes in **Fig. 5.3** using a paired sample t-test as above (null hypothesis ($H_0$) is that DINE has no impact in improving students' construction of scientific explanations), the p values obtained and respective implications are collated in **Table 5.4**.

**Table 5.4**

| class | p value (one tail t-test) | significance |
|---|---|---|
| **P** | 0.086 (>0.05) | $H_0$ is not rejected. DINE has no impact on how the students performed in their domain assessment tests. |
| **Q** | 0.028 (<0.05) | $H_0$ is rejected. There is sufficient evidence at 5% level of significance to support the claim that DINE has a significant positive impact on students' results in domain assessment tasks. |
| **R** | $2.59X10^{-05}$ (<0.05) | |
| **S** | 0.033 (<0.03) | $H_0$ is rejected. DINE has a significant negative impact on students' results in domain assessment tasks. |

A possible explanation to qualitatively explain why DINE may not have a positive impact on **Class S** will be the English Language ability of the class. A comparison of the English Language examination scores in the same time frame of this project showed that **Class S** had the lowest mean score amongst all four Express classes. The command of the English Language may have an important role to play in helping students understand what *Describe*, *Interpret* and *Evaluate* entails and the science concepts taught during the period. This would be in line with Jacob et al. (2013) who found that there was a correlation between proficiency in English language and academic performance of students in science and technical education.

On the other hand, as depicted in **Fig 5.3**, **Class P** which performed the best in the DINE pre-test among the four Express Classes obtained a slightly lower overall mean for the DINE post-test. Our act of 'intentional reduction of complexity of experimental based questions' may have caused some students to lose their interest during the focal lessons. This offers the explanation on why the null hypothesis for **Class P** is not rejected.

Therefore, the results in **Table 5.4** explicate two important facts- The weaker **Class S** needs pre-knowledge teaching and the stronger **Class P** needs a more complex zone of proximal development.

Besides, the positive results offered by **Table 5.2** and **Table 5.4** as compared with **Table 5.1** also explicates the fact that we need to apply three aspects collectively for our Scaffolding Strategy rather than merely adopt DINE instructional strategy alone.

## Qualitative analysis of student survey

Using an online survey platform, we created a survey for the students after the implementation of DINE instructional strategy to gather feedback on the usefulness of the strategy. The following questions were asked:

*Qn 1: Which type of question of data based questions (DBQ) do you find the easiest?*

- *line graphs*
- *tables*
- *diagrams*
- *pie charts*
- *descriptive paragraphs*

*Qn 2: Do you find the DINE method (Describe, INterpret, Evaluate) taught to you earlier to answer structured or essay questions effective?*

- *Yes*
- *No*

*Qn 3: What can be improved on for DINE?*

For question 1 on the type of data based questions the students found confidence in, the results are shown in the graph below (**Fig. 5.5**). From the data, it shows that students find analysis of tabular data to be the easiest, followed by line graphs and pie charts. They also seem to have least confidence in questions with evidence provided in descriptive paragraphs. The lack of confidence in constructing scientific explanations from evidence found in descriptive paragraphs may also stem from the poor foundation in language ability to be able to analyse texts. The differences shown in **Fig. 5.5** may be a good indicator of the amount of prior exposure the students have to the different question types.

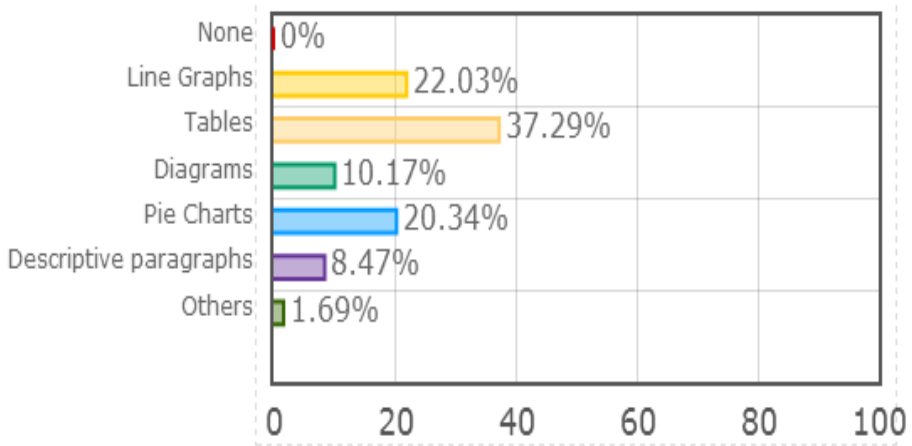



**Fig. 5.5**

For question 2 on the effectiveness of DINE instructional strategy in constructing scientific explanations for data-based questions, the results are shown in the graph below (**Fig. 5.6**). It seems that an 85% majority of students do see the need for a structured approach to help train skills for construction of scientific explanations.

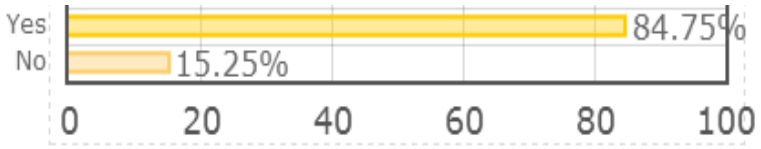



**Fig. 5.6**

For question 3 on the possible improvements for the DINE action strategy, the students' comments are listed in the table below (**Table 5.7**).

**Table 5.7**

| positive | areas for improvement |
|---|---|
| • Nothing; it is good enough<br>• Outdoor experiments makes questions related/requires the DINE method makes it more easy and fun to do.<br>• DINE has already covered all the question needed for explanation question as long as we follow the DINE approach there shouldn't be any other things to add on hence i think the DINE approach is good enough. | • Teachers can explain the way of answering questions using this method better as students may not know when and how to use this method when a question is given to them to answer. They can also **give some examples** of students answering the questions correctly using the DINE method.<br>• For example the IN in DINE, the meaning is to INterpret. It is **not really clear** what to interpret when you already describe your answer.<br>• Use it **more often** for most questions and also expand its use to elaborate answers longer.<br>• The DINE method can be improved by adding on **extra information** about the method and tips on how to answer the questions with better answers when using the DINE method. |

**Qualitative analysis of students' performance in Focal lessons 1 to 3**

In Focal lesson 1, when students were given the ownership to critique the work of their peers, it seems that they were better at pointing out the missing gaps.

(a) "*…although all three statements are correct, the whole explanation does not make sense. In the 'E' column, how did the process of osmosis cause the potato strip to increase in length? The group only provided the definition of osmosis and even the explanation is incomplete (what does the water molecules pass through?).*" (Appendix E)

In the above comment (a) from a student on a group's answer, he/she accurately pinpoints the mistakes that students have been making over the years- they are able to reproduce theoretical knowledge, but unable to link that domain knowledge to the context in the question given.

(b) "*You should be more specific and state it as "potato strip" instead of potato as there's a difference between a whole potato and just a strip.*" (Appendix E)

(c) *"The definition is incomplete, they should have mentioned 'osmosis' in their answer as it is a key word…"* (Appendix E)

(d) *"Lowest pH level = 2 (pond with dead fish), Highest pH level = 3 (pond with dead fish), Average= 2.5"* (Appendix K)

In the critiques (b), (c) and answer (d) above, students echo the common mantra of teachers for students to be *more specific* in writing their scientific explanations- students tend to be careless with keywords and use of scientific terms in their daily work.

(e) *"I agree that the process is diffusion. It is because the potato strip became softer, thus the particles moved out of the potato strip by the process of diffusion."* (Appendix E)

(f) *"The readings signify that the water quality is bad…If there are dead fishes in the water, it means that the water quality is not good."* (Appendix K)

In the previous examples, despite the fact that most students were aware of the importance of linking contextual evidence to theoretical knowledge, and the specificity in terms used, some students still led other fellow students on the incorrect path as seen from the example (e) above. In example (f), the students used vague words, '*bad'* and *'not good'*, to describe the water quality when data on pH was provided. It implies that the students are unclear about how pH can affect water quality for fish survival. These examples fully support the importance of role of domain knowledge in applying scaffolding strategies as substantiated by Vygotsky (1978). Without sufficient domain knowledge, the scaffolding is not within their zone of proximal development, hence, it is not effective and it does not help to extend their potential of constructing proper scientific explanations.

In summary, our adopted Scaffolding Strategy requires the collective use of 'DINE', 'Bite-size Learning', and 'Focal Lesson'.

## ACTION RESEARCH CYCLE SIX: JUSTIFICATION FOR OUR ADOPTED SCAFFOLDING STRATEGY

The justification for our collective use of 'DINE', 'Bite-size Learning', and 'Focal Lesson' can be explained using the notion of Connective Approach as described in the work of Strawson (1992), Tay (2003) and Tay et al (2010).

At the heart of the connective approach are the three distinct dimensions of ontology, epistemology and logic. Ontology is defined by Reber (1995) and Zuber-Skerritt (2001) as an aspect of metaphysical inquiry concerned with the question of existence apart from specific objects and events. It is one's assumptions about the nature of being and reality. As pointed out by Nita (1999), ontology takes on two meanings. The first meaning takes reference to the real world, where experience is characterized in terms of what is 'out there'. The second meaning includes belief in the existence of the things in question such that these things are separated and related in time and space.

Epistemology is defined by Reber (1995) and Zuber-Skerritt (2001) as the branch of philosophy that is concerned with the origins, nature, methods and limits of human knowledge. It is our assumptions about the nature of knowledge and knowing. As pointed out by Nita (1999), epistemology is either something objective, to be accumulated independently of the perceptions of any particular observer or something subjective, a product created by the observer. In other words, epistemology is the use of concepts in judgement or belief. It refers to the personal and subjective phenomenon. The experience is characterized in terms of what is 'in the head' of humans.

In Strawson's view, logic is the study of the general forms of the proposition and of their relations of logical dependence and independence. It has no concern with the internal structure of uncompounded propositions that enter into its compounds. It has nothing to say about the content of logically simple propositions. It has nothing to do with an ontological order. According to Bench-Capon (1990), the main concern of logic is with the soundness and unsoundness of arguments. Its goal is to represent an argument in such a way that it will be uncontroversial as to whether that argument is acceptable or not.

As pointed out by Strawson (1992), the concepts to be included in the connective approach must be highly general, irreducible, and non-contingent.

The term 'general' is described by Reber (1995) as a judgement or decision that is applicable to an entire class or category of objects, events or phenomena. For example, the word 'flower' can be used as a general term to refer to the bud, the stalk, the leaves, and the root.

The term 'irreducibility' does not mean or imply 'simple'. A concept may be complex, in the sense that its elucidation requires the establishment of its connections with other concepts. At the same time, it is also irreducible, in the sense that it cannot be defined away, without circularity, in terms of those other concepts to which it is necessarily related.

The term 'non-contingency' is defined by Reber (1995) as something strengthened by an event. It is considered to be the learned response of a bond between that response and stimulus. It occurs independently of any behaviour. It has a role to play in the development and maintenance of that behaviour. Beyond that, the very concept of experience itself would be lost.

Ontology, epistemology and logic are identified by Strawson (1992) as the three dimensions of a unified enquiry. Therefore, a connective approach is established when these three dimensions can be incorporated in a DES.

In our adopted collective approach, the ontological dimension is represented by a particular Focal Lesson. The epistemological dimension is represented by the set of pre-requisite knowledge taught to students in class. The logic dimension refers to the DINE approach.
As pointed out by Tay (2003), the use of the three dimensions in our collective approach can be justified using the notions of generality, irreducibility and non-contingency.

Firstly, the three dimensions are general in nature. The 'Focal Lesson' is based on the general theory of being. It applies the notion of ontology by ensuring all its phenomena take reference to the real world. All the phenomena observed by students must be found in the physical setting associated with that Focal Lesson. The set of pre-requisite knowledge adopts the general theory of knowledge. It represents the collective body of information where students can use the underlying nouns, verbs, phrases or sentences to construct their concepts or explanations. DINE uses the general theory of proposition. It is concerned with what is true or false.

Secondly, all the three dimensions are irreducible. This is based on the fact that against judgements or beliefs derived from pre-requisite knowledge is the natural world or the physical setting associated with a respective Focal Lesson to which the judgements or beliefs relate. In order to determine whether the judgements or beliefs are true or false, the DINE approach is required by students to process the states gathered from the relations of judgements or beliefs derived from pre-requisite knowledge with that of the natural world associated with the Focal Lesson.

Thirdly, the three dimensions are non-contingent. Each element contains a distinct feature that is non-contingent. The Focal Lesson is concerned with things that are 'out there'. A pre-requisite knowledge is concerned with things that are 'in the heads' of humans. And the DINE approach is only concerned with the reasoning process. It interprets neither the content of the things in a Focal Lesson nor the concepts derived from pre-requisite knowledge.

Therefore, during the processing of applying our derived approach, the students traverse through an elaborate network of connected objects and concepts that enables students to construct an explanation concisely and comprehensively and also to be able to interpret observed phenomena systemically and at higher level of complexity as witnessed from the results of this research study.

## ACTION RESEARCH CYCLE SEVEN: PERSONAL REFLECTION AND LEARNING

At the end of this research study, it became apparent that there are three factors that must converge to impact the development of a student's ability to construct scientific explanations and consequently, better understanding of scientific concepts. They are as follow:

1) DINE action strategy (Logic)
2) Domain knowledge through bite-size classroom teaching (Epistemology)
3) Focal lessons within ZPD (Ontology)

The relationship between the three factors can be represented in **Fig. 7.1**.

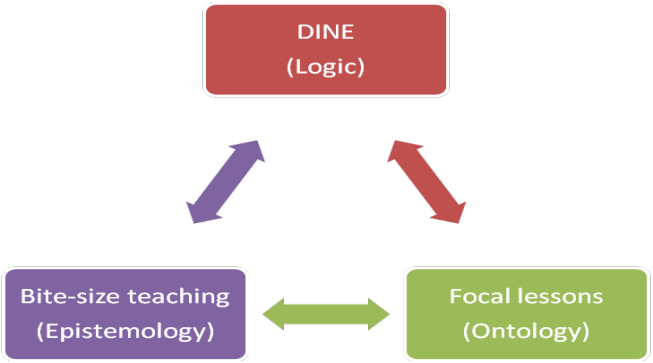



**Fig. 7.1**

**DINE Action Strategy**

The DINE instructional strategy consists of 3 elements of thought; Describe, Interpret and Elaborate. In order to be effective in inducing the thought processes of constructing scientific explanations, DINE has to be implemented together with students' domain knowledge within the students' zone of proximal development.

*a) Implementation*

DINE instructional strategy should be made more explicit and pervasive in the classroom– creation of a visual poster to constantly remind students to be more conscious of using DINE to help them construct their scientific explanations. Teachers should also increase articulation of DINE and create routines, for instance, ensuring that students think about DINE first before constructing their scientific explanations.

Teachers should also try to increase exposure to experimental based questions and be more mindful of the use of DINE to help students construct their explanations. Increasing exposure to experimental based questions is also in alignment with the Ministry of Education's move towards critical thinking.

Some students have given feedback that they are unable to differentiate the Interpret and Evaluate in DINE. It is true that the roles of both Interpret and Evaluate may overlap. We hope to have a clearer unpacking of DINE through use of guiding questions for each. We may also consider the need to collapse both Interpret and Evaluate with reference to other structured approaches in the teaching of construction of scientific explanations, e.g. Toulmin's model of argumentation (Toulmin, 1958) or McNeill's model of Claim-Evidence-Reason (McNeill et. al., 2006).

*b) Data collection*

Although the pre-test and post-test was created to identify if DINE is useful in helping students to structure their thought process in construction of scientific explanations, the multiple choice questions do not explicitly target the literal construction of scientific explanations. Perhaps, a better measurement will be using the same selected UNSW questions

and translating them into appropriate open-ended questions for students to explicitly construct their scientific explanations with the DINE instructional strategy.

**Domain Knowledge through bite-size classroom teaching**

The preparation of students' domain knowledge to ensure students have a sound understanding of new knowledge should not be taken lightly. Without a proper lesson structure, alternative conceptions may arise in students and this will hinder the learning progress of each student. The student will not be stretched to his/her true potential because of alternative conceptions which may be incorrect.

In Pasir Ris Secondary School, we adopt the AI3R lesson structure for most of our lessons. They include the elements, authentic learning (A), interactive (I), integrated (I), independent (I), reflective (R) in lesson planning. AI3R is the school's pedagogical framework developed in-house in 2005. This approach is aligned to the PETALS™ framework rolled out by Ministry of Education Singapore (MOE) in 2008. MOE's PETALS™ Framework is derived from a culmination of teachers' experiences, students' feedback, researchers' data and sound education theories. It comprises five dimensions of learning and teaching that contribute to student engaged learning in the Singapore classroom. The five dimensions: Pedagogy, Experience of learning, Tone of environment, Assessment, and Learning content are abbreviated into the acronym "PETALS". In short, students are engaged when teachers:

a. select Pedagogy that considers students' readiness to learn and their learning styles;
b. design an Experience of learning that stretches thinking, promotes inter-connectedness and develops independent learning;
c. create a Tone of environment that is safe, stimulating and which engenders trust;
d. adopt Assessment practices that provide information on how well students have performed and provide timely feedback to improve learning; and
e. select relevant and meaningful Learning content that makes learning authentic for the students.

Through application of AI3R, it helps teachers plan student-centred and engaging lessons. Engaged learning is positively correlated with academic achievement and can be manifested to positive attitudes in learning as well as a desire to achieve mastery in the subject.

**Designing focal lessons within ZPD**

We used the Biological Sciences Curriculum Study (BSCS) 5E instruction model (Bybee et al., 2006) to structure our instructional program. The BSCS 5E instructional model consists of the following phases: engagement, exploration, explanation, elaboration, and evaluation. Each phase has a specific function to guide the teachers in the planning of their instruction.

The 5E instructional model is used in Focal lesson 3 where the ecogarden activity was used as follow up to the unit on the "The Process of Scientific Inquiry." In the different phases of the instructional model, the students observe the biodiversity in the ecogarden and come up with their own hypothesis (*engage*); design a simple experiment to test out their hypothesis

(*explore*); Use the instructional strategies learnt in DINE to analyse the data given (*explain* and *elaborate*) and give a conclusion to their hypothesis, stating whether it was possibly true or possibly false, and why (*evaluate*).

In Focal lesson 1, while some students were capable to providing correct feedback to their peers, some students were unable to identify the misconceptions by the group and proceeded to concur with the misconception (Appendix E). The teacher can correct these misconceptions by entering comments or guiding questions in the adjoining column beside each individual student's feedback in the same Google document. This will help the groups and students realise where they have had alternative conceptions.

In Focal lesson 2, it was difficult for a teacher to be able to customise feedback to a class of 40 students with regards to the use of DINE in answering the experimental based question. Perhaps, more teachers are able to come in to support in the focal lessons or the use of technology can help in collection of individual feedback.

## CONCLUSION

This action research project has encouraged us to re-look at how we teach techniques to answer experimental based questions and more importantly, in the construction of scientific explanations. In constructing scientific explanations, it also gradually trains the students' ability to understand science concepts better (McNeill et. al, 2003). By trying this new initiative on the Secondary 1 Express students, it also helps teachers realise the importance of building up essential skills in Lower Secondary to help students transit better into the more rigourous Upper Secondary curriculum with an increased number of experimental based questions. Through this study, we also realised the value of scaffolding in helping students learn. With proper scaffolding within the zone of proximal development (Vygotsky, 1978), an educator will be able to assist students to reach their potential level of problem solving capabilities.

Statistical results through the measurement of domain pre-test and domain post-test scores have shown a significant improvement in student performance in two out of four classes. This means that in order to develop a successful scaffolding strategy for answering experimental based questions; we need a collective approach of "DINE", "Bite-size Learning", and "Focal Lesson". From our student survey feedback, most of the students have found the DINE instructional strategy helpful in the construction of scientific explanation. However, clearer unpacking of the DINE strategy and teacher articulation to increase pervasiveness of DINE in the classroom will help improve the effectiveness of implementation. This research study has benefited our teachers and enhanced our understanding on how to guide our students to construct scientific explanations. Action research is also a powerful way to improve teacher professional development. From this action research project, our team hopes to extend this strategy to Upper Secondary Science and other subject disciplines and work collaboratively to further develop it. We anticipated that in adapting the Feldman's model of art criticism and developing this instructional model of scientific explanation, it can be used across different content and contexts in the secondary school curriculum. Argument or explanation has been a

learning objective across various domains including language arts (Reznitskaya & Anderson, 2002), mathematics (Cobb, 2002) and science (Driver et. al., 2000).

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