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# AN INVESTIGATION INTO MICROBIOLOGY STUDENTS' UNDERSTANDING OF MICROBES

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**A thesis submitted in partial fulfilment  
of the requirements for the degree of  
Master of Philosophy**

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**Chow Kheong K. Gregory**

**School of Education  
Durham University  
2008**

**23 JUN 2009**

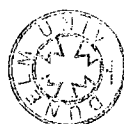


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## **ABSTRACT**

The research aimed to investigate students' understanding of microbes. Data on understanding of microbiology concepts were collected from biotechnology students during their formal 4-month microbiology course. Written tests and semi-structured interviews were used for data collection. For 2005 cohort, 120 students participated in semester 1 pretests while 112 students participated in semester 2 pretests. Seven and 8 students from semester 1 and 2 respectively took part in the post interviews. Classroom pretest was conducted two weeks after the microbiology course commenced while post intervention interviews (post interviews) were held a week before the semester ends. For 2007 cohort, 15 students were involved in the pre and post interviews. To probe students' thinking towards understanding the nature of microbes, interview questions were devised to answer 4 sub-research questions on student ideas on terminology, living characteristics, classification and occurrence of microbes. It hoped that results gathered will provide basic considerations for future teachings in microbiology to enhance student understanding on the concepts learnt during their early phase of learning life sciences.

Students generally had the idea that microbes were harmless even though they knew bacteria and virus could be pathogenic to humans. Such thinking was derived from their own personal experience of not falling ill despite being exposed to the microbial organisms and having microbes in their bodies. These microbes were thought to be ubiquitous and its occurrences mainly in the aerial environment and intestinal tract. The idea of a microbe as a small living organism requiring the microscope for viewing was prevalent amongst the students. Use of dimension of organisms was unreliable and prevented them from understanding the microbiology concepts. Students had most difficulty in understanding the term 'microbe' and that would have contributed to their poor conceptual understanding of microbial classification. There was no improvement on students' understanding of microbes for 2005 cohort. Understanding microbial classification and microbial growth improved slightly for 2007 cohort, but there

were no students with sound understanding on growth as a living characteristic for microbes. For the respiration concept, students knew organisms needed air to live but failed to associate the purpose of nutrients for energy release necessary for microbial reproduction, growth and movement. In reproduction, students were able to describe binary fission but were unable to explain its association with chromosomes for inheritance purposes. Limited scientific knowledge caused poor understanding when learning about virus particularly in the biological processes for viral nutrition and reproduction. Their attempt to explain ideas with limited scientific knowledge gave rise to the utilisation of anthropomorphic expressions.

Case study involving 6 students of the 2007 cohort showed that there was little development on ideas for concept of classification of microbes at the end of the microbiology course. The course did not help them gained an understanding that microbes were single celled organisms capable of functioning independently. Concepts of microbial growth and living characteristics of virus were most difficult to understand and learn. Students were not aware of the microbes' ability to undergo cell division rapidly. Misconceptions were also uncovered in the investigation and until these were corrected, students would continue to experience difficulty when learning microbiology. The concept model for understanding the nature of microbes was proposed with the recommendation that students should first respond with ideas on living characteristics before proceeding to classify the organisms. With adequate scientific knowledge, the concept model could enhance a better appreciation and understanding on the complex nature of microbes.



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**LIST OF ABBREVIATIONS**

<i>E. coli</i>	<i>Escherichia coli</i>
EIBE	European Initiation for Biotechnology Education
IS	Interdisciplinary Studies
IT	Information technology
ITE	Institute of Technical Education
MOE	Ministry of Education
NLM	Ngee Ann Learning Module
NP	Ngee Ann Polytechnic
TIMSS	Trends in International Mathematics and Science Study

## **DECLARATION**

This work has not been previously submitted for a degree or diploma in a university. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person, except where due reference is made in the thesis itself.

Chow Kheong K Gregory

Date: 28 Oct 2008

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Date: 28 Oct 2008

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# **AN INVESTIGATION INTO MICROBIOLOGY STUDENTS' UNDERSTANDING OF MICROBES**

---

## **- CHAPTER 1 -**

### **INTRODUCTION**

This study will investigate the polytechnic students' understanding in biological science specifically on microbiology, a first year biotechnology module. To begin, this chapter will discuss the background of the changing education scene in Singapore and Ngee Ann Polytechnic's (Ngee Ann) response towards a changing world as it moved to the 21<sup>st</sup> century. Attempt is also made to highlight Singapore's education system and that of Ngee Ann's efforts to improve their quality of graduates when responding to globalisation. The rationale for Ngee Ann's action restructuring its academic system resulting in curriculum changes on a biotechnology diploma will be discussed to provide the background and impetus of this study.

#### **1.1 Education in Singapore**

Education in Singapore begins from pre-school, primary, secondary through to tertiary levels. Students go through 6 years of primary education and 4 years of secondary education. All students will sit for their GCE O-levels at the end of their secondary education which lead them to three options of post-secondary education; the Institute of Technical Education (ITE), polytechnic or the A-levels. The O-level results are used to determine if they are suited for the practical orientation of an ITE or polytechnic education, or the academic and theoretical orientation of A-levels education. The polytechnic and A-level students would then proceed to the university.

To endure the industrial and economic demands of the 60s, 70s and 80s, the education system was fine-tuned through the utilisation of standard textbooks and common syllabus to cope with the intake of secondary students to train





production and technical workers. This resulted in the education system being 'efficiency-driven'. In the 1970s when the industrial growth and economy were the primary focus of the government, technical and engineering skills were in great demand. The education policy was geared towards technical and vocational education. Back then the objective was to produce competent engineers and technicians to drive the industrial processes and construction industries. Students entering polytechnics were normally from secondary schools. Here, the subjects taught were highly technical emphasising on engineering and physical sciences. The training period for full time study was 3 years.

Educating and training workers for the manufacturing and construction industries has been the charter of Singapore educational institutions since the 1960s. During those years, Singapore relied on technical institutions and the polytechnics to provide training of technically skilled graduates. That was the aim of Singapore's education when it was rebuilding the nation in the post World War II period.

Ngee Ann Polytechnic has grown steadily from a small technical college in 1964 during the looming economic and political crisis of the 1950s to become a major postsecondary educational institution with 1,600 staff members and 14,500 full time students. Together with 4 other polytechnics in Singapore such as Temasek, Singapore, Nanyang and Republic, Ngee Ann admits 40% of each cohort across the nation making a typical Singaporean likely to be a polytechnic graduate (Education Statistics Digest, 2006). Currently, more than 50 diplomas courses ranging from biotechnology to biomedical sciences, engineering, maritime studies, business, optometry, nursing, information technology and e-commerce are offered by these 5 polytechnics. The 3-year polytechnic education would appeal to students who prefer applied and practice-oriented training. Students with good grades can then pursue their tertiary education at local or overseas universities.

Of these, 74% of the polytechnic students are trained in engineering and technology as compared to the combined figures of 56% of the local universities (National University of Singapore and Nanyang Technological University) doing science and engineering courses. Hence, these graduates have been known as the "the backbone of Singapore's industrialisation" (Chen, 2001).

Typical entry requirements for full-time diploma courses in the polytechnic will require applicants to have 5 O-level passes of which will include English Language, 2 relevant subjects (depending on the nature of the course) plus 2 other best subjects. Once they met the eligibility for selection, their results were then ranked against other applicants based on the selection of 5 subjects for aggregate score computation. Lower scores enhance the applicant's chances of getting his or her choice of study. Table 1 below shows a typical student's GCE O-level results which satisfy the entry requirements for a Diploma in Biotechnology and its computation of the aggregate score.

Table1: Aggregate score computation of a GCE O-level result to rank its eligibility for selection into Diploma in Biotechnology

Subject	Grade obtained	Grades of subjects selected for computation
English as 1 <sup>st</sup> Language	B3	3
Mathematics	A1	1
Geography	B4	4
Science (Physics and Chemistry)	A1	1
Chinese	B3	3
English Literature	C6	-
Biology	C6	-
Aggregate		12

## **1.2 Education Response to Globalisation**

With the dawn of knowledge-base economies dominated by rapid information technology (IT) advances, the Singapore government soon realised that it was no longer sufficient for schools and tertiary institutions to provide basic education and train workers for traditional jobs like technical production operators, computer programmers or accountants. Post secondary education at institutions like Ngee Ann, was also affected due to the changing demands of the industry that have shifted from labour-intensive manufacturing assembly to knowledge intensive economic production and services (Mok and Lee, 2003).

This knowledge-base economy or the new economy as it is sometimes referred to, has forced educators and policy makers to “overhaul” the education system. The new economy is about innovation, creativity and a knowledge economy. It is recognised that intellectual capital will be the key in meeting the demands of the new economy where progress and economic growth is heavily dependent on the creation and exploitation of knowledge. To fuel this new economy, life sciences has been identified as a pillar of Singapore's manufacturing sector (Lim, 2004). A typical example is the contrasting approach which the conventional method of manufacturing pharmaceutical drugs by chemical synthetic processes is now replaced by new drugs made by living organisms through microbial fermentation or mammalian cell culture. To prepare the students in embracing biotechnology and equip them with the knowledge and skills, life science curriculum have been widely encouraged at both primary and secondary levels of the Singapore education system (Wiskin, 2004).

Determined to train a new generation of workers with creative thinking skills, the Singapore Ministry of Education (MOE) launched a nation wide programme ‘Thinking Schools Learning Nation’ in 1997. MOE’s vision was to ensure that Singaporeans realise their full potential and inculcate a passion for life-long learning. Through nurturing a mindset of continuous learning, MOE hoped that the students would succeed in the future (Goh, 1997). For this to

transpire, schools were asked to cut back on content knowledge, evaluate their curriculum and assessment methods whilst ensuring that the mastery on core knowledge and concepts were not sacrificed.

To further enhance the workforce competitiveness, IT has been integrated into most schools. The argument was to use IT to complement the cognitive skills of students and help them develop skills relating to critical thinking, communication and independent learning. All these skills would prepare these students for the 21<sup>st</sup> century by ensuring that they were proficient at the workplace and self-motivated. On the other hand, there were also calls to improve core skills and competencies when preparing students to be globally competitive. This argument was however more for training students for blue collar jobs at a vocational level to be a knowledge worker (Yim-Teo, 2004). Similar observations were also reported in Australia, New Zealand, Germany and UK which called for greater enhancement of core skills and competencies in the workplace (Werner, 1994). Although these countries recognise the importance of core skills as part of their vocation and technical of students, they also emphasised the need to balance with literacy and thinking skills if they are to be ready for the challenges of the knowledge economy (Yim-Teo, 2004).

### **1.3 Industry**

Is the industry being pressured to adapt and respond to the demands of the new economy driven by knowledge and innovation? With schools incorporating innovation, creativity and information technology (IT) in the school curriculum, employers too realised that knowledge and content training alone are no longer adequate for the 21st century work environment. In comparison to the period before globalisation, new technologies have affected the workplace where jobs are no longer routine but knowledge generated. What this means is that being employed comes with broader job responsibilities and among the skills sought after are the ability to work as a team and problem solving. Such a situation where a workplace becomes such a sophisticated environment will

place high demands on workers with higher education and knowledge (Yim-Teo, 2004). Hence, to function effectively in a workplace, she further mooted the idea that abilities, such as identifying, analysing and problem solving, are more important assets to possess than being knowledgeable alone.

While the ability to apply facts or following systematic procedures and incorporating scientific analytical skills were important during pre-knowledge economy era, such abilities were however currently inadequate. Present industries with cutting edge technologies such as nanotechnology, stem cell clinical trials and biofuel were just some of the industries replacing general biomedical work in the research laboratory or field work in Singapore.

Twenty years ago, a research assistant with an O-level education would just assist researchers to prepare experiments, performing the tasks as directed with little thinking or input required of them. Any problems encountered in the process would be dealt by the researcher. Nowadays with additional demands expected from the same job, applicants are more likely to have a higher education qualification of not lower than a basic science degree (Today, 2006). Currently, a Technical Executive's job responsibility, with a basic science degree working at a local university's biological chemistry laboratory, is to provide technical and administrative support on the following functions;

- use of statistical analyses to analyse research data
- new undergraduate laboratory teaching experiments
- assist lecturers on research projects
- preparation of materials, procedures and manuals
- purchase and maintenance of NMR or mass spectrometers
- maintaining of inventory of invoicing and purchases
- implement safety protocol and safety compliance
- asset and inventory management

Apart from their core skills and knowledge, the technical executive is expected to be able to multitask, possess organisational decision making and problem solving skills to plan and conduct experiments and feasibility studies on the university's biological chemistry curriculum. Looking at the above job

functions, before the knowledge economy sets in, it used to be handled by 4 to 5 staff members, namely an inventory officer, a safety officer, a laboratory assistant and a technical cum research officer. Currently, these are all done by a single staff. As the life science industry advances, spurred by the growth of globalisation and the internet, both academic and practical expertise is also expected to increase to meet its work demands. Thus, in the pursuit of increasing productivity to stay ahead, the skills required for the same job will change.

Whether the work output is a laboratory manual, a processed analytical data sheet or implementing a new experimental protocol, each of these activities will require trouble shooting, solving problem or carryout logical sequence of actions. In carrying out these actions effectively, thinking and understanding are needed in the coordination of multifaceted job functions.

#### **1.4 Qualified Science Students for Tomorrow's Workforce**

Hence, the areas of concern were whether students were well prepared to meet the challenges of the future, or if they were able to analyse, reason and communicate their ideas effectively. Educational institutions do need to respond appropriately and be sensitive to the changing requirements of the industry. Ngee Ann was worried that its current academic system and teaching delivery may not be meeting the changing needs of the Singapore economy. To keep up with times, especially in economies derived from technology, the polytechnic has to align itself with the needs of the higher education arena, business and political landscape. By placing importance on a creative curriculum development, Ngee Ann aims to redefine its strategies and culture to that of a learning organization.

In this light, Ngee Ann's academic system was eventually restructured through the introduction of the Ngee Ann Learning Module (NLM) to prepare students for both pre-employment education and training. The result is a curriculum change, which incorporates the rationalisation of disciplinary and

common modules offered across schools and courses. It also provides an all round development and promote lifelong learning.

Through this curriculum change, Ngee Ann students will gain a better balance of essential skills in scientific understanding and core discipline knowledge, while receiving a broad-based education. It anticipated that the end result will be an emergence of creative and enterprising graduates. By equipping these students with problem solving skills and knowledge beyond their basic disciplinary studies, it will make them more employable. In an OECD education report released in Dec 2007, it revealed that the 2006 Programme for International Student Assessment (PISA) endorsed the relevance and importance of understanding science in technology-based economies (ST, 2007). In this report which PISA surveyed 400,000 15-year-olds from 57 countries on their scientific knowledge, it alleged that,

*“In today’s technology-based societies, understanding fundamental scientific concepts and theories, and the ability to structure and solve scientific problems are more important than ever.”*  
(ST, 2007, p. 27)

Similar observations were also noted by Coles (1997) who supported the fact that the ability to solve problems was highly required of an industrial scientist. Samavedham (2006) concurred with this view by arguing that technical expertise alone is no longer favoured by employers if employees are unable to understand concepts and theories which are necessary towards acquisition of problem-solving abilities. Such was the view of Grubb *et al.* (1991) that in preparing students for the “real world”, they advocated integrating academic studies with vocational education.

To be ready for the new economy of the 21<sup>st</sup> century, acquisition of new knowledge and understanding scientific concepts were necessary. That involved learning and retraining throughout ones life that calls for mindset to be changed and old theories challenged. Thus, over-specialisation without proper broad

perspectives do not equip students a competitive edge and limit their career development, which Ngee Ann was trying to avoid. The importance of acquiring new knowledge was visible in Delors' argument when he conveyed that;

*"Today, no one can hope to amass during his or her youth a initial fund of knowledge which will serve for a lifetime. The swift changes taking place in the world calls for knowledge to be continuously updated....."* (Delors, 1996 p. 99)

Similar views were also echoed by Alvin Toffler, a noted futurist when he gave his opinions on 'shelf-life' of scientific knowledge. He emphasised that individuals need to 'learn, unlearn and relearn' if they were to fit into the new economy (ST, 2000). Ignoring such message could result in unemployment if one was overly dependent on their specialised but stagnant talent.

### **1.5 Ngee Ann's Response: Ngee Ann Learning Model**

Acknowledging the fact that it was not possible to provide a common track education for every single Ngee Ann student, the next approach Ngee Ann took was to adopt an open and flexible learning system to provide students with some level of control and responsibility over what, how and when they learn at a pace in sync with their abilities and interest. The NLM is Ngee Ann's way of responding to the knowledge-based economy and to MOE's effort of customising education at the institutional level. Such a move allows students to select modules from other disciplines thereby customising a curriculum for oneself. This autonomy enables Ngee Ann to provide a holistic and broad-base education to students.

Ngee Ann Learning Module (NLM), introduced in July 2001, is Ngee Ann's strategic response to provide students with a broad foundation education to meet the industrial needs of the 21<sup>st</sup> century. All Ngee Ann's courses will contain a curriculum that emphasises both a discipline and an interdisciplinary focus. Typically, a diploma course at Ngee Ann consists of modules pertaining to each respective discipline (eg. biotechnology) and interdisciplinary (outside the



biotechnology course) modules. The rationale for such an all-rounded approach is to enable students to seek knowledge and acquire skills beyond the traditional discipline expertise. The resulting outcome of the NLM will hopefully produce a new generation of graduates capable of responding and managing more effectively changes of the future.

Similar support for changes in the education system where learning mode was radically changed to meet industry's expectations caused by globalisation was documented by Holtzhausen's (2001) South African experience where they aimed to produce more adaptable self-learning students. In this case, Resource-based Learning placed an emphasis on teachers managing the learning contents which are then made accessible to students. Holtzhausen argued that the alternate learning style;

*" ....is regarded as an appropriate delivery mode and a key principle to meet the challenges (e.g. the expectations of the learners, the realities of the work place, and to maintain high standard graduates) posed to the university system." (p.3)*

Ngee Ann's discipline modules are modules specific to a discipline. These modules can be classified as core (must know) discipline or elective (good to know) discipline modules, which can be modules from other sub-disciplines within the main discipline. For example, life science is the main discipline, within which exist sub-disciplines like biotechnology, horticulture and chemical engineering. Hence, modules specific to biotechnology can be taken by horticulture students will be classified as an elective discipline module. On the other hand, modules that are specific to horticulture and taken by horticulture students will be classified as core discipline modules.

Interdisciplinary studies (IS) modules are defined as modules which are outside the core discipline and these are further classified into prescribed interdisciplinary or general interdisciplinary modules. Prescribed interdisciplinary are compulsory while for general interdisciplinary modules, students are able to

exercise their choice in the selection of modules according to their interest. Thomas (1987) claimed that his definition of interdisciplinary was not simply a mix of specialty areas but it was where separate disciplines (e.g., art, music and literature) were taught together in some reduced form. His views were in agreement with the NLM as only the gist from the IS modules would be provided to students to provide them the exposure and necessary awareness.

**1.5.1 Changes in course curriculum of the Diploma in Biotechnology**

The curriculum for the Diploma in Biotechnology course was restructured as a result of Ngee Ann's adoption of a flexible learning system, to keep abreast with the changing needs of the industry. The main changes to the biotechnology course structure would see the introduction of more molecular content and updating the latest developments in life sciences. With the curriculum being updated, the skills of the students were then in tandem with the industry needs.

Table 2 lists both the pre-NLM biotechnology curriculum and the new or restructured curriculum when the NLM took effect. To further better prepare the biotechnology students for the work place, the industrial attachment programme, a 3<sup>rd</sup> year module was increased from 8 weeks to 15 weeks. In this module, students were sent to the industry to allow them to gain real industrial experience.

Table 2: Comparison of the pre-NLM and NLM course modules for the curriculum of Diploma in Biotechnology

<b>Pre-NLM modules</b>	<b>Current NLM modules</b>
<b>Year 1</b>	<b>Year 1</b>
<ul style="list-style-type: none"> <li>• Comprehension &amp; Technical Writing</li> <li>• Information Technology</li> </ul>	<ul style="list-style-type: none"> <li>• Inorganic &amp; Physical Chemistry</li> <li>• Microbiology</li> </ul>
<ul style="list-style-type: none"> <li>• Cell Biology</li> <li>• Organic &amp; Biological Chemistry</li> <li>• Biostatistics I</li> <li>• English and Technical Writing</li> <li>• Mathematics</li> <li>• Inorganic and Physical Chemistry</li> </ul>	<ul style="list-style-type: none"> <li>• Mathematics and Statistics 1</li> <li>• Physiological Systems</li> <li>• Cell Biology</li> <li>• Organic and Biological Chemistry</li> <li>• Trends in Life Sciences</li> <li>• Information Technology for the Life Sciences</li> </ul>
<ul style="list-style-type: none"> <li>• Microbiology</li> </ul>	<b>Interdisciplinary Studies (IS) modules</b>
	<ul style="list-style-type: none"> <li>• Individual &amp; the Community</li> </ul>
	<ul style="list-style-type: none"> <li>• Creativity and Applied Thinking Skills</li> </ul>
	<ul style="list-style-type: none"> <li>• Sports and Wellness</li> <li>• Communication Toolkit</li> </ul>
<b>Year 2</b>	<b>Year 2</b>
<ul style="list-style-type: none"> <li>• Immunology</li> <li>• Applied Microbiology</li> <li>• Analytical Biochemistry</li> <li>• Executive Development Skills (7 week module)</li> <li>• Productivity &amp; Quality Studies</li> <li>• Social Community Values 1 (7 week module)</li> <li>• Oral &amp; Written Communication</li> <li>• Molecular Genetics</li> <li>• Plant Tissue Culture</li> <li>• Biostatistics II</li> <li>• Instrumentation</li> </ul>	<ul style="list-style-type: none"> <li>• Applied &amp; Molecular Microbiology</li> <li>• Immunology</li> <li>• Mathematics &amp; Statistics 2</li> <li>• Analytical Biochemistry</li> <li>• Cell Culture &amp; Tissue Applications</li> <li>• Instrumentations</li> <li>• Advanced Cell &amp; Molecular Biology</li> </ul>
	<b>Elective Modules</b>
	<ul style="list-style-type: none"> <li>• Aquaculture Management</li> <li>• Agrotechnology &amp; Plant Tissue Culture</li> </ul>
	<b>Interdisciplinary Studies (IS) modules</b>
	<ul style="list-style-type: none"> <li>• Innovation &amp; Enterprise in Action</li> <li>• Any 2 IS general modules *</li> </ul>
<b>Year 3</b>	<b>Year 3</b>
<ul style="list-style-type: none"> <li>• Biochemical Engineering</li> <li>• Project Part 1</li> <li>• Aquaculture &amp; Livestock Management</li> <li>• Animal Cell &amp; Hybridoma Technology</li> </ul>	<ul style="list-style-type: none"> <li>• Integrated Laboratory 1</li> <li>• Integrated Laboratory 2</li> <li>• Project Parts A &amp; B</li> <li>• Bioprocess Technology</li> </ul>
<ul style="list-style-type: none"> <li>• Social Community Values 2 (7 week module)</li> <li>• Recombinant DNA Technology</li> <li>• Project Part 2</li> </ul>	<ul style="list-style-type: none"> <li>• Life Sciences Seminar Series</li> <li>• Proteomics</li> <li>• Industrial attachment Programme (15 weeks)</li> </ul>
<ul style="list-style-type: none"> <li>• Advanced Analytical Biochemistry</li> <li>• Plant Agrotechnology</li> <li>• Industrial attachment Programme (8 weeks)</li> </ul>	<ul style="list-style-type: none"> <li>• Advances in Genomics</li> <li>• Bioinformatics</li> <li>• Current Good Manufacturing Practice</li> </ul>

	<ul style="list-style-type: none"> <li>• Product Development &amp; Commercialisation</li> </ul>
	<ul style="list-style-type: none"> <li>• Drug Discovery &amp; Development</li> </ul>
	<b>Interdisciplinary Studies (IS) modules</b>
	<ul style="list-style-type: none"> <li>• World Issues: A Singapore Perspective</li> </ul>
	<ul style="list-style-type: none"> <li>• Any 1 IS general module **</li> </ul>

\* Year 2 IS general modules: Life Skills, Entrepreneurship and Media & Arts  
 \*\* Year 3 IS general module:

### 1.6 Why Microbiology?

Even though the biotechnology curriculum brings great promise in training the students, there is a concern among educators that it is one thing to attain technical expertise but it is different altogether if there is a lack of understanding on the various biological concepts and analytical skills associated with the knowledge. It appears that internationally, science teachers too adopt the stand that where student learning is concerned, understanding of scientific concepts is important. From the TIMSS (1996) survey data where teachers’ perceptions on core practices when teaching science were obtained, Toh *et al.* (2004) reported that teachers from UK, US, Japan and Singapore perceived the importance in understanding concepts for their students;

*“....science teachers across all the four countries are unanimous in recognising the importance of making sure that their students understand concepts taught, are involved in logical and creative thinking, and can provide reasons for the conclusions they arrived at”.*  
 (Toh *et al.*, 2004 p. 9)

Still, since the launch of “Thinking School, Learning Nation” in 1997 to promote thinking skills amongst the students, there has been little research or published data into Singapore science education where student thinking and science understanding is concerned (Venthan, 2006). It is imperative that for students to solve scientific problems, understanding of scientific principles need to be inculcated in students as it will allow them to think through the problem and find their own solutions. Kass and Macdonald (1999) argued that students need to ‘act’ on their knowledge and nor just verbalise it. Earlier, in the study of Toh *et al.*

(1996) on collaborative efforts to co-develop curriculum between teachers and academics, they found that teachers were more concerned on subject matter. In fact;

*“Building understanding becomes less of a concern than covering content and preparing for success in examinations.”*

(Toh *et al.*, 1996 p. 691)

Thus, to succeed in learning this biotechnology course, it was recognised that student must be able to understand fundamental concepts in biology especially those found in microbiology. Understanding the concepts in microbiology provided a basic tool towards dealing with practical issues in genetic engineering, medicine, agriculture and industry as it involved the living cells (Madigan *et al*, 2000). Bishop (2000) supported this notion that by educating students in microbiology, students will better appreciate the microbial organisms and its contributing effects on other related scientific disciplines like medical, agriculture or the environment. With their understanding in the microbiology concepts and familiarity with the learning approaches in the module, students will be better trained in biotechnology and become a more effective employee for the workforce.

With this, it then leads to the issue whether the present structure of the microbiology syllabus is suitable for the biotechnology student to learn and understand its various concepts. To get some sense on its suitability, students understanding on microbiology must first be established. Hence, this study was conducted to probe students' thinking on the 'essence' of microbiology, the microbe.

## 1.7 Summary

During the last 40 years, Singapore relied on polytechnics to educate and train technically skilled workers for the manufacturing and construction industries. The current establishment of a knowledge-based economy, driven by globalisation and rapid biotechnological advances, has created a demand for new breed of multitasked and adaptable workers.

The impact of globalisation on the Singapore education system has required Ngee Ann to stay relevant to the needs of the life science industry. The restructuring of Ngee Ann's curriculum and its impact on the biotechnology diploma programme in particular the microbiology module, was highlighted to show cause on the need to emphasise students' understanding of concepts rather than knowledge or skills acquisition. Biological scientists of the future will have to be not only knowledgeable, but more importantly be able to understand a problem and solve it. Towards the end of chapter 1, a background was established to the intention of this study to investigate microbiology students' understanding of microbes. In chapter 2, literature on students' understanding in microbiology, will be reviewed to build arguments on establishing the focus of inquiry in this study.

## - CHAPTER 2 -

### **ANALYSES OF THE LITERATURE**

This chapter discussed researchers' efforts on what characterised the 'understanding of microbiology and its concepts', and its associated complexities. It began with the review of the microbiology syllabus for the diploma in biotechnology which set a background for the discussion of the literature analyses. In the attempt to understand the nature of microbes, the analysis will show the misconceptions which hamper the learning of microbiology. Following the analyses of the literature, the conceptual areas of ideas needed towards understanding the nature of microbes will be identified. The main research question and its sub-research questions will then be established at the end of this chapter based on the conceptual areas of interest to the study.

#### **2.1 Microbiology**

Microbiology is a study which involves visualising living objects that are below human visual sensitivity with the aid of microscope. These living objects can exist as single cells or cell clusters (Madigan *et al.*, 2000). Microbiology also includes the study of attributes resulting from these living things for instance the metabolic processes like fermentation and respiration and their effects. Examples of these effects are diseases, decay, and industrial products that include food (i.e., alcohol, cheese, yoghurt) and medicinal drugs (i.e., vaccines, antibiotics). Within the context of its importance to humans, the study of microbiology has become more integrated and holistic with the inclusion of medical microbiology, food microbiology and environmental microbiology.

## 2.2 Microbiology Syllabus

Microbiology is one of the modules that polytechnic students take in order to be awarded the diploma in biotechnology. When the biotechnology course was restructured during the implementation of the NLM in 2001, changes were only made to the practical component of the microbiology syllabus where 4 of the 10 practical sessions were modified (see section 2.3) while the lecture topics remained relatively the same as these topics were deemed relevant and provided a good foundation for their study of other biotechnology modules. For its learning outcomes, it was expected that upon completion of the microbiology module, students should be able to:

1. Understand microbial concepts, including microbial characteristics, classification, cell structure and function, metabolism, nutrition, growth and regulation, and factors affecting growth.
2. Perform microbiological media preparation, microbial isolation and cultivation of pure cultures, microbial counting, staining, size measurement and microscopy.
3. Have an understanding of microorganisms and their applications.

Table 3 showed the framework for the lecture topics that were taught to biotechnology students over a 4-month period.



Table 3: Framework for microbiology lecture topics

No	Topics	Topic Details
1.	<b>Principles of microbiology</b> Introduction to Microbiology (2 Hours)	<ul style="list-style-type: none"> <li>Define microbiology,</li> <li>Characteristics of microbes</li> <li>Types of microorganism : cellular and acellular</li> </ul>
2.	Microbial diversity (5 Hours)	<ul style="list-style-type: none"> <li>Naming and classification,</li> <li>Structures of cell</li> <li>Metabolic activities</li> <li>Microbial locomotion</li> </ul>
3.	Cell structure and function (8 Hours)	<p><u>Cell Membrane</u></p> <ul style="list-style-type: none"> <li>Functions, composition, arrangement, comparison between eubacteria, archaebacteria and eukaryotic cells</li> </ul> <p><u>Cell Wall</u></p> <ul style="list-style-type: none"> <li>Function, composition, arrangement, comparison between eubacteria, archaebacteria and eukaryotic cells walls</li> <li>Gram-staining</li> <li>Effects of penicillin and lysozyme</li> </ul> <p><u>Cell surface Structures</u></p> <ul style="list-style-type: none"> <li>Structure and function of flagella, pili, fimbriae, capsules</li> <li>Comparison between prokaryotes and eukaryotes</li> </ul> <p><u>Internal structures</u></p> <ul style="list-style-type: none"> <li>Function and types of storage granule</li> <li>Function of gas vesicles; endospore properties, structure, formation and types; sulphur granules</li> <li>Chloroplast</li> </ul>
4.	Virology (2 Hours)	<ul style="list-style-type: none"> <li>Virus classification and replication overview</li> <li>Virus structure and replication</li> <li>Cell transformation and cancer</li> <li>Viroids and prions</li> </ul>
5.	Nutrition and metabolism (2 Hours)	<ul style="list-style-type: none"> <li>Microbial nutrition</li> <li>Macronutrients, micronutrients</li> <li>Micro-biological media and formulation for isolation</li> <li>Oxidation/reduction</li> <li>Fermentation and aerobic/anaerobic respiration</li> <li>Energy and Carbon</li> </ul>
6.	Microbial growth (4 Hours)	<ul style="list-style-type: none"> <li>Growth rate, generation time, microbial growth curve and stages in growth,</li> <li>Quantitative expression of microbial growth</li> <li>Environmental factors: effects and types</li> <li>Effect of osmosis, pH, temperature, water activity (salt, sugar, dry environments) on growth,</li> </ul>
7.	<b>Evolutionary microbiology</b>	<ul style="list-style-type: none"> <li>Introduction to fungal form and hyphal growth</li> <li>Fungus classification</li> <li>Types of spores</li> <li>Asexual and sexual reproduction in the fungi, spore</li> </ul>

	Mycology (4 Hours)	discharge and dispersal • Beneficial and detrimental effects of fungi to the environment.
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The module explores the diversity of microbial life by introducing the concept of life functions starting from the prokaryotic and eukaryotic cell types. Students will learn how microbes function and interact with their environment. The importance of both beneficial and harmful views of these interactions will be reflected on.

The bulk of the lectures cover 2 main headings which are principles of microbiology (dwell mainly on ‘microbial diversity’, ‘structure and function’, and ‘microbial growth’) and ‘evolutionary microbiology’. In ‘evolutionary microbiology’, students were introduced to the complexities of fungal reproduction and classification into fungal groupings. Each of these individual topics would require about 4 to 8 hours of lectures to cover the concepts involved (Table 3). For the remaining framework of lectures, topics such as ‘Introduction to Microbiology’, ‘virology’, ‘nutrition and metabolism’ required 2 hours of lessons to complete each lecture topic.

It was anticipated that knowledge gathered and lessons learnt from the 1<sup>st</sup> year microbiology module will be useful pertaining to 2<sup>nd</sup> and 3<sup>rd</sup> year modules of the biotechnology programme which include topics on food, energy, shelter, environment and biomedical. For instance, as microbiological techniques and engineering practices begin to link, study of ‘classical’ microbiology in the 1<sup>st</sup> year on microbes alone soon gave way to a diversification of cells. This occurs in genomics, a 3<sup>rd</sup> year module which demonstrated that such cells, manipulated by microbiological techniques would eventually become new sub-specie of microbes or species of plants and animals. Thus, from the fundamental knowledge gathered about the nature of microbes and its interactions with the environment and humans, students will appreciate the beneficial and harmful impact which microbial organisms have on mankind.

Why was the microbe regarded as essential for the students' life sciences education? Dreyfus and Jungwirth (1988) considered the '*general functional idea of the living cell as the "basic unit of life"*' (p. 221)'. So essential was the living cell concept to the secondary biological education in Israel that it was made into a compulsory topic for 9<sup>th</sup> grade students. Similarly, the microbial cell is also the basic cellular unit capable of producing products (i.e. chemicals, alcohol, dairy products, genetically engineered products) and causing destruction and decay. Nowadays, it has affected so many human activities particularly those in agriculture and health that it has become political agenda to push through microbiological issues such as genetically modified products and HIV clinical trials (Bishop, 2000).

### 2.3 Practical

Table 4 lists both the pre-NLM microbiology practical syllabus and the restructured syllabus when the NLM took effect.

Table 4: Comparison of the pre-NLM and NLM microbiology practical syllabus

Pre-NLM	Current NLM
1. <u>Introduction to Microbiology</u> <ul style="list-style-type: none"> <li>Types of glassware and equipment</li> <li>Laboratory rules</li> <li>Types of media; preparation of media, autoclave</li> </ul>	<u>Introduction to Microbiology</u> <ul style="list-style-type: none"> <li>Types of glassware and equipment</li> <li>Laboratory rules</li> <li>Types of media; preparation of media, autoclave</li> </ul>
2. <u>Aseptic Techniques</u> <ul style="list-style-type: none"> <li>Melting and pouring media</li> <li>Transferring of cells into tubes, bottles, 16 streak dilution of sample for isolation</li> </ul>	<u>Aseptic Techniques</u> <ul style="list-style-type: none"> <li>Melting and pouring media</li> <li>Transferring of cells into tubes, bottles, 16 streak dilution of sample for isolation</li> </ul>
3. <u>Determining Culture Purity</u> <ul style="list-style-type: none"> <li>Observation of colony types</li> <li>Selection of one colony for further purification</li> </ul>	* <u>Determining Culture Purity</u> <ul style="list-style-type: none"> <li>Culturing of microbes</li> <li>Maintenance of culture purity</li> </ul>
4. <u>Smear Preparation, Fixation &amp; Simple Staining with Basic Dyes</u> <ul style="list-style-type: none"> <li>Basic and acidic dyes to observe morphology of cells</li> </ul>	<u>Smear Preparation, Fixation &amp; Simple Staining with Basic Dyes</u> <ul style="list-style-type: none"> <li>Basic and acidic dyes to observe morphology of cells</li> </ul>
5. <u>Principles and Care of the Light Microscope</u> <ul style="list-style-type: none"> <li>Demonstration on the use of</li> </ul>	* <u>Principles and Care of the Light Microscope</u> <ul style="list-style-type: none"> <li>Slide preparation</li> </ul>

microscope to observe cells on prepared slides	<ul style="list-style-type: none"> <li>• Correct usage of the microscope to observe cells</li> </ul>
6. <u>Gram Stain</u> <ul style="list-style-type: none"> <li>• To obtain the Gram reaction of bacterial cells.</li> <li>• Interpretation of the results of the Gram stain</li> </ul>	<u>Gram Stain</u> <ul style="list-style-type: none"> <li>• To obtain the Gram reaction of bacterial cells.</li> <li>• Interpretation of the results of the Gram stain</li> </ul>
7. <u>Agar-Slant, Agar-Deep and Broth Cultures</u> <ul style="list-style-type: none"> <li>• Inoculate agar slants, agar deeps and broth</li> <li>• Recognise the appearance of microbial growth on cultures</li> </ul>	<u>Agar-Slant, Agar-Deep and Broth Cultures</u> <ul style="list-style-type: none"> <li>• Inoculate agar slants, agar deeps and broth</li> <li>• Recognise the appearance of microbial growth on cultures</li> </ul>
8. <u>Microscopic Measurements of Microorganisms</u> <ul style="list-style-type: none"> <li>• Measurement of microbes</li> </ul>	* <u>Microscopic Measurements of Microorganisms</u> <ul style="list-style-type: none"> <li>• Calibration of ocular micrometer using stage micrometer</li> <li>• Measurement of microbes</li> </ul>
9. <u>Characterisation of Microorganisms</u> <ul style="list-style-type: none"> <li>• KOH test, Cytochrome C (Oxidase) test, Catalase test, Starch hydrolysis test, Hugh and Liefson test, Nitrate Reduction test, Motility test</li> </ul>	<u>Characterisation of Microorganisms</u> <ul style="list-style-type: none"> <li>• KOH test, Cytochrome C (Oxidase) test, Catalase test, Starch hydrolysis test, Hugh and Liefson test, Nitrate Reduction test, Motility test</li> </ul>
10. <u>Counting Viable Cells</u> <ul style="list-style-type: none"> <li>• Serial dilution and spread plate of a sample</li> <li>• Total count and viable count.</li> </ul>	* <u>Counting Viable Cells</u> <ul style="list-style-type: none"> <li>• Preparation of serial dilution and spread plate of a sample</li> <li>• Reliability of total count and viable count.</li> </ul>

\* Effective changes in the NLM microbiology practicals

A pre-NLM microbiology science practical class is one that leads students to acquire practical skills associated with predetermined results or observations to demonstrate laws and principles. All the pre-NLM practical sessions involved heavily on substantive understanding where a body of knowledge (facts or contents) constitutes towards acquiring practical skills to solve problems (Roberts and Gott, 2000). Table 4 showed the majority of the pre-NLM practicals were laboratory sessions with pre-setup apparatus that allow the students to record outcome of practicals without their active involvement in the preparation. This can be seen in practical 3, 5 and 8 where colony culture plates and microbial slides were prepared; and microscopes already calibrated by the technical support staff.

Unlike the pre-NLM practicals, minimal assistance was provided throughout the NLM practical session to give them the opportunities to discover for themselves on why a procedure was conducted in a particular manner and think through a scientific problem instead of following the protocols strictly and recording 'known' results. As shown in NLM microbiology practical 3, 5 and 8, the students now had to culture and maintain the microbial plates, prepare the microbial slides and calibrate the microscopes themselves. Along the way, they had to reason why contamination occurred and provide suggestions and amend the procedures to achieve their objective.

Of the 10 practicals above, only practical session 8 (microscopic measurements of microorganisms) and 10 (counting viable cells) required students to demonstrate their procedural understandings. For example in the practical 'Microscopic Measurements of Microorganisms', students had to identify and measure the dimensions (continuous dependent variables) of unknown cellular organisms (categoric independent variables). No assistance was entertained on enquiries with regard to procedures in operating the microscope and proper staining techniques on slide preparation.

Even though the intention was to encourage independent learning and improve procedural understanding with proper methods of gathering information and evaluating data as illustrated by Gott and Duggan (1995; 2003), acquisition of laboratory skills were still the dominant intention at Ngee Ann. Overall, the microbiology syllabus still lacked investigative-type activity with approximately 20% of the laboratory practicals incorporated good understanding of scientific evidence.

## 2.4 What is a Microbe?

The living object that is of interest to this research is the microbe otherwise also known as the microorganism. The microbe is a single cell, isolated from other cells by a cell membrane and within this boundary contains a variety of sub-cellular structures and chemicals. The cell membrane is found at the border in all cells. Besides its microscopic size, the microbes have some features also found in other cells. For instance, the hereditary material known as the DNA and gel-like cytoplasm are also found in other cells. All these observations were made possible with the invention of the microscope and advancement in microscopy technology. So what sets the microbe apart from the other living cells? To get a glimpse into the microbe's characteristics as cells and its diversity, major introductory microbiology textbooks had supported the basis that most living cells are categorised into 2 broad groups of organisms, the prokaryotes and eukaryotes (Alcamo, 2001; Madigan *et al.*, 2000).

Application of the polymerase chain reaction (PCR) has clarified that prokaryotes in its simplest sense are made up of bacteria and archaea (Lovell, 2000). These organisms do not have the nucleus or organelles which eukaryotes (mainly fungi, animal and plant cells) do. Though the term 'bacteria' from the Latin *bacterium* means 'rod', it has now become synonymous to prokaryotes (Madigan *et al.*, 2003). Prokaryotes also include microbes of other shapes and sizes such as helically shape spirochetes, or round shape streptococcus and staphylococcus. That meant the term 'bacteria' will also include species with other morphologies besides the rod-shape microbes. Bishop (2000) said that since the development of molecular biological tools in the second half of the 20<sup>th</sup> century, microbiology has advanced our molecular understanding of microbes. Application of such tools has made it possible to characterise microbes further according to its morphology, physiology and behaviour (Lovell, 2000).

In the empirical investigation of students' conceptual frameworks such as notions and principles on microbes, Hilge and Kattmann (1999) gathered views by interviewing them for their ideas as living things, metabolic activity and decomposition. Students' scientific conceptions on microbes were then compared to the established scientific conceptions where results of the analyses were used to generate guidelines to develop better methodology to teach microbiology.

## **2.5 Understanding on Nature of Microbes**

It was once thought that only living organisms contain organic molecules such as amino acids and glucose and these provide the life force (Bauman, 2007). Now that these organic molecules can be synthesised in the laboratory, the question then is what is the difference between living and nonliving organisms? Thus, instead of defining what is 'life' which Biologist Bauman claimed could be difficult to do, he suggested a more objective manner to tackle this issue, which is to describe the characteristics common to all living things. According to biologists, the following characteristics like cellular structures, responses, metabolism, differentiation, reproduction and evolution are life processes which are scientific concepts, common to living cells of multicellular organisms and single-celled microbes (Dreyfus and Jungwirth, 1989; Madigan *et al.*, 2003; Bauman, 2007). In Dreyfus and Jungwirth (1988, 1989) research to uncover the ideas of 'the living cell', views sought from Israeli educationists teachers also established that these basic processes of life takes place in all cells including the microbe. Hence, having the 6 living characteristics mentioned does not constitute an organism to be a microbe. This fact could perhaps cause confusion in students when learning about the nature of the organism in the microbiology course. So what kind of ideas or thinking do the students have concerning the microbes?

Hence, microbes can be applied to understand and study life processes for the fact that microbial organisms do share fundamental biologic principles

with all living things. In essence, most microbes (except viruses) contained cellular structures which are membrane-bound. All living cells including animal and plant cells are membrane bound. Does this impede the understanding of microbiology concepts due to common biology principles between microbes and the other living cells? Other cellular structures such as the cell wall, mitochondria, DNA, RNA and ribosomes are involved in the chemical reactions (or metabolism) which has an affect on the microbial growth (increase in size), reproduction (increase in microbial numbers) and its ability to react to environmental stimuli (response). Most of these structures i.e., mitochondria, DNA, RNA and ribosomes which allow the microbes to be free-living and self-sufficient, are also found in other living animal and plant cells.

To many students studying microbiology for the first time, it does come to no surprises that the very word 'microbe' or 'microorganism' is usually regarded as pathogenic or 'germs'. Prout (1985) reckoned such negative and biased views were partly contributed by the simplistic manner in which the topic of infection theory was taught in schools. The term 'germ' seems to be synonymous to 'bacteria' and 'virus' with the reference of 'microbe' or 'microorganism' on a lesser extent (Maxted, 1984). The idea of germs gathered from children of 12-13 years old arose more of their influence by external factors such as TV media and folklore.

However, Wallace (1986) on the other hand observed that similar aged children linked microbes to specific organisms like bacteria and fungi and associated the idea of microbe to its minute size. In that brainstorming exercise involving children of 11 to 13 years of age, the 11-year-olds however, linked microbes with disease and unsanitary conditions. Ideas from the older 13-year-old students about microbes shifted away from disease and related more towards beneficial function like food making. But these observations were believed to be made due to their recent experiment after being taught and memory still fresh on the subject. It was not surprising that Prout's earlier results suggested that



students may not realise that bacteria and virus are different types of organisms' altogether (Prout, 1985). On whether age of child has an influence on such views that microbe or germ caused specific disease, Driver *et al.* (1994) do not seem to think so. Generally, children of less than 15 years old do have an idea that small size germs do cause some kind of disease (Maxted, 1984). In Nagy's (1953) interviews on American and UK 5-11 year-old children, the elementary pupils had the idea that microbes are germs and caused illness therefore harmful to humans.

The thinking that illness or disease is caused by germs is not shared by society as a whole. In Brumby *et al.*'s (1985) study of students' understanding of health, secondary students described health in its physical terms where they viewed food and exercise as contributors to good health while the older tertiary students' idea was about well being involving mental health and lifestyle. In the Philippines, secondary students also related the health concept to that of well-being such as fitness and happiness (Villavicenzio, 1981). For the adults, health as an absence of disease is considered as having the ability to carry out daily activities (Palmore and Luikart, 1972). None of the arguments above attributed ill health to microbes. Perhaps, what Natapoff (1978) had earlier argued was worth noting when he theorised that students' idea and meaning of health increase with sophistication as they grew older.

The use of students' conception as a component in efforts to help student learning in microbiology is also the position adopted by Maxted (1984). Though this was acknowledged to be the case, Simonneaux (2000) observed that students' knowledge and opinion in fact varied due to their different personal experience as well as influences from family, school and science media. In her study of microbial concepts, involving ten 5<sup>th</sup> form European agricultural students, she noted that their ideas on virus and bacteria varied differently and none of the organisms could be described successfully with high level of consistency. Her

results revealed that students' had incorrect views and descriptions on bacteria and virus where their classifications are concerned;

*"Viruses and bacteria are identical and the two terms are interchangeable.....Since viruses and bacteria are living organisms, that posses one (nucleus), the student see the nucleus as the 'heart'...."*

Simonneaux (2000 p. 624-625)

Three of the 10 students classified the bacteria as identical to virus while 4 students were in the opinion that bacteria are identical to cells. They based this on the idea that organisms of different species like bacteria, virus and cells have the same internal part such as nucleus. Nucleus, found in plant and animal cells, is not found in viral particles and bacteria. It can be seen that their ideas about the cellular characteristics when clarified wrongly and not associated with established scientific knowledge could lead to inaccurate classification of organisms as demonstrated above in Simonneaux's study.

### **2.5.1 Living characteristics**

Piaget's (1929) early research on children's idea of 'living' lead to an idea of 5 stage development of 'living concept'. Children of 6-7 year old interpreted 'lifeless' objects as living as long as the objects were seen to be active in some way for example a clock producing some type of noise. Such view was carried on till the age of 10 where river and sun were considered alive when associated with movements. Carey (1985) termed such physical phenomena as 'naïve psychology' of human behaviour since the children were too young to accumulate adequate knowledge to form any idea of biological process like those of the digestive system. Others would only believe that things were living only if they saw it. Thus, for living things to be actively doing something and moving about, its action-associated movement have become an expected common visual phenomenon for young children to consider it alive.

What about the microscopic organisms like the microbes? Even with its vigorous physical movements from the flagella, they were impossible to be seen and hence, could be mistaken as dead things. This was reported by Maxted (1984) when his 12-13 year old American students believed that bacteria were not living organisms since they can't be visually observed. That was even after the fact that they were told on the existence of bacteria. Perhaps understanding living characteristics as a concept for minute organisms proved difficult to handle and could later possibly contribute towards their ideas about bacterial activity, i.e. growth being misconceived. The students could not understand that living processes could influence the bacterial growth cycle which contributes towards the concentration of microbial population.

Adamo (1999) believed that better understanding on microbes could be successful if students were presented with challenging and exciting tasks. To enhance such learning, he used *E. coli* model system with applied biometric analyses to capture the living characteristics of the microbe. Adamo's study enabled his students to determine distribution of *E. coli* width and length measurements demonstrating the non-uniformity of sizes and length. The idea that growing capacity of microbes were not determinate and that its growth cycle and physical enlargement of the cell could alter according to the environmental temperature it was exposed to. The results portrayed the different growth stages of *E. coli* and elucidated its living characteristics. By focussing on these growth pattern changes which have an influence on metabolic processes and reproduction, Adamo's work help students to better understand the nature of the bacterium. Earlier works on using microbial model system were used to quantify or understand the biological concepts on both live and non-living. Applications on living characteristics have been modelled after other organisms like the amoeba to study the physiology of movement (Adamo, 1964) and an icosahedron model to understand the structural aspects of a virus particle (Adamo,1996).

Ability to grasp or understand the concept of life appears to improve with age. Investigations by Looft (1974) and Bell and Barker (1982) on older children demonstrated that they were able to characterise certain items that were link to living things. The main finding from Looft's 59 second-grade children (7 years old) showed that some biological attributes associated with the concept of living were better understood than others. In this case, concept of food nourishment was best understood by the children followed by respiration and reproduction being the most difficult concept to understand. Looft (1974) argued that possession of such knowledge does not prove that the children have a biological understanding on the concept of living things. In Bell and Barker's teaching on the scientific concept of 'animal' involving 58 pupils at the age groups of 5, 10 and 14, the students' understanding on such concept appear to change and resemble more scientific in their thinking on living with older students.

Evidence of higher level of explanations on life using typical characteristics of living things like growth, reproduction, respiration, response, motility, excretion and nutrition were gathered by Brumby (1982). Fifty-two of her students were provided with written and interview responses which were non familiar to them and were required to characterize living and non-living things. The purpose was to understand how they perceive their idea on life. It was thought then that students were infact rote learning factual contents and thus understood little on the concept of life. It was obvious that they used 'movement' and 'growth' criteria to distinguish between living and nonliving and rarely mention its association with metabolic processes. It would be reasonable to assume that students would have difficulties when learning about microbes or understanding its nature especially on ideas about growth where its replication process is entire different to the growth process of a multicellular organism. It was clear that difficulty in learning about the microbial organism was a realistic one more so due to its minute physical size.

### 2.5.2 Classification

Understanding the concept of classification surrounding the nature of microbes was a challenge for the students to grasp. For instance, in the idea of reproduction, the popular notion would be the sexual type involving 2 separate organisms. Thus, it would be difficult to expect students to understand and accept that asexual reproduction was another common living characteristic, a unique feature in the microbial world, when they have not viewed it before. This method of asexual reproduction using binary fission represents the microbial nature of being independent with self sustaining living processes.

Taking a practical scenario in an environmental study where total bacterial count was determined to ensure consumer safety, difficulties were expected during interpretation of results if the student's understanding on the fundamental concepts of living like growth, reproduction and metabolism in bacteria were not properly established. Thus, a simple spread plate which was intended to reveal the bacterial colonies and its microbial concentrations would be meaningless to the user unless he understood the concept of growth (Driver *et al.*, 1994). Although the term 'growth' refers to an increase in size or cell enlargement of an individual microbe, microbiologist typically refers 'growth' to an increase in microbial population which the thesis would adopt. Bauman (2007) summed it up well with this version of microbial growth;

*".....microbial growth is a discrete colony, an aggregation of cells arising from a single parent cell.....the reproduction of an individual microorganism results in the growth of a colony."* (p. 166)

Such characteristic is unique to the microbial world where independent organism could then be classified individually as single-celled microbes unlike multicellular organisms where it was dependent on other organisms for survival and reproduction purposes. Fundamentally, such ideas are necessary to provide biotechnology students an overall 'picture' of what a microbe is in order to understanding its nature.

Classification of microbes normally served as an introduction to the learning of microbiology in pre-university and university education. According to Lovell (1968), classification enabled the systematic association and linkage of the various concepts learnt and in the process putting them into proper perspective. Inhelder and Piaget (1964) had emphasised that classification which required mental development and logical thinking was also dependent on age and nature of the objects being studied. They found that children could deal with questions about picture animals better at 12 years old while 8-year-olds could manage questions about picture of flowers. Ryman (1974) reasoned that animals were considered to be more abstract than flowers since actions carried out by animals were difficult to come by where as flowers could be easily picked and bundled. Thus, it was not surprising that for 16-year-old Singaporean learning the microbiology concepts involving classification of microbes, learning difficulties would be expected since the object could not be visually seen and handled.

While it was acknowledged that a young teenaged student could think logically and capable of learning from books, his or her perception and discernment on classifying an invisible object would most likely had ideas with non-scientific viewpoint. Classification based on incorrect ideas linking the physical sizes of 'cell' and 'molecule' partly lead to misconception about the cell. That was discovered in Dreyfus and Jungwirth's (1989) questionnaire survey on 219 16-year-old biology students on their conceptions about cells. Students were known to regard the cell being smaller than biological molecules like protein and carbohydrate which it was actually made up of. Hilge and Kattmann (1999) suggested that to overcome such incorrect ideas when educating students, their conceptions on understanding microorganisms and its related biological processes must be identified to prevent false conception from hindering their own learning. This was of concern where students would encounter difficulties in understanding concepts in subjects like microbiology which involved heavy-laden foundational content.

So when learning concepts about microbes, students must be able to draw acceptable knowledge and ideas that were relevant to the nature of microbes. These ideas must relate to the very nature of microbes in that it was made up of a single living cell. This meant that there was a need to accept the notion that microbe could regulate its own biological processes thus providing the ability to function and survive on its own. Dreyfus and Jungwirth (1989) argued that the microbe being a living entity is;

*".....a single cell can be self-sufficient and survive, i.e. an organism can consist of a single cell."*

(Dreyfus and Jungwirth (1989 p.53)

### **2.5.3 Occurrence**

The occurrence of microbes found in their habitats was believed to be diverse. Microbes could even be found or sourced on the surface of higher organisms and within the structures of plants and animals. These organisms at such locations normally thrived and multiply to such an extent that they brought benefits like nutrition to the hosts or habitat. In short, the microbes' purpose and function were linked to where they were found. The idea of naturally occurring microbes as decomposers in the environment was also documented by Hilge and Kattman (1999) and Simonneaux (2000) from their interviews with European students. Most of the students thought that the microbes were simple structured organisms and believed the organisms were both beneficial and destructive.

But how would students comprehend the existence of such microbes around their immediate living environment if the organisms cannot be seen or touched? American educators were concerned that students would only believe on the existence of small living organisms or where they could be found, provided they could first and foremost see them. Similar observation was also documented by Dreyfus and Jungwirth (1989) where their research showed that students could only understand that the cell was the basic unit of structure only

when they could observe the cells. Dreyfus and Jungwirth argued that in instances where the cells could not be observed, students would resort to inferencing only from the experiments. If such approach was adopted, then they would not be able to learn about the source or origin of the microbial organisms.

To overcome the difficulty faced by the biology students when learning about the occurrence of microbes in nature, Madigan *et al.* (2003) urged them to think of the microbe's habitat as minute in corresponding to its morphology. They illustrated with an example below with the hope that students would appreciate the intricacies on where the cellular organisms live or could be found;

*"....for a typical 3 micron rod-shaped bacterium, a distance of 3mm in its habitat is equivalent to that which a human experiences over a distance of 2km!. And across that 3mm distance chemical and physical gradients might exist that could greatly affect the organism."*

(Madigan *et al.*, 2003 p.635)

Educators had conducted small and simple classroom experiment to promote awareness on the existence of microbes. An example was the Environmental Literacy Council, an independent, non-profit organization, which assisted teachers in providing the tools to help students understand and appreciate the occurrence of microbes in the environment. One such activity involving water droplets was intended to acquaint the 10th graders to discover that microbes lived in water. The high school students initially reported that nothing existed in the water droplet. It was only later that at a microscope lab did they discover the presence of microbes (see website: <http://www.enviroliteracy.org>). It may be common for high school students not to realise that microbial organisms do occur around them and their environment. To appreciate the occurrence of microbes around them, scientists at the Marine Biological Laboratory in Woods Hole, Massachusetts, have created an interactive website, micro\*scope, a free, searchable knowledge environment where students could explore (Roland *et al.*, 2005).



Because microbes are wide spread and prevalent it was useful to get the students' idea on where they thought microbes were found, not for the purpose of knowing the location per se, but such knowledge could tribute toward their better appreciation and understanding of the organisms when studying its epidemiology. For example knowing where they were found or located would provide a lot of information about their environmental requirements to function and live. This in turn would enable and help scientists to classify the organisms and formulate the appropriate strategies to curb disease outbreak. In the case of occurrence of bacteria in sewage system, little was known about its nature with regard to its spread of antibiotic resistance in sewage.

A Danish student had thought that antibiotic resistant bacteria were more extensive at the end user. A 3-year project undertaken to study the impact of antibiotic manufacturing on the occurrence of resistant bacteria in sewage revealed that occurrence of single and multiple-resistant bacteria *Acinetobacter* sp. from pharmaceutical plants was greater than hospital waste effluent (Guardabassi, 2000; Guardabassi and Dalsgaard, 2002). This suggests that waste effluents from pharmaceutical plants manufacturing antibiotics were an important source for selecting resistant bacteria in sewage. Having such knowledge and understanding on the occurrence of resistant bacteria would help to establish a meaningful and significant health programme such as occupational risk assessment for the health professionals. Besides that, occurrence of both simple and multiple resistant bacteria would have a certain degree of difference in its living characteristic in particular the cellular structure, i.e., cell wall.

#### **2.5.4 Terminology**

In acquiring the mastery of the new module, students must be comfortable with the proper usage of its terminology. Learning these terms which are not part of everyday English can be overwhelming especially to novices. It appeared that terminology had an influence on the understanding of concepts. In Hilge and Kattman's (1999) research design on students' conceptions of microbes, they

acknowledged that microbiological terms and their meanings must be clarified since it has an affect on students' learning process;

*"The scientific clarification concerns important elements of scientific theories and concepts on microbiology and microbial processes, their genesis, function and meanings. Also the use of terms and their meaning towards learning processes are part of the analysis."*

(Hilge and Kattman, 1999 p. 2)

This was also reflected in Simonneaux's (2000) research in biotechnology education with regard to students' notion of immune system with microbes where she began the interviews by targeting its terminology (e.g. antigen and antibody). In that instant she discovered that none of the 10 5<sup>th</sup>-form French students knew what 'pathogenic agent' meant. It was also reported that students then resorted to analysing the unknown term part by part and identifying its cognates in other languages to derive its meaning. Jacobi (1993) argued that this should not be surprising and expected to happen since mother tongue could summon one's ability to reason or deduce a difficult concept.

However, the questions on terminology had a significant impact on what they understood about the nature of the immune system only soon after the students learnt what the terms meant. At that stage, it became apparent that their own ideas on immune system began to emerge;

*"The interviews focused on a number of biological terms (eg....antibody) and notions related to the immune system.....immune system as having to do with the principle of the body's defences....This principle is based on .....intrusive agents (microbes, viruses, bacteria...)... and defence agents (white cells, antibodies...)....The students' discourse on the function of the immune system revolved around three main ideas: pitched battles, rejection of what is alien to self, and hygiene"*

(Simonneaux, 2000 p. 622)

Such importance in communicating effectively was more crucial nowadays when research projects were often of a collaborative nature involving experts from various disciplines. Walker and Cox (1995) gave an example where a microbial screening project involved a multidisciplinary team of microbiologist, pharmacologist, biochemist and chemist attempted to search for bioactive compounds. They reiterated that for a microbiologist to integrate his expertise with the pharmacologist or chemist successfully and prevented miscommunication; he needed to understand the 'jargon' used by his collaborators and vice-versa. This was due to the fact that the term used could mean differently to different people from another discipline.

Contributing to the confusion was the use of terminology of Greek origin in many microbiology textbooks and that may have created discomfort among the students (Bauman, 2007). Further difficulty in understanding the concept arose partly due to misunderstanding the terminology itself brought about by students memorising the processes.

2.6 Concept Model for Understanding Nature of Microbes

Thus, so far arguments have shown that for a 'novice' student, learning microbiology involved understanding the nature of microbes. Fundamental ideas bounding its areas of conceptual study such as classification, terminology, living characteristics and occurrence can be seen to be 'evolved' in Fig. 1.

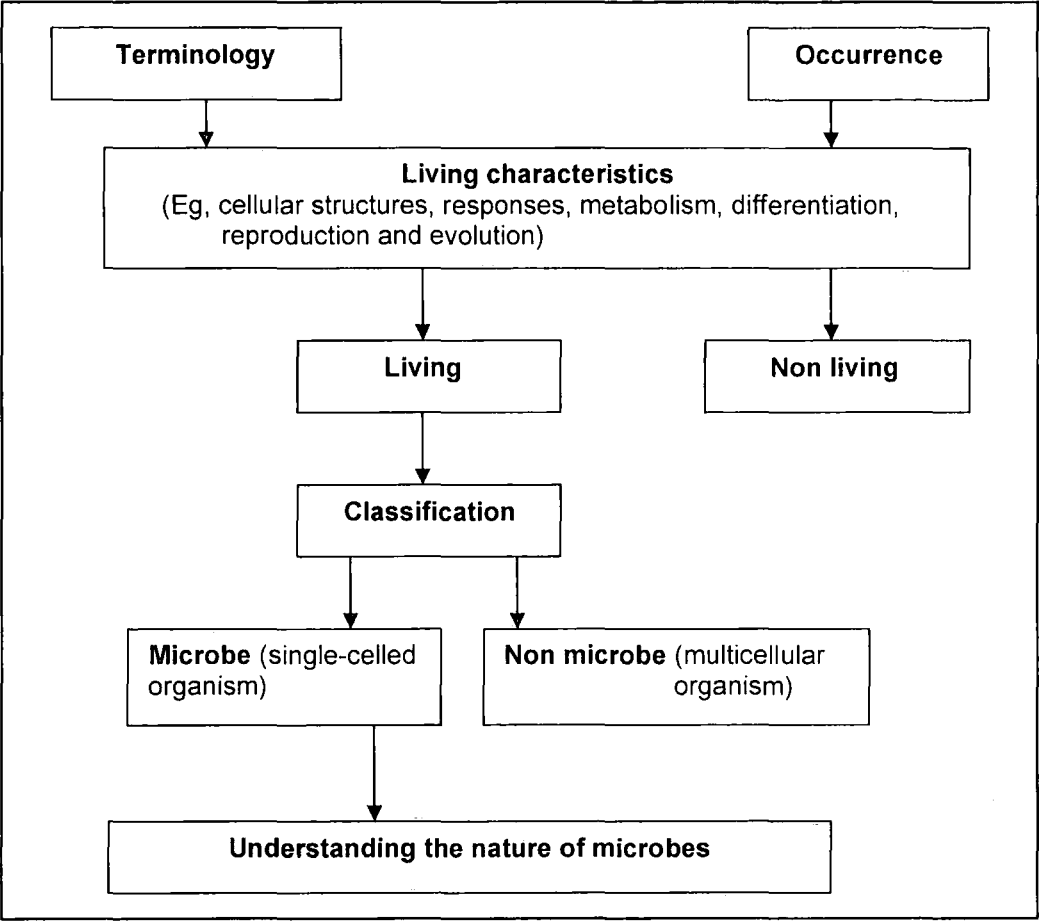


Fig 1: Model on conceptual areas needed in understanding the nature of microbes

The development of these conceptual areas needed in understanding the nature of microbes were also similar to that of Baird and Mitchell's (1986) research on cells. Their results on students' responses to cells, reported by White and Gunstone (1992), were gathered from 2 groups of 15-year-old students. The teenagers were asked to respond on what they understood about cells and also to provide questions about cells which they would like answered. What they knew about cells would demonstrate their conceptual understanding

while their questions would reflect the ideas which they thought they should have understood. The collective results (students' responses in the form of answers and questions) adapted from Baird and Mitchell (1986 p. 67) were then categorised according to concepts (i.e. living characteristics, classification and occurrence) needed in understanding the nature of cells.

Table 5: Categorisation of collective results adapted from Baird and Mitchell (1986 p. 67) according to ideas needed in understanding about the nature of cells (living characteristics - L, classification- C, and occurrence – O)

<p><b>What students understood about cells</b></p> <ul style="list-style-type: none"> <li>- They grow and reproduce (L)</li> <li>- Plant cells hold the plant up (C)</li> <li>- There are plant and animal cells (C)</li> <li>- All cells are small (C)</li> <li>- Plant cells have got thick walls (C)</li> <li>- They have a nucleus (C)</li> <li>- Cells are made up of different components (L)</li> <li>- They are in all living things (L)</li> <li>- Different shapes and sizes (C)</li> <li>- That cells die (L)</li> <li>- Cells hold us together (C)</li> <li>- Two kinds: animal, plant (C)</li> <li>- Cells need food to survive (L)</li> <li>- They need nourishment (L)</li> <li>- Cells are in all parts of the body (O)</li> </ul>
<p><b>Questions about cells which they would like answered</b></p> <ul style="list-style-type: none"> <li>- What happens to them when they die? Do they shrivel, decompose, etc (L)</li> <li>- How do cells get from one place to another? i.e. if someone touches another person, are they transmitted? (O)</li> <li>- When a person (living thing dies), what happens to the cells? (L)</li> <li>- How many times can one cell break (multiply) or grow? (L)</li> <li>- If cells have a constant supply of food do they live eternally? (L)</li> <li>- If all living things are made of cells, is bacteria made up of cells or is it in cells (C)/(L)</li> <li>- Is hair dead cells or made up of cells? (L)</li> <li>- What are cells made up of? (C)</li> <li>- Have animal cells got thin walls or no walls at all? (C)</li> <li>- What is the diameter of an average animal cell? (C)</li> </ul>

Table 5 illustrated that students' conceptual understanding about cells were mainly on living characteristics and classification. Most of the responses to Baird and Mitchell's queries of 'What questions about cells would you like

answered?' were found to be ideas concerning living characteristics and classification of cells which students thought they should have understood. The remaining 2 responses were about microbial occurrence on humans. Thus, if the cells concerned were microbial cells, then it could be argued that Baird and Mitchell's research seem to suggest that students' ideas needed in understanding the nature of microbes indeed centre around living characteristics, classification; and to a lesser extend, on occurrence.

From Fig 1 and table 5, it could be seen that in learning about the nature of microbes, students must be able to distinguish the microbial cells apart from other living cellular organisms which are non-microbial in nature. To distinguish these microbes, occurrence and understanding on the properties unique to the microbes must be known. Occurrence of microbes in a certain habitat would provide an idea on the organism's living characteristics and eventually its proper classification. For instance, organism found in hot springs would have different mineral nutrition activities compared to organisms found in the air. Such knowledge would indicate the function or the organism leading to its classification.

So far, more reports have been written about the 'life' concept of the multicellular organisms (Brumby, 1982). What about the learning on the unique properties of living singled cellular organism? This critical aspect of microbiology warrants the attention of learners to understand so that a good foundation could be established in learning the subject better.

## **2.7 Summary**

Literature on post secondary students' understanding of microbes was scanty. Some of the existing influential literature and research seem to indicate that classifying cellular organisms, mainly by associating ideas of living things or living characteristics (Piaget, 1929; Ryman, 1974; Brumby, 1981, 1982; Maxted, 1984) though, are important may be inadequate. Failure in having a sound

understanding about microbes during the early stage of the microbiology course would have a negative impact on the life sciences education. Worse, it may lead to misconceptions which these studies have shown when learning biological concepts concerning 'microbes', (Nagy, 1953; Simonneaux, 2000), 'cell' (Dreyfus and Jungwirth, 1988, 1989), and 'life' (Looft, 1974; Brumby, 1981, 1982). This has also brought about children or older students' understanding on the nature of microbe which gave the impression that microbial organisms were dangerous.

In the realms of biotechnology, the importance of microbes cannot be emphasised enough if one is to consider its application in environmental, food and medical sectors of the industry. To enable students to have a better learning in microbiology, they must have knowledge and understanding on the properties unique to the microbial cells. Many of the studies do not deal this issue as they reported mainly about ideas of children on general living characteristics of multicellular organisms. Research about ideas needed in learning about the unique properties of single living cellular organism is lacking, especially ideas from post secondary students. How do polytechnic students characterised the microbes? Hence, this study provided the opportunity to device written test and interview questions to probe the 'key' ideas vital on understanding the microbes.

### **2.7.1 Purpose of research**

Understanding and knowing something about the microbes are critical in the learning of microbiology in its entirety. Due to the large scope of the microbiology syllabus and time constraint, this research will investigate the students' ideas surrounding the living characteristics, classification, terminology and occurrence of microbes towards understanding the nature of microbes. Successful probing into students' ideas and knowing what they understand about the concepts will enable the teaching of microbiology to achieve learning outcome 1 (see section 2.2).

**2.7.1.1 Research question:** As seen in the literature, difficulty in learning microbiology by students was expected if their ideas on the various microbial concepts were misunderstood. Analyses of the literature towards students' understanding microbiology resulted in development of a model showing the conceptual areas needed in understanding the nature of microbes. These conceptual areas are terminology, living characteristics, classification and occurrence of microbes.

To be effective in teaching future microbiologist to solve problem and adapt in the life science industry, it is essential to know what the students understand about the microbial organism. Hence, this research intends to investigate the microbiology students' thinking towards understanding the nature of microbes. With these arguments in mind and with reference to the literature in chapter 2, the research question below was established for the study.

**What are students' ideas that constitute towards understanding the nature of microbes?**

**2.7.1.2 Sub-research questions:** The research question was subdivided into 4 sub-research questions to get an in-depth understanding of students' ideas on terminology, living characteristics, classification and occurrence of microbes.

- a) What are students' ideas on terminology of microbes?
- b) What are students' ideas on living characteristics of microbes?
- c) What are students' ideas on classification of microbes?
- d) What are students' ideas on occurrence of microbes?

As a follow up to this literature review, chapter 3 on research methodology will detail the process deployed when investigating students' ideas that constitute towards understanding the nature of microbes.



## **- CHAPTER 3 -**

### **RESEARCH METHODOLOGY**

In chapter 2, it was argued that understanding microbiology concepts would remain a difficult task for students to achieve due to the complexity on the many facets involved in learning the subject. This chapter would initially describe the general approach to its research methodology, before proceeding to the specific instruments and analytical techniques used in answering the research questions surrounding understanding the nature of microbes.

#### **3.1 Research Design**

Figure 2 showed the research design for collecting data on the study of students' understanding of microbiology concepts during a formal 4-month microbiology course. The course required students to attend weekly 2-hour lectures and doing 3-hour laboratory practical. Although students were introduced to microbiology lecture topics and practical syllabus as shown in Table 3 and 4 respectively, in this research however, the intervention would refer to the teaching of contents relating to concepts of terminology, living characteristics, classification and occurrence of microbial organisms. Figure 3 showed the outline of the contents covered by the teaching scheme during the intervention.

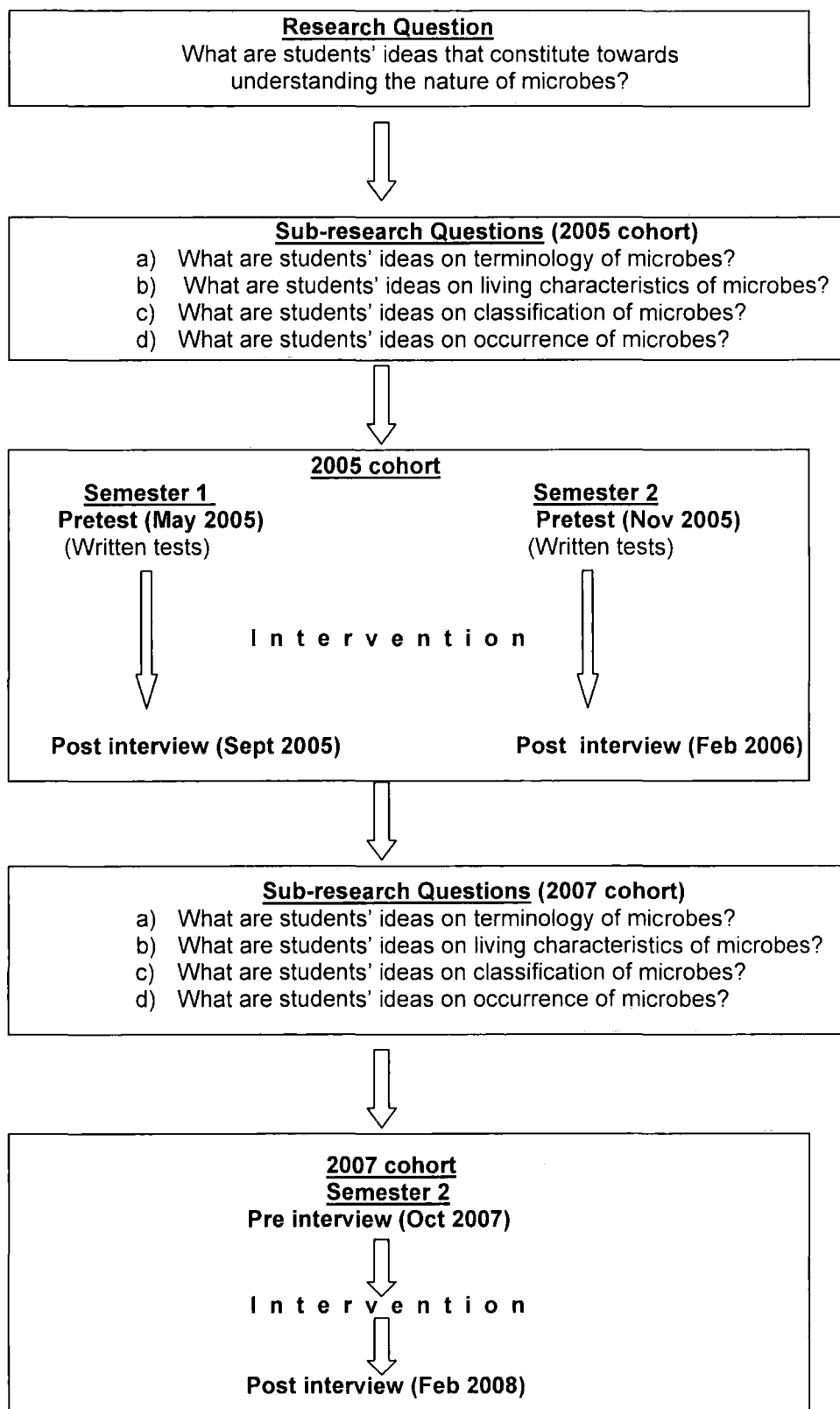


Fig 2: Research design and data collection

3.1.1 Intervention

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1.	Topic: Introduction to Microbiology
	<u>Living characteristics of microbes</u>
Metabolism:	Uptake of chemical substances from the environment which then undergo transformation
Reproduction:	Resulting in cell division to form 2 cells
Movement:	Organisms capable of moving on their own
Communication:	Interaction of cells through secretion of chemicals
Evolution:	Adaptation of cells through development of new characteristics
2.	Topic: In all Lectures
	<u>Terminology</u>
	Focussing the correct definition and explanation for each of the microbiological terms used in each topic
	<u>Occurrence</u>
	Shows the variation in location on where microbes are found. Microbial occurrence normally brings benefit to the habitat as its function is associated to where its found.
3.	Topic: Microbial diversity
	<u>Classification of microbes</u>
Morphology:	Cell sizes, arrangements and shapes
Locomotion:	Motility in microbes in response to changes in environment
Metabolic activities:	Highly diverse metabolism of bacterium response to presence of air and chemicals
Structures of the cell:	Similarities and differences between eukaryotes and prokaryotes
4.	Topic: Microbial growth
	<u>Microbial growth</u>
Microbial growth:	Characteristic growth pattern for a bacterial population. Growth occurs by binary fission and increase in the number of cells

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Fig 3: Outline of the contents covered by the teaching scheme during the intervention

Students from cohorts of 2005 and 2007 were taught the same lecture contents as outlined in Fig 3. The time spent on all the concepts under the various lecture topics were also the same. The concepts surrounding the living characteristics of microbes were exposed to fresh students of microbiology. The concept was taught in the 2-hour lecture ‘Introduction to Microbiology’ where microbes were examined with regard to how and where it existed in nature.

The microbes' living characteristics were basically made up of 5 characteristics. Students were informed that metabolism existed in all living cells and that it involved uptake of chemical substances and transforming them in the cell for it to use. The by-products or waste was then eliminated to the external environment. In reproduction, students were shown series of biochemical events leading to the cell division resulting in the formation of 2 cells. Ability of microbes to communicate with other cells and respond to its environment was established to students as a living characteristic. The availability of different mechanisms of motility or movement in living microbes were introduced in that the organisms were able to propel itself. The class was finally shown that unlike non-living things, microbes were able to evolve where it altered its characteristics to adapt to its immediate environment.

At the beginning of each new lecture throughout the microbiology course, terms involved in each of the topic which was most likely to be unfamiliar to the class, were defined and explained. Similarly to learning the terminology, the occurrence of microbes found in their various diverse habitats was highlighted to the class during the study of microbiology. The diversity of locations where these organisms normally thrive and multiply helped to reveal and explain about its characteristics. In short, having an idea on occurrence of microbes would present a better perception to students on its purpose and function of the respective microbial organisms.

In the 5-hour lecture on 'microbial diversity', cells and structures were examined leading to discussion on similarities and differences between the 2 main cell types, eukaryotic and prokaryotic cells. Students were told that due to the diversity of cells which existed in the world of plants and animals (eukaryotic cells), ability to classify and recognize microbes (prokaryotic cells) was therefore important in the study of microbiology. The idea of classifying microbes based on morphology (cell size and shape), motility and metabolic activities especially those that relate to presence and absence of oxygen, were explained to them so that they were able to understand and distinguished the differences amongst

cellular organisms. For the 4-hour lecture topic of microbial growth, students were taught that the process typically began by binary fission followed by cell enlargement and the microbe has its own growth pattern. Microbes were shown to live as a group of related cells that derived by repeated cell replication from a single microbial cell.

3.1.2 Time line of activities

Academic year / semester	Dates	Activities
1 / 1	May 2005	Pretest (written test) on ideas about terminology, classification and occurrence of microbes
1 / 1	Sept 2005	Post interview on ideas about living in organisms, growth and classification of microbes
1 / 2	Nov 2005	Pretest (written test) on ideas about terminology, classification and occurrence of microbes
1 / 2	Feb 2006	Post interview on ideas about living in organisms, growth and classification of microbes
1 / 2	Oct 2007	Pre interview on ideas about terminology, growth, classification, occurrence and living characteristics of microbes
1 / 2	Feb 2008	Post interview on ideas about terminology, growth, classification, occurrence and living characteristics of microbes

Fig 4: Dates and activities held with regard to the collection of data for the study.

The association between the activities such as pretest, pre and post interviews with its respective student cohorts and the timings were summarised and presented in Fig 4. Each academic year is made up of 2 semesters. For the 2005 cohort, semester 1 students began their microbiology course in May 2005 while semester 2 students began in Nov 2005. The 2007 cohort commenced their microbiology course in Oct 2007.

### **3.2 Student Profile of 2005 and 2007 Cohorts**

The 2 cohort of students taking part in this research had completed their GCE O-level examinations. They had embarked on a 3-year biotechnology diploma programme at the School of Life Sciences & Chemical Technology, taking microbiology course as one of their first year module. The 2005 cohort was made up of 232 first year biotechnology students (full time). These students were predominantly Chinese at 92% with the rest being Malays, Eurasians and Indians. The students consented to provide the data after they were briefed on the purpose of the study. Of this cohort, 120 students registered to do their microbiology in semester 1 (May–Sept 2005) while the other 112 students studied for the same module in semester 2 (Nov 2005–March 2006). Students from both semester 1 (16–18 years) and 2 (17–24 years) were subjected to the same pretest questions. The student volunteers were then selected from high and low scores from their pretest conducted earlier for the post intervention interviews. Post intervention interviews for the 1<sup>st</sup> semester consisted of 5 male and 2 female students while the 2<sup>nd</sup> semester had 3 male and 5 female students.

For 2007 cohort, 105 students studied microbiology in semester 2 (Oct 2007–Feb 2008). The 16-19 years old students were predominantly Chinese at 91% with the rest being Malays, Eurasians and Indians. Students were assured of their confidentiality and would not be identified in the research. Fifteen students volunteered to be interviewed at the beginning of the semester (pre intervention) and following a period of 4 months study in microbiology, another 15 students were interviewed (post intervention). Of these, only 6 students were

available for both pre and post interviews and thus were used as case studies (see section 3.3.2.2). The remainder 9 students which made up the 15 interviewees at the respective pre and post interviews were different individuals. Both pre and post intervention student samples consisted of 8 male and 7 female student volunteers. To achieve a fair and wide spectrum of data distribution, students were selected from a range of high and low achievers for O-level examination taken in 2006. High achievers for GCE O-level would have a typical aggregate score of 10-11 and low achievers would have a score of 15.

**3.2.1 Scientific background of students**

From chapter 2, it can be seen that the entire lecture topics required 14 weeks to complete. It was expected that teaching microbiology to the students would be a challenging task as the topics listed in the syllabus were indeed heavy on factual content. Teaching was made more arduous as the students came with various levels of scientific background with different scientific education. A simple analysis on their scientific background revealed not all students studied both O-level biology and chemistry (Table 6).

Table 6: Proportion of biotechnology students in 2005 cohort (semester 1 and 2) and 2007 cohort (semester 2) with their respective O-level science education

O- level science education	Semester 1, 2005 cohort (n=120)	Semester 2, 2005 cohort (n=112)	Semester 2, 2007 cohort (n=105)
Studied both biology and chemistry	43 (35.8%)	38 (34.0%)	35 (33.3%)
Studied biology only	18 (15%)	23 (20.5%)	18 (17.2%)
Studied chemistry only	59 (49.2%)	51 (45.5%)	52 (49.5%)

Less than 35% of students from across both cohorts studied the 2 science subjects at O-levels. Percentage of students from semester 1 and 2 (2005 cohort) did O-level biology at 15% and 20.5% respectively while for O-level chemistry, less than 50% of students studied the subject. Similarly, a small group of 2007 cohort students studied solely O-level biology (17.2%) and approximately

half of that cohort studied O-level chemistry. With such diverse scientific background with many students studying only one O-level science subject, it is thus logical that when teaching microbiology to these students, basic concepts concerning the understanding of microbes and its characteristics must be emphasised to these 'new learners'.

### **3.3 Instruments for Data Collection**

#### **3.3.1 2005 cohort (semesters 1 and 2)**

Written tests and interviews were selected for data collection. Before the pretest and post interviews were carried, students were informed that in order to teach microbiology more effectively, the lecturer needed to know what facts they already knew on the contents of the subject so that the lecturer would not assume things they did not know or go into areas beyond their realms of understanding. They were also assured that the activities were not examinable and that their final grades remained unaffected.

Taking into consideration of non-homogeneity of students' science educational background, microbiology pretest contained questions that probed students' ideas on microbes at the introductory phase of studying microbiology. Of this cohort, 120 students participated in May 2005 pretests (semester 1) while the other 112 students participated in Nov 2005 pretest (semester 2) two weeks after the course commenced.

**3.3.1.1 Written pretests:** This written test conducted in a classroom, assessed and probed the students' existing knowledge and ideas on concepts constituting towards a microbe. The pretest contained 4 questions that assessed students' ideas on an array of microbial concepts like terminology, classification and occurrence of microbes.

Questions given to the students began with general type questions asking what the students knew about microbiology and their ideas about cellular



organisms and microbes. For instance, students were asked what they thought of the term “microbiology” and to explain what “microorganism” meant to them (Q1 and Q2). The questions later progressed in depth seeking student’s idea – and reasons behind it - on what constituted towards the difference between various cellular organisms and microbes (Q3). Question 4 portrayed significance of microbes in daily encounters where it probed students’ ideas on occurrence of bacteria at the start of their microbiology course.

Table 7 presented the research questions and the corresponding pretest questions probing students of cohort 2005 on terminology, classification and occurrence of microbes

Table 7: Research and pretest questions for cohort of 2005

Research questions	Ideas about	Pretest questions
1. What are students' ideas that constitute towards understanding the nature of microbes?	Terminology	1. What is the first thing that come to your mind when the term "microbiology" is mentioned?
		2. Explain what a microorganism is to you
	Classification	3. Can the following cells be considered a microorganism? Briefly explain reasons for your answer after indicating either a "Yes" or "No".  a) Nerve cell b) Blood cell c) Fungi d) Algae e) Pollen
	Occurrence of bacteria	4. Indicate either a "True" or "False" and briefly explain your reasons for your answer.  a) Bacteria are everywhere in our environment. Most are harmless.  b) Healthy employees do not harbour bacteria.

Probing existing ideas through the use of pretest had its limitations in that it could not assess the students' thinking behind the idea that was present during the time of assessment. Thus, in order to detect students' thinking at the end of the semester i.e., after intervention, students understanding were gathered by means of interviews.

**3.3.1.2**      Post intervention interviews:      To reflect a more accurate state of students' understanding on microbial concepts, semi-structured interviews were conducted. The post intervention interview (post interview) for semester 1 was conducted in Sept 2005 while for semester 2, it was held in Feb 2006. Post

interviews were held a week before the semester ends. The interview questions taken by both semester 1 and semester 2 students were the same.

In post interview, students were given the opportunity to describe their ideas about general understanding of microbiology concepts after the 4-month formal study. To probe students' conceptions on ideas that constitute towards microbes, post interview Q1-3 were devised to probe student ideas on living characteristics and classification of microbes.

Post interview Q1 examined the general ideas about living organisms from the students. They were expected to apply the properties that form the underlying concept of living that existed in most organisms. The intent of using the word 'soft' was similar to Lucas *et al.* (1979) methodology where 944 students of grade 2-10 were shown black and white photos of damp smooth dough during evaluation for their ideas on concept of life. The students were told to write down ways which they thought would indicate the object was alive.

For this study, Q1 focussed on weight gain and movement as criteria for studying students' ideas about living. To prevent an incident where the student may not realise that the movement of soft substance could be an attribute, others such as weight gain and how it obtained its food, were used to enable students more opportunities to provide other evidences on living. This technique of countering 'force criteria' upon test subjects was also practiced by Lucas *et al.* (1979).

Question 2 would attempt to draw their views on microbial concept of living characteristics in microbes. Of interest concerning the living characteristic was the idea on microbial growth towards its environment. In post interview Q2, students were told to describe an experiment using only test tubes to learn something about the living characteristics an unknown microbial organism. The term 'growth' was not mentioned as the purpose was to find out if they could

provide explanation to suggest that the cloudiness in the test-tubes were due to the growth of microbes.

In post interview Q3, students were interviewed on classifying microbial cells. Post interview Q3 allowed students to explain how organisms could be considered or classified as a microbe. In other words, they would share their ideas of what microbes meant to them. Table 8 presented the sub-research questions and its corresponding post interview questions when searching for students ideas on 'living' and 'growth' and 'microbial classification' for cohort of 2005.

Table 8: Sub-research and post intervention questions for cohort of 2005

<p><b>Sub-research question:</b> What are students' ideas on 'living' in organisms?</p> <p><b>Ideas about:</b> Living</p> <p><b>Post intervention Q1:</b>          "A child found a lump of soft substance in a forest. He wants to know if it is living. How will you explain to him, whether the soft substance is living or not?"</p> <p>(if no answer...will ask leading question... <i>Will there be any weight gain, over a period of time?</i>)</p> <ul style="list-style-type: none"> <li>- <i>How does the weight gain come about? Can you explain it?</i></li> <li>- <i>Any idea on how the soft substance obtains its food, i.e if it is living?</i></li> <li>- <i>If the soft substance is living it is left on a table for a few days, what you think will happen?</i></li> <li>- <i>Do you think the substance is able to move? How can you tell?</i>              (if no answer.....<i>how about exposing it to a type of stimuli eg. fire, light, darkness?</i>)</li> </ul>
<p><b>Sub-research question:</b> What are students' ideas on living characteristics of microbes?</p> <p><b>Ideas about:</b> Microbial growth</p> <p><b>Post intervention Q2:</b>          "You're given an unidentified microbe XYZ. Your aim is learn something about the characteristics or properties of this microbe through the visual observation in test tubes only. You have a maximum of 8 days to complete your investigation."</p> <ul style="list-style-type: none"> <li>- <i>How would you go about designing an experiment to achieve this?</i>              (If student has difficulties.....<i>would you inoculate microbe XYZ in test tubes and incubate them?</i>)</li> <li>- <i>How about recording the observations at interval 3 days? Will you agree to this?</i></li> <li>- <i>How about daily recording? Is that a waste of time and effort?</i></li> <li>- <i>How could you tell if microbes are present in the test tubes?</i>              (if no answer....<i>will you see clear solution or dark or something?</i>)</li> <li>- <i>If the test tubes are cloudy, what do you think you'll see if you leave them for 2 days and then come back to observe?</i>              (if no answer...<i>will you see precipitates forming?</i>)</li> <li>- <i>Where do you think the precipitates will occur?</i></li> <li>- <i>If they're found at the surface of the nutrient, what can you conclude about it?</i></li> <li>- <i>And if they're found at the bottom?</i></li> </ul>
<p><b>Sub-research question:</b> What are students' ideas on classification of microbes?</p>

**Ideas about:** What a microbe is (classification).

**Post intervention Q3:**

- *How would you classify a "thing" to be considered a microorganism?*
- *Can you explain why?*

*(if nothing, will assist student by asking leading questions ....Would you consider all small, tiny living things to be a microorganism say ant, pollen, skin cell, yeast cell ?)*

- *Some ants are very small, wouldn't you consider it as a microorganism?*
- *How about the pollen, it is extremely small, is it a microorganism?*
- *Can you provide some examples of microorganisms?*

Pretests responses together with post interview data would then establish a background of students' ideas on living characteristics and classification of microbial organisms. These were then used to develop more detail interview questions for 2007 cohort towards researching students understanding of microbiology. For example, the general line of questioning on living organisms for 2005 cohort, were used to prepare interview questions specifically on microbial growth, for 2007 cohort. They were also used for preparing interview questions on living characteristics of specific microbes like virus and bacteria.

### **3.3.2 2007 cohort (semester 2)**

Questions from 2005 cohort were used to improve the interview questions in 2007 cohort. For example, the general line of questioning on living organisms in cohort 2005 (Q1) were used to prepare 2007 cohort interview questions specifically on living characteristics of virus and bacteria (Q5).

Interview questions on microbial growth for 2007 cohort (Q2) allowed a more candid manner for the students to express their ideas by improving circumstances (i.e., stream water) surrounding which the questions were derived as compared to 2005 cohort (Q2) where students were told on the presence of

an unidentified organism. Experience gained from microbial classification in 2005 cohort (Q3) helped to prepare the cohort 2007 interview (Q3) on microbial classification in relation to other various organisms such as ants, pollen, skin and yeast cells.

Attempts to answer the 4 sub-research questions were made by putting together interview questions as shown in Table 9.

**3.3.2.1**      Pre and post interviews: In cohort 2007, pre intervention interviews (pre interview) were conducted at the beginning of semester and post intervention interviews (post interview) at the end of semester. Pre interview was conducted in week 2 of Oct 07 semester while post interview was conducted in week 15 of the 16-week semester. The questions involved in pre and post interviews were identical. By maintaining identical questions the research hoped that development of students' ideas such as their perception and understanding of the various microbiology concepts that occurred at the beginning and after microbiology was taught, could be monitored. Haefner and Zembal-Saul (2001) argued that only by revisiting the same questions during post interviews, could changes or improvements in students' ideas be tracked.

During the interview, no hint was given on the type or identity of microbe since it was meant to draw students' own idea of organisms and its respective functions. To probe students' thinking towards understanding the nature of microbes, 5 interview questions were devised to answer 4 sub-research questions on student ideas on terminology, living characteristics, classification and occurrence of microbes for 2007 cohort (Table 9).

In interview Q1, they were expected to apply the properties that form the underlying concept of living that existed in most organisms. These include students' ideas on the common terminology used when studying microbiology. It

was also designed to record their preconception so that it could be taken into account when teaching microbiology.

Interview Q2 probed into their thinking about ideas on living characteristics especially microbial growth. In interview Q2, students were interviewed about an experiment using test tubes to show that minute microscopic organisms present in water, were capable of growing and reproducing with time. The growth process would eventually be made obvious when cloudy appearance was observed in the test tube indicating an increase in microbial population. Growth constituted towards the processes of life as one of the living characteristics present in microbial organisms (Madigan *et al.*, 2003; Bauman, 2007)

Interview Q3 allowed students to explain how organisms could be considered or classified as a microbe. Examples of other organisms such as pollen and ant were used to provide opportunities for them to reinforce their explanations and responses behind their idea on classifying microbes. In other words, they would share their ideas of what microbes meant to them. Such questioning would eventually seek students' ideas about characteristics or properties of microbes and establish their understanding on the nature about microbial organisms.

Interview Q4 allowed students' to express their views and ideas with regard to daily encounter with microbial organisms particularly on its occurrence. Information about the occurrence of microbes would supplement a better 'picture' on students' understanding of microbes. The interview followed similar guidelines to that developed by University of Kiel which collected data from German, Dutch and French students with regard to locations on where bacteria were found. The Kiel's interviews were developed as part of developing new teaching material in biotechnology education commissioned by the European Initiation for Biotechnology Education (EIBE). Question 4 was modified by taking a general approach focussing on microbes rather than bacteria (Simonneaux, 2000) which



otherwise may limit the opportunity to display their understanding. Usage of 'microbes' instead of 'bacteria' will promote greater flexibility in the students' response allowing greater level of participation. It allowed students better opportunity to express their ideas on whereabouts of other types of microbes apart from bacteria. Further modifications on Interview Q4 allowed students' to express their views and ideas with regard to daily encounter with microbes on their occurrence in the environment and humans.

Probes to further draw specific views on living characteristics were done in interview Q5 where 2 types of microbes (virus and bacteria) were involved. Interview Q5 provided the students opportunities to express their thinking or reasons on why they consider microbes such as virus and bacteria to be living. It must be acknowledged in some ways, the virus may not be an ideal candidate to seek their views on living due to the unique atypical nature as compared to bacteria. However, due to its economic importance and influence it had in the medical field, it was thus listed as a candidate. The guide for interview Q5 was adapted from University of Kiel which developed the interviews as part of EIBE's biotechnology educational programme

Table 9 presented the 4 sub-research questions and its corresponding post interview questions for cohort 2007.

Table 9: Sub-research, pre and post interview questions for cohort of 2007

<b>Sub-research question:</b> What are students' ideas on terminology of microbes?	
<b>Ideas about:</b>	Terminology
<b>Post interview Q1:</b> <ul style="list-style-type: none"> <li>- <i>What is meant by the term "microbiology" ?</i></li> <li>- <i>Explain what a microbe is to you?</i></li> <li>- <i>What is meant by "colony"?</i></li> <li>- <i>What is the meaning of "antibiotics"?</i></li> <li>- <i>What are the functions of the microbes?</i> (no hint will be given on the type or identity of microbe since it is meant to draw students' own idea of organisms and its respective functions)</li> </ul>	
<b>Sub-research question :</b> What are students' ideas on living characteristics of microbes?	
<b>Ideas about:</b>	Microbial growth
<b>Post interview Q2:</b> "You're given a test tube containing 100ml clear water taken from a nearby stream." <ul style="list-style-type: none"> <li>- <i>What do you see?</i> (If student has difficulties.....<i>why is it that you see nothing?</i>) (if yes.....<i>How do you know and why did you say that?</i>)</li> <li>- <i>What do you expect to see in 3 days time?</i></li> <li>- <i>Is there anything growing in there?</i> (If no.....<i>Why did you say that?</i>)  (If yes.....<i>What do you think you'll see?</i>)</li> <li>- <i>What are the things in there? Explain</i></li> <li>- <i>If there are no living things in the test tube, do you expect to see anything in 3 days time? Why?</i></li> <li>- <i>If there are living things in the test tube, do you expect to see anything in 3 days time? Why?</i></li> <li>- <i>Can you see anything right now? Explain</i></li> </ul>	
<b>Sub-research question:</b> What are students' ideas on classification of microbes?	
<b>Ideas about:</b>	What a microbe is (classification).

**Post interview Q3:**

- *How would you classify a "thing" to be considered a microorganism?*
- *Can you explain why?*

(if no answer, will assist student by asking leading questions ....*Would you consider all small, tiny living things to be a microorganism say ant, pollen, skin cell, yeast cell ?*)

- *Some ants are very small, wouldn't you consider it as a microorganism?*
- *How about the pollen, it is extremely small, is it a microorganism?*
- *Can you provide some examples of microorganisms? Why?*

**Sub-research question:** What are students' ideas on occurrence of microbes?

**Ideas about:** Occurrence of microbes

**Post interview Q4:**

- *We are advised to wash our hands before lunch or dinner. Why?*
- *Is it advisable to use soap when washing hands? Why do you think so?*
- *Is water alone sufficient when washing hands? Why?*
- *Where else can microbes be found?*
- (If no answer.....*Are there microbes in the air? How about the water?*)
- *Do you have any microbes on you?*
- *Where do they come from?*
- *If you have them, what microbes are they? What will happen to you?*
- *How come you're not sick? Explain*
- *How do microbes enter the human body?*
- *Where can you find microbes in the human body?*  
(If answer is 'stomach' ..... *What do microbes do in there?*)  
(If answer is 'digestion' ....*Do microbes stomach only participate in digestion?*)
- *Do microbes behave the same way outside the human body?*
- *Do microbes in the stomach have other functions?*  
(If answer is 'intestine')
- *What function do microbes have in the intestine?*  
(If answer is 'digestion' .... *Is that all it does?.*)
- *Do intestinal microbes have other functions?*
- (If mentioned other organs .....*What effect do microbes have there?*)

- *How do the microbes get there?*

**Sub-research question:** What are students' ideas on living characteristics of microbes?

**Ideas about:** Living characteristics

**Post interview Q5:**

About a Virus

- *Explain what a virus looks like to you?*
- *How big is a viruse? Can you see them?*
- *Are viruses living organisms? Explain.*  
(If yes, ...ask these questions)
- *Are viruses plants or animals or neither?*
- *Do they breathe? How?*
- *How Do viruses feed? How?*
- *Do viruses move? How?*
- *Do viruses reproduce? How? How fast?*

About a bacterium

- *Explain what a bacterium looks like to you?*
- *How big is a bacterium? Can you see them?*
- *Are bacteria living organisims? Explain your answer*  
(If yes,.....ask these questions)
- *How do you know that bacteria are living things?*
- *Are there other living organisms with similar structure to bacteria?*
- *Are bacteria plants or animals or neither? Explain*
- *Do bacteria feed? How?*
- *Do bacteris move? How?*
- *Do bacteria reproduce? How? How fast?*
- *Are there living organisms made up of bacteria?*

3.3.2.2 Six case studies of 2007 cohort: To gain a better understanding on the development of students' ideas on terminology, living characteristics, classification and occurrence of microbes, 6 students from the 15 student sample of 2007 cohort were interviewed for both pre and post interviews. In this investigation, these 6 students (3 males and 3 females), aged 16-17 years old, were used as case studies. This would allow a proper assessment on each individual student's understanding on nature of microbes by probing their ideas before and after their study of microbiology.

The procedures and questions deployed were the same as reported in section 3.3.2.1. Efforts to persuade all the same 15 students to participate in both pre and post interviews were unsuccessful when they realised the laborious efforts expected of them and the possible stressful experience involved.

### **3.4 Qualitative Data Analyses of 2005 Cohort**

#### **3.4.1 Pretests**

For this pretest pilot study in 2005, the primary aim is to illustrate the students' ideas about microbes. Responses and explanations that were common or similar for each question from all students at their respective semester were pooled and combined. These data were then conceptualised by providing a name to each idea from an explanation. These ideas which represent a phenomenon were given common key words, phrases and themes. Similar ideas of responses and explanations from each question were then grouped into a category with its corresponding frequencies recorded.

#### **3.4.2 Post intervention interviews**

Post intervention interviews (post interview) were held after 4 months of studying microbiology in Sept 2005 and Feb 2006. Semi-structured interviews were shown to allow a deeper investigation on whether students learn science by understanding (Duit *et al.*, 1996; Johnson and Gott, 1996), common sense (Ekborg, 2003) or just rote learning. Hitchcock and Hughes (1995) noted that

semi-structured interviews permits the interviewer the likelihood to follow-up and develop on the students' responses. Hilge and Kattmann (1999) and Simonneaux (2000) observed that interviews enabled data on students' conception and preconception respectively to be made known.

The interview schedule also included follow-up questions to anticipate certain responses. The interview questions hoped to capture responses that were consistent with the concepts associated with understanding found in the respective questions. As such, it attempted to provide students the opportunity to demonstrate their understanding on the various microbiology concepts. The interviews also demonstrated the researcher's sincere interest on students' views and valued their opinions and at the same time allowed clarification of confusing facts and provide better understanding on their reasoning. The interview questions were tried on 2 biotechnology students before it was applied onto the students of cohorts 2005 and 2007.

In cohort 2005, the 1<sup>st</sup> semester student sample consisted of 5 male and 2 female students while the 2<sup>nd</sup> semester had 3 male and 5 female students. Even gender sample was not achieved as the students volunteered as test subjects. The students were selected from high and low test scores for their pretest conducted earlier in the semester. Unlike Papageorgiou and Johnson's (2005) approach where students of intermediate performance band were included (besides high and low bands), this mode was not taken as the 15 students from high and low performance of pretest should provide a wide spectrum of views. Each interview was conducted individually which took approximately 45 min to complete. Idea that was of interest from the transcribed data of each student interview was highlighted and coded using grounded theory (Strauss and Corbin, 1990) with the aim to categorise them. During the categorising process, such questions like "*What is this? What does it represents?*" were asked (Strauss and Corbin, 1990 p. 63).

Typically, grounded theory is used to gather data and analyse them to allow a theory to emerge. However, for this study, the primary aim was to generate categories of ideas so as to illustrate the students' understandings on microbes. Responses and explanations provided for each question from all students were conceptualised by providing each category of idea from an explanation with a name. This was done according to Open Coding of Strauss and Corbin (1990);

Open Coding: *".....is the analytic process by which concepts are identified and developed in terms of their properties and dimensions.....Similar events and incidents are labelled and grouped to form categories."*  
(p. 74)

Since the study aimed to conceptualise students' thinking on the various concepts of microbiology, only the procedure of open coding in grounded theory was applied. Strauss and Corbin (1990) argued that application of open coding procedure alone is acceptable, *"if your purpose is just to pull out themes, then you can pretty much stop here."* (p.67). Grouping of students' responses into category using key words and themes would present a clearer explanation towards their understanding the nature of microbes. Through open coding, the essence of students' thinking was less likely to be 'lost' which could happen if the transcribed data were summarised instead. The process of categorization enabled massive statements to be rephrased into simple thematic statements. This approach was also adopted by Pekmez *et al.* (2005) in capturing the essence of long sentences recorded in interviews. He then condensed the statements and grouped them into categories.

This technique was also used by White and Gunstone (1992) where they analysed their transcripts about concepts by rewording the inter-related responses under a heading. Thus, by rephrasing massive statements into categories of thematic words, frequency scoring was also made possible. At this point, it must be acknowledged that the more knowledge types (facts or images) a student had would possibly increase the scoring. However, this would not

determine the quality of understanding if some of the statements of knowledge were false or vague (White and Gunstone, 1992). In this research, views or responses that were provided readily without any coercion would be regarded and accepted as quality data of understanding though the understanding of that concept may be low. Majority of such quality responses to each of the respective questions were found to contain single idea. Quality responses that had dual ideas were combined as a single entity. To obtain a perspective on their level of understanding for each area towards learning about microbes, the categorised responses that corresponded or matched with the most relevant key ideas were listed at the top of the results' table claiming students' understanding on the concept. Subsequent responses with category of ideas considered relevant but of lesser significance were listed downwards indicating some understanding. This method of assessing ideas for their level of understanding continued until the bottom category of ideas that represent the least conceptual understanding. Relevant quotes from these transcribed data would be extracted and commented upon when highlighting the discussions on the results in chapter 5.

### **3.5 Qualitative Data Analyses of 2007 Cohort**

#### **3.5.1 Pre and post intervention interviews**

Many studies have favoured interviews as the main instrument for data collection (White, and Gunstone, (1992); Cohen and Manion, 1994; and Pekmez *et al.*, 2005). They found that interviews offer the chance to probe in-depth understanding of the subjects' ideas. As for the student, the interview session offers him a chance to speak up freely, of course after being assured that his grade will not be affected as a result of the interview outcome. In that manner, he would be more incline to say meaningful things when he felt relax. This then presents an opportunity for the interviewer to use his interpersonal skills to venture in-depth into interesting views raised by the student (Cohen *et al.*, 2000).

The qualitative data obtained from 15 students who volunteered to be interviewed at each pre and post interviews were transcribed verbatim. Interview



transcriptions from students of high and low O-level aggregate scores were collected with the intention to capture responses establishing a wider range of thinking. Those extracted responses were then identified to characterize the students' ideas. Similar views from each interview question that explain their common understanding of ideas were grouped into a category. Grouping into category using key words and themes were done the same as that for cohort 2005 post interview as described in section 3.4.2. Such categorization enabled massive statements to be rephrased into simple thematic statements.

### **3.5.2 Case studies**

Data gathered from the 6 students were analysed qualitatively according to section 3.4.2.

## **3.6 Summary**

This chapter discussed all the activities involved in this investigation executed from May 2005 till Feb 2008. Data were collected during pretests (N = 232) and post interviews (N = 15) for cohort 2005 (May 2005–March 2006). A total of 30 students were involved in the pre-post interviews for cohort 2007 (Oct 2007-Feb 2008). Responses gathered from cohort 2005 would establish a background and then used to generate a more detail interview questions for cohort 2007 towards researching students understanding on the nature of microbes. For cohort 2007, students' ideas on terminology, living characteristics, classification and occurrence were collected and analysed. Six student interviews were conducted as case studies to better understand the development of ideas throughout semester 2 in 2007. Qualitative data from interviews gathered in 2005 and 2007 would enhance the reliability and validity of the results. It would also complement and add meaningful interpretations to the students' ideas gathered from the 3 semesters over the 2005 and 2007 cohorts.

## **- CHAPTER 4 -**

### **RESULTS**

In this chapter, the results were presented in 2 sections. Section A featured the broad spectrum of ideas gathered from cohorts 2005 and 2007. Section B featured the case studies' results which reported on the development of ideas of 6 students from cohort 2007.

#### **(SECTION A)**

##### **4.1 Pretest of 2005 Cohort**

###### **4.1.1 Terminology: 'microbiology and microorganism'**

Table 10 provided a conceptualized data of categories and responses for students' idea on the term 'microbiology'. More than half of the students in each semester thought that this terminology was about the study of microbes. This was followed by their ideas about studying of small living things; and bacteria and virus. The 2005 cohort centered their explanations around the fact that studying of small cells, microbes, bacteria and virus was done at a microscopic level. One semester 1 student thought microbiology was about genes and another related it to worms.

When asked to explain what a microorganism was to them, the students opened up with more categories of explanations. Majority of 2005 cohort (77.5% semester 1 and 91.1% semester 2) seemed to think that microorganisms were about the need of microscope to view them. In this category, they explained that because small living organisms can't be seen with naked eye, a microscope was therefore required to view them. Few students had the correct idea that the microbe was a single-celled organism (8 students, semester 2) and have the capability of reproducing (5 students, semester 1) and surviving independently (7 students, semester 1).

## **4.1.2 Classification of organisms**

**4.1.2.1      Nerve cell:** Slightly more than half (56.7%) of semester 1 students did not consider nerve cells as microbes giving the reason that nerve cells were eukaryotic cells and larger than microbes. Eight (6.7%) semester 1 students did not offer any explanation for their thinking that a nerve cell was not a microbe.

Fifty percent of semester 2 students thought that nerve cell was a microbe. Reasons provided under the category of 'cellular characteristics' were that nerve cells cannot live independently and considered as part of an organism or tissues. They also explained that nerve cells require other cells to support its functions. The rest did not consider nerve cells as microbes citing reasons that nerve cells are eukaryotes (10.7%) and its dimension larger than a microbe (21.4%).

**4.1.2.2      Red blood cell:** More students (68.3% semester 1 and 65.2% semester 2) did not consider red blood cell (RBC) to be a microbe. Main category of explanations supporting their decision was its cellular characteristics (47.5%) that described RBCs' function to carry oxygen, inability to survive and reproduce independently; and presence of its internal structures. Other ideas that supported it as a non microbial organism were based on its occurrence (5.8%) in human and not in air (semester 1). Incorrect students' thinking of RBCs as eukaryotic cells were recorded in both semesters 1 and 2 at 5.0% and 5.4% respectively.

**4.1.2.3      Fungi:** More students in semester 1 (61.7%) than semester 2 (42.9%) considered fungi as microorganisms based their decisions on its category of 'cellular characteristics'. Common responses found in both semesters behind this main category of ideas were fungi's independence to function and reproduce. Other common ideas of fungi being a microbe between the 2 semesters were that fungi were tiny living things and its existence of yeast cells as unicellular cells. The main idea for not accepting fungi as a microbe in both semesters was due to their thinking being fungi were multicellular eukaryotes.

**4.1.2.4**      Algae: More students from semester 1 (64.2%) than semester 2 (45.5%) classified algae as microbes based on its category 'cellular characteristics' such as its ability to reproduce, live independently and synthesizing its own food from the environment. Common explanations for classifying algae as microbes from the category 'cell types' concerned algae as single-celled organism, were observed in semester 1 (16 students) and semester 2 (9 students). Of the 54.5% of semester 2 students' for not classifying algae as microbes, the thinking of being able to see the algae unaided was the single greatest contributor (11.6%) towards wrong classification. The 11.7% semester 1 students who correctly classify algae as microorganisms, provided erroneous reasons which do not support the classification. Their reasons related to the algae being parasitic, eukaryotic, bacterial in nature and equal in size to the bacteria. This suggests not all the students who classified algae as microbes understood the concept of microbial classification.

**4.1.2.5**      Pollen: More semester 1 (71.7%) students than semester 2 (66.1%) thought that pollen was a microbe. Reasons provided by students did not support their decision. For example, semester 1 students thought of pollen as dependent where it cannot conduct metabolic activity (21.7%) and it was part of a reproductive system (20.8%). Similarly, flawed reasons were also provided by semester 2 students with pollen being part of a reproductive system (15.2%) and inability to conduct its own living processes (17.9%). Eight and 12 students in semester 1 and 2 respectively, had the incorrect idea that pollen was a non-living organism.

### **4.1.3 Occurrence of microbes**

#### **4.1.3.1**      Bacteria are everywhere in our environment. Most are harmless:

Similar proportions (two-thirds) of students in each of the respective semesters believed that bacteria occurred everywhere in the environment and that most were harmless. Their common reason stemmed from the assumption that microbes were everywhere and that they would be getting sick daily if

microbes were indeed pathogenic. Beneficial affects of bacteria under the categories of 'pathogenic characteristics' and 'functions', provided by both group of students, further strengthen their rational for their opinion of harmless bacteria. For example, 5.8% semester 1 students mentioned yeast and microbes that recycled sulfur, nitrogen and carbon while 6.3% semester 2 students had idea involving bacterial application in food production.

The category on 'pathogenic characteristics' of only some harmful microbes producing toxins and building up of immunity in body helped to further explain the 2005 cohort's thinking of why there were more 'harmless' microbes in the environment. This idea of bacteria helping to boost immunity and antibody production in the body formed the 2<sup>nd</sup> most common response from students (12.5% in semester 1 and 13.4% in semester 2) who regard most bacteria as harmless.

**4.1.3.2**      Healthy employees do not harbour bacteria: Ninety percent of semester 1 students disagreed with the notion that healthy employees do not harbour bacteria. Forty-eight students (40.0%) have a preconception that since bacteria were found everywhere, the site where bacteria was found had to include human as well. This was supported by their thinking that people do not seem to get sick with the bacteria around and in them. Twenty-six students (21.7%) explained that microbes in healthy humans occurred especially in their intestines.

In contrast, 40.2% of semester 2 students believed that healthy employees do not harbour bacteria. Twenty-five students (22.3%) from this group did not explain why bacteria were present only in sick and not in healthy employees. The remaining 59.8% thought that healthy employees did contain bacteria in them. Some of the preconceptions were the existence of bacteria around them and in their body. Twenty-one (18.8%) semester 2 students explained that microbes present in healthy people were good bacteria and

harmless. Specific locations where beneficial microbes were mainly found were the intestine followed by the mouth and food. Students' thinking was that since the bacteria were beneficial and harmless, humans were therefore unlikely to be sick.

Table 10: Categories of responses of 2005 cohort’s existing knowledge and ideas on microbiology at pretest

<i>What is the first thing that come to your mind when the term "microbiology" is mentioned?</i>			
	<u>Semester 1</u>		<u>Semester 2</u>
<u>Study of small living things</u>			
Study of small living things at microscopic level	34		44
Microbial organisms	67		58
Bacteria / virus	17		10
<u>Others</u>			
Genes	1		0
Worms	1		0
Total	120		112
<i>Explain what a microorganism is to you.</i>			
<u>Require microscope</u>			
View tiny living things / organisms that cannot be seen with naked eye	85		91
Looking at virus, bacteria and fungi under microscope	8		11
<u>Function of microorganism</u>			
Simple living cells that are either good or bad to human	8		0
<u>Morphology</u>			
Single cell microorganism	0		8
<u>Cellular characteristics</u>			
Capable of reproducing	5		0
Able to survive on its own	7		0
<u>Others</u>			
Kind of small living cell	6		2
Lower form of organism	1		0
Total	120		112
<i>Can the following cells be considered a microorganism? Briefly explain reasons for your answer after indicating either a "Yes" or "No".</i>			
a) Nerve cell	<u>Semester 1</u>		<u>Semester 2</u>
	<u>No</u>	<u>Yes</u>	<u>No</u> <u>Yes</u>
<u>Cellular characteristics</u>			
Metabolise	2	0	0      0
Has organelles	0	0	0      2
Cannot function or live independently	2	14	7      12
Respond to stimuli	0	3	0      0
Does not reproduce	3	9	0      6
Part of organism / tissue	7	6	5      22
Different cellular structures	2	0	6      4
Has DNA	0	1	0      0

	<u>Semester 1</u>		<u>Semester 2</u>	
	<u>No</u>	<u>Yes</u>	<u>No</u>	<u>Yes</u>
<u>Cell types</u>				
Larger than microorganisms	25	0	24	0
Eukaryotic cells	15	0	12	2
<u>Others</u>				
Not a living thing	0	12	0	4
Living cells	4	7	0	0
No comments	8	0	2	4
Total	68	52	56	56

<b>b) Red blood cell</b>				
	<u>Semester 1</u>		<u>Semester 2</u>	
	<u>No</u>	<u>Yes</u>	<u>No</u>	<u>Yes</u>
<u>Cellular characteristics</u>				
Cells carry only oxygen/has haemoglobin	7	3	6	2
Cannot reproduce on its own	15	5	11	4
No nucleus	8	3	5	3
Cannot survive independently	14	7	13	5
No mobility	3	2	3	1
Have nucleus	4	4	2	3
Able to move on its own	0	5	1	5
Part of an organism	6	0	3	0
<u>Occurrence</u>				
In human/blood system	7	2	8	5
Not found in air	0	1	2	2
<u>Cell types</u>				
Larger than microbe	5	0	9	0
Eukaryotic cells	6	0	6	2
<u>Others</u>				
Tiny living things	2	6	0	6
Not living	2	0	3	0
No comments	3	0	1	1
Total	82	38	73	39

<b>(c) Fungi</b>				
	<u>Semester 1</u>		<u>Semester 2</u>	
	<u>No</u>	<u>Yes</u>	<u>No</u>	<u>Yes</u>
<u>Cellular characteristics</u>				
Reproduce	6	21	9	8
Respire	3	0	0	2
Have spores	5	0	4	0
Live /function independently	2	24	10	9
<u>Cell types</u>				
Unicellular organism/yeast	0	8	5	11



Eukaryotic cells	7	3	16	2
Multi-cellular organism	12	4	14	2
Prokaryotic cells	0	0	0	5
	<u>Semester 1</u>		<u>Semester 2</u>	
	<u>No</u>	<u>Yes</u>	<u>No</u>	<u>Yes</u>
<u>Function</u>				
Decay organic materials	3	0	0	2
Make nutrients from environment	5	5	6	1
<u>Others</u>				
Present in environment everywhere	3	2	0	0
Tiny living things	0	7	0	4
Need microscope to see it	0	0	0	2
Total	46	74	64	48

#### (d) Algae

	<u>Semester 1</u>		<u>Semester 2</u>	
	<u>No</u>	<u>Yes</u>	<u>No</u>	<u>Yes</u>
<u>Cellular characteristics</u>				
Photosynthesise / make own food	15	20	8	14
Capable of reproduction by itself	3	10	8	11
Survive / live independently	8	17	10	9
<u>Cell types</u>				
A fungi	2	0	0	0
Parasite	0	5	0	0
Eukaryotes	0	3	4	0
Multicellular cells	2	0	6	2
Contain bacteria	0	3	0	0
Clustered of cells	3	0	7	0
Unicellular organisms	0	16	3	9
<u>Others</u>				
Tiny living things or plants	0	0	2	4
Same size as a microbe	0	3	0	0
Need a microscope to see it	0	0	0	2
Can be seen by naked eye	10	0	13	0
Total	43	77	61	51

#### e) Pollen

	<u>Semester 1</u>		<u>Semester 2</u>	
	<u>No</u>	<u>Yes</u>	<u>No</u>	<u>Yes</u>
<u>Cellular characteristics</u>				
Part of reproductive/fertilising purposes	6	25	6	17
Part of an organism	5	21	7	18
Cannot metabolise or carry life processes	10	26	12	20
An independent organism	0	4	0	2
Not part of an organism	0	2	0	4
Cannot reproduce	0	1	0	2
Dependent on others	2	1	1	2

#### Others

Non living	5	3	7	5
Too large in size	6	3	5	4
Total	34	86	38	74

Indicate either a "True" or "False" and briefly explain your reasons for your answer.

#### a) Bacteria are everywhere in our environment. Most are harmless.

Preconception	Semester 1		Semester 2	
	TRUE	FALSE	TRUE	FALSE
Pathogens form a small percentage of microbes	4	0	5	0
People will be sick daily if organisms not harmless	26	0	27	0
Not all microbes are adaptable to environment	2	0	1	2
Microorganisms are everywhere	8	4	10	4
Pathogenic characteristics				
Always mutating	3	4	1	0
Some harmful microbes produce diseases/toxins	11	11	9	14
Organisms help to get antibody production / boost immunity	15	8	15	6
Most bacteria causes diseases	0	17	0	11
Functions				
Some organisms are harmless e.g. yeast, or organisms recycle sulfur, nitrogen or carbon	7	0	0	0
Some bacteria used in food production	0	0	7	0
Total	76	44	75	37

#### b) Healthy employees do not harbour bacteria

Preconception	Semester 1		Semester 2	
	TRUE	FALSE	TRUE	FALSE
Bacteria are everywhere and in humans	1	48	6	27
Humans don't appear sick as many bacteria are harmless/beneficial	0	26	3	21
Present only in sick and not healthy	8	0	25	0
Occurrence				
Intestine	3	26	8	11
Mouth	0	8	3	5
Food	0	0	0	3
Total	12	108	45	67

**4.2 Post Intervention Interview of 2005 Cohort**

**4.2.1 Students’ ideas on ‘living’**

Fifteen students (7 from semester 1 and 8 from semester 2) were asked to explain if the soft lump of substance found in the forest was alive. Their ideas towards understanding the concept of ‘living’ were shown in Table 11. The categories of ideas were grouped in codes A, B and C to indicate the various levels of understanding. Student category of responses with key ideas demonstrating an understanding on ‘living’ was grouped into code A. The most widespread existing ideas on ‘living’ gathered from 2005 cohort at the start of their microbiology course, were on category of ‘metabolism’. Ideas gathered under ‘metabolism’ revolved around 6 students’ thinking on nutritional aspects where food was consumed by living things (Looft, 1974). These involved respiration and; production of waste like CO<sub>2</sub> and water;

- “May be when you give it something to eat, there’ll be some waste product around the site……”* (S1)
- : *“.....perhaps we give it some food and then it will react to it or see if it will eat....waste product coming from the thing.....”* (S2)
- “ .....maybe secretions on the outside, suggest that it’s living.... I mean if there.... are no other living things around the substance, then if there is any waste or excretion, it has to come from this soft substance.”* (S3)
- “If it takes in food right...Then it will...break down... like maybe carbon dioxide or something.... It eats and if there’s any waste, this carbon dioxide is one of the waste.....”* (S7)
- “.....see if there is any features on the lump that enable it to see or eat.....mouth or something which it can feed by.....All living things must eat and for this lump to live ...must have a mouth for food to go in.”* (S13)

Student S15 had the idea that living things must respire. She explained her thinking that living organism respired to provide water to cool off. The use of

plastic to cover the soft substance showed her intention of attempting to prove that water derived from the 'living' substance and not from else where.

S15: *I will put a plastic sheet over it (soft lump of substance).....so for a living organism they normally... respire...which means they give out give out water vapor to cool down so if it's respiring then it's a living organism.*

Q: *How do you know it is respiring?*

S15: *..If there is water droplets condensed on this plastic sheet of paper.*

Ideas of S4 and S11 were on category of 'reproduction' (code B) where their thinking was about microbes or creatures deriving from part of soft substance. S4 assumed the lump of substance was some kind of microbial organism. Going along with his assumption that the lump was a microbe, S4 did not realise the soft substance being a multicellular organism and had little knowledge about the microbe being a single-cell. Both S4 and S11 described asexual reproduction as their ideas of 'living' where progeny arose from a single parent but it was unlikely they realised it since there was no mention on the principles behind it;

*".....scrape the surface to get some of it's, culture it and leave for a week and then come back .....become microorganism ...."*

(S4)

*".....see whether there's any budding or.....any signs of reproduction or ...whether there's ...any similar substance in the area.....or whether there's similar creatures around it..."*

(S11)

S5 and S9 justified that 'things' must increase in size if they were 'living'. Both in the 'growth' category briefly said that nutrients and food were necessary for the size of substance to change (assuming an increase in size) which would indicate it was growing and therefore alive;

*"Culture it in the lab...and provide some nutrients and then..see how it grows....can see the change in size....means it's growing."*

(S5)

*".....if it's living...it needs food to survive... ..it will grow....See the changes.....You need to measure the size....like before and after feeding."*

(S9)

For S8, his idea of living was measuring weight gain increment to indicate growth. There was no explanation to connect weight gain with metabolic reactions or cell replication. His thinking was that over time the living substance was expected to gain more mass or weight. S10 had no explanation on his idea of living things having to feed in order to grow. There was also no mention of its association with any biological processes like digestion or respiration. His thinking was simplistic being that one needed to eat in order to grow. Such was a reflection of his poor understanding on concept of 'living'. S10 had to be guided during the interview with hints given to assist him along.

Q: *.....if this thing is living, do you think it will gain weight?*

S10: *Ya.*

Q: *How would I go about making sure it will gain weight?*

S10: *I feed it.*

Q: *Do you think it will put on weight if it is a living thing?*

S10: *....should right?...because if got take in means got grow right?*

Q: *.....what other signs or evidence to show that this particular thing is living...once you feed it.*

S10: *(Silence)*

S6 in category 1 'respond to stimuli' thought that the organism would move towards the food that it liked and suggested a voluntary and independent response;

*".....you could like try give it....some food and assume that it.....really likes a certain kind of food so you present it and see if it goes there and consumes. When it moves towards the food...shows it's a living thing" (S6)*

S14 thought that living organisms contained blood. However when asked if such reasoning could be applied to plants since plants were living things, she admitted *"...I have no idea why would it be a living thing. Cause living thing will have blood and things in them."* Her perception of living objects concerned mainly about animals only and it did not occur to her that plants were also living things and do not have blood in its system.

S12 in the ‘texture’ category mentioned about idea of substance with a slimy surface for her response on ‘living’. She said, “.....if it’s slimy almost definitely there is something on it....that’s living.” Her thinking was that the slimy substance could not be produced spontaneously from a non living and could only occur (slime secretion) by something that was alive. “Something must produce the slime, right? If not living how does the slime come about? Can’t come out of nothing.” Brumby (1982) recorded similar reason from 5 of her 95 students who were tested if the rock was alive. The 5 students gave nonscientific answers such as expecting moisture content from the rock;

“Moisture, either on the surface or internally if it was cut open.....”  
(Brumby, 1982 p. 618)

Table 11: Categories and frequencies of students’ responses for ideas on ‘living’ at post intervention of 2005 cohort

Code	Categories	Student no. in semester 1							Student no. in semester 2							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
A	<b>1. Respond to stimuli</b>															
	Moving towards food						√									
	<b>2. Metabolism</b>															
	Production of waste products after food consumption	√	√													
	Breaking down of food substances into waste i.e.CO <sub>2</sub>							√								
	Presence of external features eg. mouth for feeding													√		
	Respire (water droplets are produced and condensed)															√
	Presence of secretions or waste in internal body			√												
B	<b>3. Reproduction</b>															
	Production of microbes / creatures from part of soft substance				√							√				
	<b>4. Growth</b>								√							
	Increase in weight gain															
	Increase in size					√				√						
	<b>5. Blood</b>															
	Organism will draw blood														√	
C	<b>6. Texture</b>															
	Existence of slimy substance												√			
	<b>7. Others</b>															
	No idea										√					

- A: There is an understanding on a characteristic of ‘living’
- B: There is some understanding on a characteristic of ‘living’
- C: There is little or no understanding on any of the characteristic of ‘living’

#### 4.2.2 Students' ideas on microbial growth as a living characteristic

The categories of ideas were grouped in codes D, E and F to indicate the different levels of understanding (Table 12). Student ideas suggesting an increase in microbial population due to an aggregation of cells arising from a single parent cell (Bauman, 2007) were grouped into code D, demonstrating an understanding on growth of microbes. Code E illustrated some understanding on microbial growth which was associated with other factors affecting its life cycle during cell division. Code F represented ideas with little or no understanding.

S1 thought that the microbes only needed a short period of a day or 2 to multiply enough to cause the test tube water to become cloudy or turbid. He had the knowledge that the microbes were able to reproduce within a short time.

*“.....after ½ day may not be enough to see anything...after one, two days can then check for cloudiness.....or water becomes turbid....it has presence of organisms. ....The organisms in there will not take long to multiply....so can see something by then....”*  
(S1)

Requirement of a short time span for bacterial growth was also observed in S5 and S6. S5's idea of growth in the 'rapid growing' category concerned the microbe's fast growing nature requiring only a few hours to accumulate cells. He further commented on cells accumulating *“.....at the bottom. Cells growing and.....accumulate .....sinking to the bottom.”* Due to the rapid growth of microbes, S6 recommended the recording of growth twice daily. No explanation was provided by both students on how the cells grew and multiplied in the test tubes.

S12 had similar ideas as S1. She reckoned it was the rapid growth and reproduction of organisms that turned the test tube cloudy within a day. Her thinking on the reproductive intensity of the microbes was illustrated by her description of bacterial 'lumps' becoming dense which sank down the tube. While S12 did not ascribe the 'lumps' to the accumulation of new cells that arise from a

single bacterium, she acknowledged that *"The bacteria reproduce quite fast so (the lump) can become heavy after a while."*

Another main idea of cohort 2005 was the growth of microbes responding to various oxygen levels (category 4). Eight (4 in each semester) students related their thinking about microbes growing in both aerobic and anaerobic conditions. They provided explanations on designing an experiment to indicate that microbial growth was possible in presence and absence of oxygen. Bacterial growth was represented by the 'cloudiness' of the test tube. There was no mention of production of new cells contributing towards population growth, reflecting a lack of proper understanding of growth, or cell division in all the students' responses. S2's idea on microbial growth also associated the 'appearance' of microbes to the short time frame required (a day) suggesting that he knew cells needed a short time to grow. S2 concluded that *"...the microorganism is either aerobic or anaerobic....."* with the argument;

*".....aerobic organisms will float on the surface on the tube...because of more oxygen and those at the bottom of test tubes will indicate that they are anaerobic types. At the bottom there are lesser air, so only anaerobic microbes can grow there."*  
(S2)

A summary of responses below from category 4 'response to oxygen', presented students' (S3, S4 and S15) ideas on ability of microbes to grow in the presence and absence of oxygen. Their responses reflected how they would design their experiment and interpreted the results.

### S3

A: *Basically to find out if it's aerobic or anaerobic, so I would cover one and not the other.....then see which organism is growing in.*

Q: *Which is the one without oxygen?*

A: *The one that is covered with cap or paraffin. ... if aerobic see if microorganism is growing in open tube...if there's both aerobic and anaerobic then I'll see growth in both tubes.*

Q: *.....Anything else you expect to see?*

A: *.... top part of tube ....will be the pellicle.....sediment at the bottom, anaerobic.*



S4

A: *Nutrient broth....same amount in all tubes and XYZ (microbe) in both. End cap on being anaerobic. ...by sealing it's cap.*

Q: *Why?*

A: *Sealing its cap cuts off oxygen. See if it's grows in aerobic or anaerobic tubes.*

Q: *How?*

A: *If's there's microbes in open cap tubes with oxygen, then ...solution is cloudier , less transparent. If it grows in cap tubes....it is also cloudy.*

Q: *Will there be any clear tubes?*

A: *I think so...then there's not much microbes growing.*

S15

A: *I think anaerobic will be at the bottom.....Then for aerobic will be at the top layer*

Q: *How would you know microbes are present...say at aerobic tube?*

A: *.....maybe something appearing like black things on the surface.*

Q: *And for anaerobic tube?*

A: *Also the same.....black things seen at the bottom of the tube.*

Q: *Ok. In which tube?*

A: *In the one covered with plastic.*

Responses from S9 suggested that he knew something about the growth of microbes being influenced by oxygen. He could not provide further explanations when asked to clarify. There were doubts with regard to his answers, and most likely it was a recalled of his experience acquired from the laboratory practicals.

Q: *.....What would you want to know?*

S9: *Whether you (organism) are aerobic or..... Then see whether.....it go at the bottom.....anaerobic*

Q: *What happens if it goes on top (surface)?*

S9: *Aerobic*

Q: *How would you know?*

S9: *The other answer is just to see whether it's anaerobic...cause bottom.....lesser oxygen*

Only S10 insisted on using agar instead of nutrient broth. The responses from S10 may not be valid since agar in test tube was known to test the motility of microorganisms and he may have opted for the interview questions on agar

since he was more familiar on it. Thus, the information recorded may not be what it intended to be. His thinking on microbial motility which concerned the organism's movement in search for food was listed in code F indicating little understanding on microbial growth.

Q: *Assuming agar....so I give you agar...all in tubes....how would you go about conducting your experiment ..... to find out about the characteristics of microbe XYZ?*

S10: *First...test the motility .....by using.....the loop ....after a few days then....see whether it is motile or not.*

Q: *....how many test tubes would you use?*

S10: *1 or 2.....don't need a lot of it...can see whether it will move quite easily right? ...*

Q: *Why motility?*

S10: *It has to search for food.*

Students S11 and S14 were confused and had difficulty when answering the questions. S11 was guided throughout and despite hints on growth being mentioned during the interview, the task of probing remained difficult.

Q: *..... How do you go about, achieving your aim of telling me the characteristics?...you will need to grow them.....(hint)*

S11: *(silence)*

Q: *.....how would you go about it.....*

S11: *I mean .....incubate .....is it? Incubation.*

Q: *.....I give you test-tubes ...and the culture.*

S11: *I'll .....a prepare .....with the micropipette.....then.....sterilize .....*

Q: *What sort of characteristics would you look out for me?*

S11: *.....(silence)*

Q: *.....would you be able to see how it produced by looking....from test-tubes alone? (hint)*

S11: *No, I need to go to the microscope.*

Table 12: Categories and frequencies of students' responses for ideas on microbial growth at post intervention of 2005 cohort

Code	Categories	Student no. in semester 1							Student no. in semester 2							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
D	<b>1. Microbial population</b>															
	Increase in microbial numbers arising from a single parent cell															
E	<b>2. Rapid growing</b>															
	Rapid multiplication of microbes	√											√			
	Presence of microbes within a day						√									
	Fast growing cells within a few hours					√										
	<b>3. Rapid growing / Response to oxygen</b>															
	Presence of microbes within a day/ microbes grow in both aerobic and anaerobic conditions		√													
	<b>4. Response to oxygen</b>															
	Microbes grow in both aerobic and anaerobic conditions			√	√			√	√					√		√
	Know about									√						
F	<b>5. Motility</b>															
	Move in search for food										√					
	<b>6. I don't know</b>															
	Confused											√			√	

D: There is an understanding on microbial growth  
E: There is some understanding on microbial growth  
F: There is no or little understanding on microbial growth

4.2.3 Students' ideas on classification of 'things' as microbes

Ideas involved in understanding the concept of classifying 'things' as microbes were shown in Table 13. The categories of ideas were coded G, H and I to indicate the various levels of understanding. Madigan *et al.* (2000) established that microbes belonged to a group of microscopic organisms which subsisted as single cells and distinct from animal and plant cells. These microbes were able to conduct their life processes (i.e., reproduction of cells) independently of other cells. Thus, ideas in code G, that demonstrated an understanding in classifying microbes would include students' thinking of singular cells and its independence for self sustenance. Other responses associated with the following living characteristics of a microbe i.e., cellular structures,

responses, metabolism, differentiation, reproduction and evolution were grouped into code H which demonstrated some understanding on their microbial classification. Code I illustrated little or no understanding from students.

At least half of students' understanding seemed to come from the categories linking the size of organisms and need of microscopes. They were also in the opinion that a microscope was needed to view them (microbes) since they were too small to be seen with their eyes;

*"...it's too small .....it can only be seen by the microscope.... a microorganism is something you can't really see with the eye... 'Micro' means small .....* (S8)

*"Anything that cannot be seen by the naked eyes.. must be seen by microscopes only is..I think a microbe. One cannot see a microbe just like that, so a microscope will help."* (S9)

Such typical responses for their ideas on size were obtained using the ant an example. Most students gave brief reasons that the ant was not a microbe since it could be visually observed without the microscope. Using the same rationale, a dog flea was classified as a microbe by S14 because he could not see it with his eyes.

S14: *I think I will consider any living organism that can't be seen with the naked eye as a microorganism.*

Q: *.....what about an ant , is it a microbe?*

S14: *No, I can see with my naked eye*

Q: *.....what about a dog flea?*

S14: *Ya, I think so.....Because it is a very small organism that cannot be seen by the naked eyes and it has a life of its own*

The 'size' category students, grouped as having little understanding on classification of 'things' as microbes classified organisms based on their physical dimension. The thinking behind the idea of using size to classify a 'thing' as a microbe even proceeded to a molecular level where S6 suggested there was a link between molecules and size of microbe. The student did not realise the organism was in fact made up of protein, fat and carbohydrate molecules

- Q: .....how would you define a microorganism then?  
 S6: Molecular and cellular maybe? That a microbe is actually of a certain size and of certain molecular characteristic .....so.....maybe a small organism.

Dreyfuss and Jungwirth (1989) noted such observation where their student thought that the cell was smaller than the protein molecule. They referred this as chaotic verbal associations that caused contradictory conclusion.

*".....calling the protein molecule... 'giant' and the microbe....very 'tiny', makes some pupils infer uncritically, that a cell can be smaller than the molecules of which it is built."*

Dreyfus and Jungwirth (1989, p. 51)

S4 appeared to have the 'correct' idea of classifying microbes which concerned the small single-celled living organism. However S4 was unconvinced and later opted for the use of microscope.

- Q: How would you classify a "thing" to be considered a microorganism?  
 S4: Very small organism, single cell,.. living,  
 Q: Why do say small living is classified as an organism?  
 S4: You can't see ...it needs a microscope  
 Q: If I can't see and it needs a microscope, then it's a microorganism?  
 S4: Yes, I think so.

Students S2, S3 and S12 recognised the fact and knew that a microbe must be able to reproduce independently, for it to be considered as one. They could distinguish that pollen and ant were not microbes due to its inability to replicate itself.

## S2

- A: Micro mean small and also do what an organism is able to do ....like function, grow, only that its small  
 Q: Pollen..is it a microorganism?  
 A: No, it does not reproduce by itself..... so its not

## S3

- SA: Microorganism is... able to replicate and live on it's own life  
 Q: Would you consider an ant as a microorganism?  
 A: Ant is not microorganism,.. ant cannot replicate by themselves.



## S12

A: *...a pollen by itself cannot grow and reproduce whereas like something like a.. fungus can. ...A pollen is not a microorganism because it cannot reproduce itself*

There was no explanation on the self sustaining ability of microbes or the ant and pollen reproduction process which would further show their understanding and thinking behind their classification process. Even though they could classify organisms as microbes (code G), S3 had difficulty on understanding about living. S3 regarded the pollen as a non living thing. Perhaps, it was caused by inadequate knowledge on plant reproduction system on the part of S3. A pollen is a male multicellular spore made up of vegetative (non-reproductive) and generative (reproductive) cells that eventually give rise to male gametes (sperm cells).

*"Is not...., a part of a plant not a living by itself, microorganism able to replicate and become a colony..... Microorganism can replicate to exact copy, pollen will become a plant"*

(S3)

Only S10 had a sound understanding on classification of 'things' as microbes where he responded with 2 categories of ideas (morphology and independence). He explained the attributes behind the concept of the microbe, it being a singled celled organism and its ability to live independently.

S10: *...something that can live independently and is...by itself and is very small.*

Q: *... live independently...meaning?*

S10: *Does not need a host to rely or...to feed on...it can generate its own food.*

Q: *An ant, is that a microorganism?*

S10: *... No ...it is made up many different kinds of cells.... as in many different kinds of cells come together to make up one ant....one microorganism means one type... not...like humans is not micro organisms because .....then we got like different kinds of cells like some cells, muscles cells all these come together...*

Description of responses recorded from S11 suggested presence of rote learning. No explanations were given with regard to her responses and she

demonstrated her textbook factual content on microbes. Terminologies were used incoherently without proper reasoning and inconsistencies were detected. For example, she knew the ant was a small eukaryote and not a microbe and her replies were mainly an attempt to describe what an eukaryote was, with "presence of membrane bound organelles." In the process, she got mixed up on the terminologies between 'unicellular' and 'complex' nature of the cells by referring the ant as a single celled organism.

S11: *microorganism .....probably something that doesn't have..... membrane-bound organelles and...usually you expect it small...like ...unicellular and acellular...is very small.*

Q: *.....if I got an ant.... Would you consider that as a microorganism?*

S11: *No .....it (ant) has membrane-bound organelles.....it's (ant) unicellular and.....it's more complex*

Q: *Why is it that you've got organelle means it's not a microorganism?*

S11: *I mean membrane-bound organelles..... Those (ant) are eukaryotic cells anyway.*

There was no evidence to suggest that S13 knew about self sustaining ability of microbes as her idea concerned only about microbial reproduction by cultivating it on agar plate. It indicated some level of understanding on classification of 'things' (code H). Her thinking on reproduction again resurfaced when she applied the same criteria on pollen during the interview.

Table 13: Categories and frequencies of students' responses for ideas on classification of 'things' as microbes at post intervention of 2005 cohort

Code		Categories	Student no. in semester 1							Student no. in semester 2						
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
G	<b>1. Morphology/Independence</b>															
	Single-celled/ Self sustaining										√					
	<b>2. Morphology</b>															
	Single-celled organism				√											
	<b>3. Independence</b>															
	Self sustaining															
	Reproduction		√	√									√			
H	<b>4. Living characteristics</b>															
	Cellular structures eg, organelles											√				
	Metabolism															
	Differentiation															
	Reproduction													√		
	Evolution															
	Responses															
I	<b>5. Size</b>															
	Too small to be seen with naked eye / require a microscope	√				√		√	√	√					√	√
	Molecular in size						√									

G: There is an understanding on classification of 'things' as microbes

H: There is some understanding on classification of 'things' as microbes

I: There is no or little understanding on classification of 'things' as microbes

### 4.3 Pre and Post Intervention of 2007 Cohort

#### 4.3.1 Ideas on terminology

To assess students' ideas on terminology, description and frequencies of students' responses to the terms 'microbiology', 'microbe', 'bacterial colony' and 'antibiotic' were gathered from 15 students at pre and post intervention (Table 14). The categories of ideas for each of the respective microbiological terms were all grouped in codes A, B and C according to their respective levels of understanding.

For the term 'microbiology', responses with thinking related to ideas about the study of living microbial organisms and its effect on metabolic processes or



products (Madigan *et al.*, 2000) were grouped into code A demonstrating an understanding on the term. The level of understanding was then followed by codes B and C with C coding for ideas with the least understanding about the terms.

At pre intervention, more than half of the students thought 'microbiology' was about the scientific learning of small living things or cells and understood what the term meant. Their thinking was best illustrated by student S3 who broke the term into 2 components, 'micro' and 'biology' and explained its meaning according to its definition. He responded that *"Biology is the study of living organisms"* and *"...micro is the study of things on a micro scale...something times 10 to the power minus 6...."*

The other 6 students had some understanding on the term 'microbiology' with ideas on studying living things using the microscope (code B). Their rational was that if the living organisms were really small and needed to be studied, they would then require a microscope.

Post intervention, none of the students had ideas about using the microscope to study the microbes. At this stage, only 5 students thought that microbiology was about learning small living things or cells. The rest offered more complex details about the term 'microbiology' which included ideas on its microbial functions and applications. Seven students now thought about the microbial biological functions and purposes (S6, S8, S9 and S10) and its beneficial effects on qualities of products (S4 and S13) and living organisms (S14). Examples of such change in thinking along its biological functions and benefits with reference to 'microbiology' were shown below;

*" If large molecules are not broken down, then it can't be digested and toxic waste will then accumulate. Eg. Animal waste if not broken down, this will cause disease and contamination of environment. Animal waste is made of fats and carbohydrates and proteins"*  
(S8)

*"The microbes can possibly be genetically modified to produce antibiotics for human use"* (S4)

One student thought it was about studying fungus, bacteria and virus while 2 others responded that microbiology also concerned the biological systems and its DNA application for producing new products. For instance, S7 explained below.

*S7: The biological aspects... example from physical characteristics to DNA to interacting molecules of the microorganisms with environment.*

*Q: What do you mean ...by all that?*

*S7: Use of DNA here means its application of DNA transfer and manipulation for creation of new organisms like cloning and products."*

There was little variation in the idea of what a 'microbe' was between students from pre intervention and post intervention. At pre intervention, organisms were considered as microbes if they are the smallest living things (3 students) and can't be seen by naked eyes (3 students). Eight pre intervention students' had limited knowledge on the range of microbes and were specific in identifying the microbes. Four students mentioned the bacteria and one response each for plankton and yeast associating it to the 'microbe'. Post intervention, 4 students' ideas of microbes covered a wider group of organisms (fungus, bacteria or virus) rather than being specific as observed at pre intervention. Post intervention, some students still regarded organisms as microbes if they could not be seen by naked eyes (4 students) and needed a microscope to view them (4 students).

Responses that suggested the grouping of cells of the same type, arising from the reproduction of a single microbe forming a colony (Bauman, 2007) were grouped into code A indicating an understanding of the term 'bacterial colony'. The level of understanding was then followed by codes B and C with C coding for ideas with the least understanding about the term. Nine students had never heard of the term 'bacterial colony' at the start of semester 2. During the 4 months of study, there was no change in student numbers who held the views

that 'bacterial colony' was just a grouping of microorganisms. Post intervention, 8 students accurately explained their idea about 'bacterial colony' that it concerned a large group of identical organisms from the same species. S4 answered that, *"It is obtained when a single microbe divides through asexual reproduction to form a high density of cells."*

For the term 'antibiotics', responses with students' thinking about medicines or drugs that destroy bacteria or prevented them from reproducing were categorised under code A. At pre intervention, 9 students could not explain the term 'antibiotics'. Of the remainder who thought antibiotics as some kind of a drug or medicine, only 3 students knew that such medication was used against microbial infections such as flu, virus or bacteria. Post intervention, all students responded with the view that antibiotics were drugs or compounds that destroy diseases. Eleven of these students explained that the drugs were targeted against bacteria. S4 described briefly its mechanism by detailing that antibiotics cured diseases by exerting its effect on 'targets' like kinases, receptors or DNA.

Table 14: Description and frequencies of 2007 cohort students' responses for ideas on terminology of microbes

Code	Categories	Pre intervention															Post intervention														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Microbiology																														
A	Subject on learning about small living things or cells	√	√				√		√		√		√	√	√			√	√								√	√			√
	Study of fungus, bacteria and virus																√														
	Study of living organisms on a micro scale			√																											
	Study of microbes on their functions and beneficial effects to humans																			√		√		√	√	√			√	√	
B	Biological aspects (eg. physical characteristics with interaction of DNA to environment)																				√		√								
	Study of living organisms with use of microscope				√	√		√		√		√			√																
	Microbes																														
A	Living things made up of simple few cells.																							√							
B	Bacteria					√		√				√			√			√													
	Plankton				√																										
	Yeast						√																								
	Either a fungus, bacteria or virus										√	√					√					√				√			√		
C	A living organism that requires microscope to see it																		√						√		√	√		√	
	Small living things with size 10 <sup>-6</sup> m			√																											
	Smallest living thing								√	√				√																	
	Small living organisms that are too small to be seen by naked eye	√	√												√					√	√	√			√						

Code	Categories	Pre intervention															Post intervention														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	<b>Bacterial colony</b>																														
A	Group of identical cells or a large group of organisms of the same species that are living together																	√		√		√		√			√	√	√		√
B	A single microbe divides asexually to form a high density of cells																			√											
	Bacteria or microbes grouping together			√	√					√	√	√	√						√				√		√	√	√				√
C	I don't know/ have never heard	√			√	√	√	√					√	√	√	√															
	<b>Antibiotics</b>																														
A	Have specific functions in curing disease. They may work on kinases, receptors or DNA																			√											
	Medication or drugs that kills off bacteria growth or prevent bacterial infestations													√				√	√	√		√	√	√	√		√	√		√	√
B	A drug													√	√																
	Drug which inhibits or kills microorganisms		√																						√	√					
	Compounds that cure disease.																												√		
C	Medicine taken for flu and cold	√																													
	Something that fights the virus			√																											
	I don't know				√	√	√	√	√	√	√	√	√																		

- A: There is an understanding on the terminology
- B: There is some understanding on the terminology
- C: There is no or little understanding on the terminology

#### 4.3.2 Ideas on microbial growth as a living characteristic

When considering the idea on microbial growth as a living characteristic, students' category of responses were coded according to section 4.2.2 where Bauman's ideas about microbial growth was adopted. At pre intervention, all the 15 students' categorised ideas were coded F which suggested their thinking had no or little understanding on microbial growth.

For example, two thirds of students in category 5 (I don't know) knew little when interviewed for their views about a test tube containing clear stream water (Table 15). Eight students replied nothing would be seen in the test tube for those 3 days. Such responses below typically illustrated the thinking of the 8 students of not seeing anything in the test tubes. Their ideas did not indicate any understanding about the possible growth of microbes in the test tubes.

S4

Q: *What do you see?*

A: *Clear and clean.....from the stream.....*

Q: *What do you expect to see in 3 days time?*

A: *Overall should be the same.....nothing will change there....If there nothing in there in the 1<sup>st</sup> place .you don't do anything to it there will be nothing in there.*

S7

Q: *What do you see?*

A: *.....(sigh).....of course nothing in there unless  
It's a trick question.....*

Q: *.... this tube here contains 100ml clear water taken from a nearby  
stream.....What do you expect to see in 3 days time?*

A: *It'll be the same, for sure.....Nothing in there.....water still be clear after 3  
days.....You don't put anything inside, you will not get anything extra  
coming out from there.*

S8

Q: *What will live in there?*

A: *At this moment ? Nothing, just the aquatic animals swimming.*

Q: *What aquatic animals.*

A: *Don't know.....guess in this case nothing grows there.*

Q: *What do you expect to see in 3 days time?*

A: *Should be the same.....nothing. You cannot get anything out of nothing.*

S3 and S11 said they expected microbial organisms to be inside the water but did not think that it would grow further. During the interview they seem to relate just the fact that microbes were present without making references to the rapid microbial growth. S3 made known about the odour coming from the tube but did not associate the possible cause from the growth of microbial activity. The discussion below demonstrated that they had no knowledge about the rapid growth of microbes.

### S3

Q: *What will you see?*

A: *.....clear means nothing. It's a colourless solution., maybe there's some odour...*

Q: *..... Would you expect to see anything inside?*

A: *.....I don't think can see anything inside. I know it's clear but if you want to look under microscope, then maybe some microorganisms.*

Q: *.....what happens if the same tube of water ..... leave it there and then show it to you 3 days later?*

A: *.....What most likely in the cap there's some strange odour. After 3 days.....because usually.....There's a certain smell.....*

### S11

Q: *Would you expect to see anything inside?*

A: *Maybe some microorganisms.....*

Q: *But you can't see them?*

A: *No, but cannot see them.*

Q: *.....now what happens if the same tube of water was shown to you 3 days later? What will you see anything inside?*

A: *Don't think so.*

S6 knew microbes were present in the water and when asked what would happen in the next 3 days he said the microbe "*.....grows old and then just dies... Think it'll probably die since no food is given during the 3 days.*" There was no mention about growth and reproduction of the organism. The remaining 4 students (S6, S10, S12 and S15) had the idea about the death of microbial organisms like plankton and algae due to food competition amongst the organisms. Microbes devouring each other when competing for food were



mentioned by S12. That resulted in the decomposition of organisms after the depletion of nutrients from the limited supply.

The interview also revealed student's limited knowledge concerning the reproductive capability and condition of microbes. According to S15, it was unlikely for the organisms to reproduce within 3 days which he considered was too short a time for the cells to divide and grow.

Q: *So during those 3 days....do you think it reproduces and grows really fast?*

S15: *Time is too short for it to grow. No way.*

Q: *Sure the numbers can't increase?*

S15: *No ....they will not grow.....3 days.....too short to see any significant growth.....the tube will be the same.*

The responses were different 4 months later at post intervention. None of the responses were about death of microbes when compared to pre intervention. Only S6 realised on the absence of the organisms. In the same 'I don't know' category, 4 students thought about the presence of algae in the water but did not include any idea of growth of organisms when questioned about the 3 days of incubation;

*"Still nothing except water...There is probably plenty of microscopic aquatic life living and growing in the water, since it came from a stream..... I don't think 3 days is long enough to see algae growing yet."* (S3)

*"Nothing...I suppose...perhaps some algae will grow in the water because its got light, water and invisible nutrients floating around."* (S10)

*"Nothing again. You mean I can see in there after 3 days?..... Don't think so (organisms growing)"* (S11)

S8's idea of growth as a living characteristic was with reference to mosquito larvae. Idea on microbial growth was absent during the interview even when hinted about the possibility on the presence of other living organisms.

- Q: *Is there anything growing in there?*  
 S8: *Aquatic animals present. The larvae are present due to the hatching of eggs found in the water previously.*  
 Q: *What kind of other aquatic animals? (hint)*  
 S8: *Mosquito....that is it .... just the larvae only*

Most of the responses from 9 students at post intervention were ideas about 'growth of microbes'. They described the murkiness or cloudiness of water due to growth of some kind of organisms like fungal, bacteria and algae. Only S1, S7 and S9 explained about the cloudiness of water after the 3 day period. The notion of vast number of microbes being produced was also shared by S9. He understood that after 3 days the turbidity seen was cause by "*.....microorganisms growing and reproducing inside..... quite a lot of organisms to the extend that we can now see it, you know ...turbid and all.*"

In contrast, the remaining students (S2, S4, S13 and S14) in category 2 merely knew about the presence of algae, fungal and bacterial and described its existence in cloudy or murky water without offering any explanation. The 2 students in category 3 predicted of observing colonies floating at the surface (more oxygen) inferring that it was aerobic. Those that sank down to the bottom of the tube (less oxygen) were considered anaerobic. They thought the microbe would grow at different levels of oxygen, suggesting metabolic diversity in its physiological response towards different oxygen concentrations, as a living characteristic;

*"The water could become cloudy or small colonies of bacteria suspended in the water. The aerobic colonies will be floating at the surface.....The surface has plenty of oxygen which the aerobic organisms need....so they will thrive. They will sink down to the bottom if they are anaerobic because the lower part of the test tube has lesser oxygen."*

(S5)

Table 15: Description and frequencies of 2007 cohort students' responses for ideas on 'growth' as a living characteristic of microbes

Code	Categories	Pre intervention															Post intervention														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
D	<b>1. Growth of microbes</b> Production of identical cells from a single parent cell																														
	<b>2. Growth of microbes</b> Algae / fungal / bacterial growth: cloudy or murky regions in the water (no explanation)																	√		√									√	√	
E	Microbial growth: Solution becomes cloudy and turbid																√						√		√						
	<b>3. Response to oxygen (metabolic diversity)</b> Aerobic colonies float at surface and sink down to bottom if anaerobic																				√							√			
	<b>4. Death of organisms</b> Death of algae/plankton/microbe due to food competition																														
F	Decomposition of microbes					√																									
	<b>5. I don't know / no idea</b> See nothing	√	√		√			√	√	√				√	√							√									
	Expect existence of some microbes			√								√							√						√	√					√
	<b>6. Others</b> Mosquito larvae																							√							

D: There is an understanding on 'growth' as a living characteristic

E: There is some understanding on 'growth' as a living characteristic

F: There is little or no understanding on 'growth' as a living characteristic

#### 4.3.3. Ideas on classification of microbes

When considering students' ideas on classification of microbes, questions were asked on how they would classify a "thing" to be considered a microbe. Category of responses was coded according to section 4.2.3 where Madigan's basis for microbial classification was adopted (Madigan's *et al.* 2000).

Ideas from 12 pre intervention students were coded I where their responses yielded little understanding on classification of microbes (Table 16). Majority of these responses (8) belong to 'size' category linking the use of microscopes to view small living things. S11 replied at the interview that one would classify an organism as a microbe *"When you cannot see the tiny things, so you will need a microscope. ...then you can see."* Classifying microbes under the 'size' category was also gathered from S14 where student made reference of aquatic creatures such as plankton associating his idea on the size of plankton. When asked about the dimension of the plankton, he expressed uncertainty.

S14: *Any organisms like the plankton that live in watery conditions. These creatures live in water.... the river and seas.....They are the source of food and form a food chain....*

Q: *So, can I take it that prawns are microbes living in the sea and the river?*

S14: *Prawns are too large....smaller ones like the plankton, can.*

Q: *How small?*

S14: *I'm not so sure.*

Only S3 provided an indication of the dimension while the rest did not. As long as organisms, like the ant and pollen were measured at  $10^{-6}$ , they were classified as microbes. It was assumed that S3 was referring to the measurement of a micron ( $10^{-6}$ m). None of the responses from the 'size' category fit the criteria of the microbe being a singled-cell organism. Difficulty in understanding the concept of classifying microbes was observed particular in S12, where he conceded trying to explain, saying it was his 'instinct'.

Q: *..... If I tell you that, what you are looking under the microscope is your skin cells, would you consider that as a microorganism?*

S12: *Yes.*



Q: *Why is that?*

S12: *.....(silence).....my instinct*

Although students in the 'size' category did mention of viewing small living things under the microscopes, it was not certain if all of them did understand the significance of living things that were observed. One student did not put much thought and ignore the significance of living matter (possess living characteristics), which only then could the organism be classified as a microbe apart from relying on size alone. This was observed in S6.

S6: *Things that can't be seen by our naked eyes is a microbe*

Q: *So if I've a speck of dust is it microbe?*

S6: *Of course not. It must be alive correct?*

Q: *.....you cannot see it.....so how would you know this small thing that cannot be seen with our eye is a microbe and not some non living things like the dust.?*

S6: *The microscopes will help to tell us that.*

Q: *How?.....Can you be sure they are alive?*

S6: *Oh yes....that's it isn't it you got me.....Sorry.*

Ability to move about and respond was a characteristic that 3 students in 'living characteristic' category thought were an important feature for classification of microbial organisms during pre intervention. Ideas from S1, S5 and S10 suggested that there was some understanding on this concept (Table 16). Their rationale was that the microbe has to be motile to respond and search of food in order to survive.

From the 'living characteristic' category, only S1 was able to describe that a tail or flagella was responsible for the mobility. When asked to clarify why the ant was not a microbe, S1 replied that the flagellum, which was a crucial feature in a microbe, was absent. He believed that when classifying microbes, characteristic of the organism's ability to move about via its flagella was an important consideration.

Students S4 and S7 thought that small cells containing chlorophyll were not microbes since plant cells would probably grow to become a large plant. This

image of a photosynthesizing cell becoming a large tree, apparently formed the basis for S4 to have his idea that microbes, and animals cells, do not contain chlorophyll. Though no further interview was conducted on this matter, the student may have thought that chlorophyll-containing organisms could grow to become huge plants while those that do not have chlorophyll would not. The 2 students probably did not realise that certain microbes were indeed capable of photosynthesizing. Their limited knowledge on microbe's functional capabilities and misconception that non microbial organisms were indeed plant cells containing chlorophyll probably had an adverse affect on S4 and S7's poor understanding on classification of microbes.

Compared to the responses of 6 pre intervention students who relied on the usage of a microscope to view the organism, post intervention responses were more complex involving a combination of ideas. By then, their ideas seemed to have broadened away from just the application of microscope. However, 'size' was still the main idea category at post intervention where students S2, S6, S8, S13 and S14 classified microbes based on observing organisms through microscopes only. Some improvement in understanding at the 'size' category was detected where 4 of the 5 students classified yeast cells as microbes amongst the other organisms (ant, pollen, yeast and skin) when compared to pre intervention. S6 classified wrongly when he included skin cell as a microbe for the reason "*.....cannot be seen by the naked eye.*"

In the 'living characteristics' category, 4 post intervention students' had ideas that classifying a microbe was more than just based on size. Here, students showed some understanding on classification of microbes. S4's idea was about microbe functioning as a living thing with its ability to respond and reproduce. Using these two living characteristics as ideas of classifying microbes illustrated his thinking about a living dynamic microbe instead of a static one.



Further evidence on classification of microbes based on its living characteristics were gathered from students S1, S10 and S11. They responded that an organism could only be classified as a microbe if DNA or nucleic acids were present in the cell.

Ideas from S3, S5, S7, S9, S12 and S15 in combine categories of 'morphology/independence' and 'independence' were the most relevant with their thinking contributing towards an understanding on classification of microbes. S7 regarded 'living entity' a criterion for his idea which is *"...able to survive, live, replicate on its own ...without other assistance from other cells. In fact, being independent..."* and possess DNA.

Ideas in the 'independence' category had students thinking of cells reproducing in an independent manner. Most of the students (S5, S9, S12 and S15) in this category provided description without explanation exemplifying again their 'knowing' of these critical ideas about microbial classification. They were able to classify yeast cell amongst the 3 other cells i.e., ant, pollen and skin as the microbe, citing it as a single cell being able to replicate itself, a crucial attribute for independent growth. S3 explained his idea of cell's independence in that its growth and cell replication occurred away from other cellular organisms.

*"Firstly, it has to be living to be considered an organism and not an object. Secondly, it must only be visible under a microscope to be 'micro', and lastly, it must be able to live, grow and reproduce apart from other organisms."* (S3)

In general, there was an improvement in understanding the classification of microbes after 4 months of studying microbiology. Students with low level of understanding (code I) at post intervention were reduced to 5 from a high of 12 at pre intervention. There were 6 students with good understanding (code G) at post intervention while there were none at pre intervention.

Table 16: Description and frequencies of 2007 cohort students' responses for ideas on classification of microbes

Code	Categories	Pre intervention															Post intervention														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
G	<b>1. Morphology/ independence</b>																														
	Single-celled organism / small, independent replication and possess DNA																						√								
	<b>2. Independence</b>																														
	Small, independent replication and growth																		√		√				√			√			√
H	<b>3. Living characteristics</b>																														
	Has DNA																√									√	√				
	Feed / reproduction and response										√									√											
	Responses / have a flagella	√				√																									
I	<b>4. Size</b>																														
	Small living thing seen through a microscope		√				√					√	√	√		√		√				√		√					√	√	
	Measurements at 10 <sup>-6</sup> m			√																											
	Plankton living in a watery conditions														√																
	<b>5. I don't know</b>								√	√																					
	<b>6. Others</b>																														
	Not a plant cell (no chlorophyll) and has flexible shape				√			√																							

G: There is an understanding on classification of microbes

H: There is some understanding on classification of microbes

I: There is no or little understanding on classification of microbe



#### 4.3.4 Ideas on occurrence of microbes

All students acknowledged the fact that their hands would be filled with microbes and had to be washed and cleaned to prevent food contamination. Where do these microbes come from? In this research, it would be more relevant to know the students' ideas on occurrence and location of microbes rather than why it was there. For example, it made no sense to expect students to understand the purpose and function of microbes in the desert during their initial phase of their microbiology course as it would probably be guess work rather than authentic. It was envisaged that when students' ideas about the organisms' locations were known, it would shed light on the misconceptions.

Overall at pre intervention, description of 2007 cohort's responses for occurrence of microbes were almost proportionate between categories 'environment and food'; and 'human body' (Table 17). Eight students believed that microbes were found in areas related to environment and food (category 1) while 7 students' ideas of finding microbes concerned the inside of a human body (category 3), in particular the intestine or digestive tract.

Three pre intervention students had ideas of bacteria being located in their immediate surroundings. Their beliefs why they had to wash their hands before meals were due to their constant contact with dust and air around them.

To S3, "*.....the germs are flying into the air. Then you have sticky palms then the thing sticks onto it....*" Perhaps paranoia may also influence the students' argument where S1 reasoned why food needed to be cooked and water boiled was its (food and water) exposure to dust and air. S8 in fact thought that 'bad' bacteria in the air came from the polluted environment which originates from "*...the heavy industries from Jurong (a chemical industrial island), chemical plants...the daily traffic, rubbish dump. These pollute our environment and we actually breath them.*"

Others like S5 and S14 thought that desert sand appeared to be an ideal location for bacteria to breed and the vast desert area allowed opportunity for the organisms to grow and wind to carry “.....them to the places around the world”.

While S2 briefly mentioned that microbes could be found from a combination of environmental factors such as air, food and water, the human body, more specifically at the stomach and intestine, is the 2<sup>nd</sup> major location where students thought microbes could be located. S12 and S15 responded that microbes could be found inside the stomach with its purpose of aiding digestion. They made reference to the 'good' microbes in the stomach where S12 said “...they just break down the food that we eat” while S15 reaffirmed the role of such microbes;

*“It helps in the digestion....,you know like yakult drink where there plenty of good bacteria.” (S15)*

Students in general, did not appear worried about the presence of 'bad' bacteria causing them problems or harming them as they seemed certain that the bacteria in them were more of the 'good' types. According to S12, “As far as I know, the bacteria in your stomach are good ones.”, while S15 offered a more balance view;

*“There should be good and bad bacteria. If good bacteria are greater than bacteria then we're OK. If bad is more, than we'll get stomach ache” (S15)*

Such views of both 'good' and 'bad' bacteria being found in the intestine were also held by S6 and S7. They rationalised that the 'good' bacteria prevented them from getting diarrhoea. At pre intervention, where frequency of ideas on occurrence of microbes were widely distributed amongst the specific locations like desert, dust or air, stomach, intestine and industrial pollutant, almost half of the 2007 cohort's responses concerned microbes occurring in air, food, water and human body ('everywhere' category) at post intervention. The 'everywhere' category which combined the ideas from categories 1 and 3 (some

of which were shown below) reflected the students' thoughts about microbes being found practically everywhere;

*"In the atmosphere, in (and on) living organisms, in soil, in the ocean, and... Myself, the things I have touched, other people, and rainwater....In the digestive system."*

(3)

*"They are everywhere, you know... from our immediate environment. They are also found in our body ..in digestive tract.. "*

(S8)

*"From the food we eat. From the air we breath. Also has them in our stomach and intestine"*

(S11)

It was interesting to note that of the 7 'everywhere' students at post intervention, who claimed microbes occurred in the intestinal tract, 3 students even thought beyond the existence of the intestinal microbes. For instance, S1 and S11 thought the microbes were already in their stomach and intestine the moment they were born. The issue of inheritance was only evident from students S4 and S13 when they replied that they got the microbes from their parents at birth.

The next most frequent location of microbes was the intestine (human body category) where 4 students had the idea about its occurrence. There was a 20% reduction of students with category 3 (human body) ideas at post intervention when compared to the same category at its early stage of microbiology course. Digestion was the biological process which all students thought as the function of the microbes at the intestine. However, there was limited understanding on the concept of digestion. S12 knew the purpose of the intestinal microbes but could not offer any explanation;

*"Those (microbes) in the intestines help in food breakdown... They break down food for us"*

(S13)

*"Helps break down food particles into smaller pieces"*

(S14)

According to S4, "...good or opportunistic microbes that inhabit all the available space on the human body. They take the space and prevent other more potent strains from inhabiting." Similar ideas were also noticed in S13 where negative effects on health were low;

*"If they are good microbes that inhabit in the human body. This prevents other bad microbes from inhabiting. So I'll be safe and OK."*  
(S13)

One student even had a misconception that microbes were 'good' since they were found in food stuff, hence safe to humans. In that interview, student S11 used his reason on the fermented milk product, yakult. He failed to notice under natural conditions, mixtures of 'good' and 'bad' microbes gathered in colonies but in this case 'good' microbes were specifically selected and cultivated for the purpose of incorporating into the yogurt drink.

*"Nothing will happen if the microbes are food ones....the one found in milk products.....yakult have microbes like lactobactillus. ...to break down food"*  
(S11)

Students S5, S9 and S10 mentioned that microbes could be found in the air and surfaces of everyday common items. S5 argued that surfaces around him like those of the soil, floor and seats were practically in contact with human and air all the time. He rationalised that these surfaces would not be microbe free as it could be transferred or deposited through people, animals or by air. The remaining students generally described their opinions on the occurrence of microbes in the surrounding air without explanation.

S15's idea of finding microbes was sourcing them from other living organisms, soil and the ocean. She claimed she knew about this since she had seen pictures of them before in the library. She also used the destructive capability of the microbes to explain its occurrence in the human body and soil. She said the intestinal microbes helped in food digestion while the soil microbes assisted in the decomposition of organic materials from plants and animals.

Table 17: Description and frequencies of 2007 cohort students' responses for ideas on occurrence of microbes

Categories	Pre intervention															Post intervention															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
1. Environment and food																															
Dust / air	√		√	√																											
Desert					√								√																		
Polluted environment: industrial pollutant, rubbish dump								√																							
Air, food and water		√																													
Other living organism, soil and ocean																														√	
Surrounding air and surfaces										√										√			√	√							
2. Everywhere																															
Air, food , water and human body																√		√	√		√	√	√		√						
3. Human body																															
Stomach												√			√																
Intestine or digestive tract						√	√		√		√		√				√										√	√	√		



#### 4.3.5 Ideas on living characteristics of virus

Table 18 lists the ideas involved in the understanding of living characteristics of virus. Madigan *et al.* (1999) gave an overview detailing why viruses do not share the same characteristics with living organisms. Viruses were acellular particles and contained nucleic acid surrounded by a shell of protein. When isolated, it is biologically inert and unable to replicate its genes and carry out metabolic activities. However, in a host cell (after infecting), it reproduces by having its new viral components synthesized and assembled within the infected host cell. Being strict intracellular parasites, viruses are dependent other cells for its metabolic activities.

Students' key ideas which demonstrated an understanding on living characteristics of virus as described by Madigan were coded J. Ideas demonstrating some understanding were grouped into code K and ideas illustrating little or no understanding were coded L. At pre intervention, 5 students had ideas of virus being pathogenic and making people sick;

*"It make people sick ...right...: Its mean that its poisonous...so, its alive. It must be. No way it'll make people sick if it is dead."*  
(S1)

*"Responsible for a lot of sickness around the world.like SARS and bird flu.....If its dead then its not deadly.....that's why you burn the infected bodies so that the virus are killed.....so become infective."*  
(S4)

Such assumption arose partly because of their lack of understanding that viral particles were inactive or inert once it was physically out the cells and thus can't exert its effects. Hence, their ideas categorised under pathogenic, were coded L demonstrating that they had little understanding on the virus' living characteristics. According to S2, he likened the idea of infection of virus 'eating' up the cells upon landing on them and such thinking bears no scientific knowledge.

S3 considered that the living virus was neither a plant nor animal and belonged to a special category. He was not sure whether virus consumed food and sensed its motility was probably assisted by the air since it was an air-borne organism. S3 held the view that virus reproduced via binary fission rather fast due to its small size which he guessed in the range of “...10 to the power of minus 9”. He thought the smaller the organism, the faster it reproduced.

To S6, reproduction was thought to be an indication that the virus was alive. The ability of virus to replicate into 2 was his reason behind the persistent existence of the microbes. He explained “....all microbes are able to self divide....like dividing into 2...that's a property of microbes. That's how they spread so fast. Virus will also divide and that's how they continue living and always there.” Descriptions of viral reproduction from the ideas of S3 and S6 were inaccurate as it depicted how a bacterium would double its cell numbers (code L). They did not realise that for virus to multiply, it was done inside the living cell using the genetic machinery of the host cell. Such lack of scientific knowledge would contribute towards their poor understanding of virus' living characteristics.

Like S3 and S6 at pre intervention, students S7 and S9 mentioned of virus being a living organism. They however seemed uncertain with regard to respiration and movement process of the virus. None were able to explain the attributes of respiration but acknowledge that most living organisms needed oxygen to function;

*“They do breathe ....but I don't know whether they take in oxygen or not, because some virus can survive without oxygen....”*

(S3)

S6 knew that air was needed during respiration but was intrigued as to how the air could enter the organism. Students S7 and S9 described that the virus probably 'breath' by absorbing the air at the surface directly into its body. Students S5 and S11 had difficulty in answering the questions posed to them and

were wary of their own silence and constant clarification to the questions being asked. For example, they were asked what a virus was to them and why they thought of it as living. They replied;

*"The virus is a small thing...hard to describe....any hints? You've got to help me....Yes, virus is living, that's why we are studying microbiology. Why living...(silence)...because it can grow. Give me hints! Maybe it's dangerous? It is important to study them...why live...."*  
(S5)

*"Virus is a virus....part of a kingdom of living things...hard to describe this thing...thought I knew it then...not easy....hard to say and point out about what it is that is living....Is this about to prove if it is living or not? I can say that it is living...what is it about this virus... Movement...just move right...float in the air, I suppose."*  
(S11)

S12 revealed his thinking that the term 'virus' meant a computer virus to him. He had little knowledge and understanding about the biological virus. Even the word 'virus' itself reminded him of it being IT related. While S14 at the beginning of semester had little knowledge about the virus apart from his description on the virus, he was only able to provide an image of the virus. The student was unable to discuss the reasons behind features of entity such as its (virus) head and legs during the interview.

*" The virus has....a head ...which is made up of some flat and quite regular shape type of faces, many infact. It also has legs for landing ...like those we see on space ships."*  
(S14)

Associating the ability to cause an adverse effect on human beings such as making them sick with an active virus continue to dominate students' thinking about its living characteristic.. When asked if viruses were living things, S15 quickly remarked that, *"....its deadly!"* suggesting the virus to be functional and operational which meant the organism was alive.

Post intervention, students S1, S4 S8, S10 and S13 knew that host cells were needed to allow virus to be reproduced. They understood and shared similar views that to produce more viral particles, an attribute of living, the virus



ought to be dependent on other host cells. S10 thought that virus in fact was more like parasites. S1 observed that, virus *"...don't replicate by themselves. They infect hosts and use the hosts body system to multiply."* He understood that on its own the virus is biologically inert. Brief explanation was given about its legs used for attachment during infection and later how its DNA injected *"....into host's DNA and replicate with host's DNA."* The 5 students above who realised the need for the virus to be in the host cell, had improved their understanding (code J).

Table 18 also included the category on 'novel properties' of virus which was unique to viral organisms only. 'Novel properties' category was absent from the responses of pre intervention students. Ideas of 'living' virus as capsule containing either DNA or RNA with suckers for attaching to cells during infection were described;

*"It has DNA so can replicate itself. That is why it needs to infect other cells so that it can work."*

(S11)

His understanding on the notion of the virus being 'alive' was incomplete as he believed that possessing the DNA was adequate for replication without the host cell. 'Reproduction' category had 3 students. These ideas were coded K showing students with some understanding on living characteristics of virus. Such partial understanding was seen in students S2, S6 and S14 (category 3) since they knew virus could reproduce but did not realise that the reproduction process was only possible inside the host cell. The thinking of the virus being an *"incomplete microbe"* capable of living and reproducing lead student S2 to belief such capability was due to the presence of genes. Further application of students' rationale in using the DNA to make an inference between living and non living was seen in the responses of S14;

*"Yes, having the DNA separate the living and non living organisms. Non living should not have DNA, no reason to. ...The DNA codes for various function of the virus, so if the virus can do things and carry them out, it has to be alive to do it. "*

(S14)

Other ideas concerning reproduction involved an initial destruction of cells beginning with the cell wall and membrane, were gathered from S3 and S15 (category 7). Both explained the virus initially feeding on the cell internally before reproducing;

*"Release toxins and dissolve the materials, then absorb. ...After they have fed on a cell, it then reproduce by millions of new viruses in seconds. It'll just divide and keep on dividing in the cell."*

(S3)

*"They break the cell wall/cell membrane and suck out the protoplasm inside. ...After they have fed on a cell, they use the 'spare parts' to make new viruses. They can reproduce many many new viruses within a short time."* (S15)

Responses categorised under 'shapes/cellular structures' did not support students' thinking on understanding living characteristics of virus (code L). S12 explained incorrectly that viruses were living organisms because they possessed organelles. His idea of living also hinged its close resemblance to bacteria with the virus having a flagellum and shaped like a bacterium. In the case of S5, he thought that virus was interchangeable with a bacterium and described virus just like a bacterium.

At post intervention, students S7 and S9 did not know much about the living characteristics of virus ('Shapes' category) except for its distinct shapes. S7 remembered virus, *"....must have a certain number of faces....sides to make up a symmetrical configuration."* S9 also said virus looked symmetrical and *".....can replicate just like living organisms"*.

Table 18: Description and frequencies of 2007 cohort students' responses for ideas on living characteristics of virus

Code	Categories	Pre intervention															Post intervention														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
J	1. Host cell																														
	Use host to multiply																√								√						
	Reproduce inside the cell																			√				√				√			
K	2. Novel properties																														
	Structure or capsule containing either DNA or RNA ..... with legs or suckers for attachment																									√					
	3. Reproduction																														
	No independence in reproduction																					√									
	Has genes for reproduction																	√											√		
L	4. Pathogenic																														
	It makes people sick	√	√		√				√		√					√															
	Attaches to cells												√																		
	5. Metabolism																														
	Can breath by absorbing air into surface of virus							√		√																					
	6. Shapes/ cellular structures																														
	Organelles																										√				
	Circular or rod shape / resemble a bacteria																				√										
	Regular and symmetrical shape of virus													√									√		√						
	7. Others																														
	Computer virus												√																		
	No idea / I don't know					√					√																				
	Binary fission			√			√																								
	Feed on cell than reproduce by dividing in cell																		√											√	

- J: There is an understanding on living characteristics of virus
- K: There is some understanding on living characteristics of virus
- L: There is no or little understanding on living characteristics of virus

#### 4.3.6 Ideas on living characteristics of bacteria

Madigan *et al.* (2000) established that bacteria belonged to a group of microscopic organisms which existed as single cells and distinct from animal and plant cells. Bacteria were able to conduct their life processes independently of other cells. Thus, ideas demonstrating an understanding on living characteristics of bacteria would include students' thinking about its single cell morphology (e.g., form and structure) and independent categories (code M). Ideas associated with other properties of bacteria i.e., cellular structures, motility, metabolism, differentiation, reproduction and evolution were grouped into code N demonstrating some understanding. Code O illustrated little or no understanding from students.

Pre intervention, students' ideas of bacteria were distributed amongst 2 categories, that of bacterial 'properties' and organism being 'pathogenic'. There were no students with code M ideas that supported a sound understanding on living characteristics of bacteria.

Responses on motility were obtained from 2 students at pre intervention. The idea was mainly associated with microbes' ability to move about in the body through mechanisms such as crawling, floating and the use of flagella.

In students S1 and S3 opinions, their thinking about the bacterial living characteristics included a combination of movement and reproduction. Physical characteristics of bacteria with its lack of appendages to the cell were believed to link students thinking to different mode of motility. While S1 explained that bacteria moved by floating in the blood "*It divides itself and keep dividing and becomes millions*". Student S3 viewed reproduction with its doubling effect;

*"...binary fission....the single cell will be split into 2 and then after it split into 2 ...."*  
(S3)

S10 thought that the pathogenic effect of bacteria was caused by the increase in bacterial growth. He reckoned that was the reason for the spread of

cell damage. S12 agreed that bacteria were living organisms for the reason they were known to be harmful. Both students had little understanding on the living characteristics of bacteria at code O.

To S5, S11 and S14, ideas that were prominent to them were the manner of reproduction which bacteria went through. They knew bacteria were able to divide, doubling from one cell to 2, then 4 and 8 and so forth.

*"The bacteria reproduce by dividing itself into 2 cells...then the 2 cells become 4 cells and this then...goes on and on"*

(S5)

*"They are good in binary fission....this is about the cells dividing...doubling in numbers to increase population. The type of reproduction is common in bacteria"*

(S11)

*"Way of dividing...like it splits into 2 and then the 2 cells again split becoming into 4 cells. This process can carry on for along time...as long as food are there...."*

(S14)

In category 3, S7 and S13 were noted to have the idea that bacterium, though a prokaryote, had the same cellular structures as eukaryotic cells which were factually incorrect. Interview with S13 below showed that at this early stage of study, students may not realise that bacterial cells do not have nucleus while eukaryotic cells do. Such fundamental difference was what distinguished the bacteria cells from the rest of the unicellular and multi-cellular eukaryotes.

Q: *How do you know ..that bacteria are living?*

S13: *Because of the structure inside it.... like the ones that can be found in humans cells....Mean that..things inside the cells of bacteria are also found in human cells.*

Q: *...can you give some examples?*

S13: *The bacteria will have...the structures like the nucleus, right.. DNA, the chromosomes and other types of proteins.*

Q: *And the human cells will have....*

S13: *Should be the same..since they are living things*

The largest group of ideas (from 4 students), shown in Table 19 were related to metabolism of bacteria and categorized as 'properties'. Students with

these ideas had some understanding on living characteristics of bacteria. In the course of explaining the various metabolic processes, 3 had ideas associated with nutrition and one with respiration. Their simple reasoning however applied an anthropomorphic characterisation of metabolism with terms such as 'take in', 'consume' and 'feed', for nutrition and 'breath' for respiration;

*"Bacteria take in food and digest the food stuff in the stomach. It breaks up.....the large food down into small ones.....uses enzymes for the job...."*  
(S6)

S4 explained that bacteria 'feed' by having the food absorbed and then digested. He did not realise that bacterial nutrition began with the digestion of food at the external, aided by enzymes before absorption of smaller sized products into its cell.

Respiration was another metabolic process which S9 considered a living characteristic for bacteria. Describing it as though a human breath in air to live, he said, *"Air and oxygen is required for bacteria to live....The bacteria breath, since its so small it'll take in oxygen by letting the gas to come in."* His explanation was inaccurate when he mentioned that the probable mode of 'breathing' *"...could be like osmosis to transport the oxygen in."* Osmosis concerned the movement of water and such lack of knowledge weakened S9's respiration idea as a metabolic activity supplied the essential energy for bacteria growth and reproduction.

Ten of the 15 students at post intervention interviews had at least considered reproduction by binary fission as a property of bacteria different from other eukaryotic cells. The students knew the basic description of binary fission. The explanations ranged from a basic definition;

*"A process whereby a cell is divided to get two cells."*  
(S6)

*"The separation of 1 bacterium into 2 in the last stage of bacterial reproduction. ...."*  
(S7)

*"...where a cell becomes 2 cells and then later each produces 2 more cells. It doubles each time they produce".*

(S12)

to a more complex one indicating that;

*" It is the act of which a bacterium produces enough volume and DNA for it to split. When it occurs, cleavage starts in the dead center of the cell, causing it to split into 2."*

(S4)

To evaluate if they understood the idea behind reproduction as a living characteristic, they were also asked about the involvement of chromosome during cell division to see if they understood the relevance and its association. Typical explanations about cell division and its association with chromosome revealed the daughter cells having identical copies of DNA from its parents;

*" Yes. The chromosomes need to replicate into two copies before binary fission can be carried out. This would ensure that the clone is identical to the parent."*

(S4)

*"By the stage of binary fission, chromosome number is doubled. This chromosome... enables the 2 cells.... After division to have equal genetic material. So the 2 cells become the same, identical."*

(S7)

*"Chromosomes with its gene like stuff ....are replicated through binary fission ...and so that when new cells are established, each cell will receive the same type of genetic information."*

(S8)

S1 and S12 were unable to explain the relationship between chromosome and binary fission. Of these 10 students, S3 recognised the *"....process by which single-celled organisms reproduce, and....involves the organism splitting itself into two"* while S15 commented that bacterium is a *"..single-celled organism with a cell membrane .."* which *"...live, respire, grow, reproduce and can also die."*

S3 encountered difficulty in maintaining scientific accuracy needed for substantive understanding of chromosome replication. The student seemed to



have a misconception that chromosome only split by meiosis and not by binary fission. Such misconception would lead to failure in proper understanding of the hereditary concept.

In contrast, examples of explanations provided by S4 and S8 suggested the ability of bacteria to reproduce asexually on its own and resulting in new 'daughter' cells receiving identical genetic information as its parents. It showed an understanding on living characteristics of bacteria. Responses of S4 and S8 were categorised in 'independence' which indicated students' thoughts of the bacteria functioning by itself;

*"...they can feed, move and reproduce on their own. Do all these like....not depend on others."* (S4)

*"... its living. Bacteria respire, metabolize and replicate on their own."* (S8)

According to S5, motility was regarded as an important property of bacteria. Brumby (1982) classified it as one of the traditional characteristic of living organism. S14 thought that bacteria were motile by nature and the ability to move about was due to the presence of the flagella. He could not account for the purpose of having the flagella beside an indication that the bacteria was alive, a reason considered as non-scientific. Student S5 on the other hand stressed that the *"Bacteria move using their flagella..... for moving and ....to respond to its changes"* probably for the purpose of survival from the harsh environmental conditions caused by factor changes in *"..like the pH, temperature or toxic levels."*

S13 viewed nutrition in 'metabolism' category, as one of the living characteristic for bacteria. S13's idea on nutrition began with the 'act' of feeding in which the bacteria *"....absorb nutrients from the surroundings by diffusion"*. When asked what his thoughts were on 'feeding' that was important, he replied

that food was needed for the living bacteria to move and reproduce. The notion of energy was not mentioned and probably did not realise the requirement for energy during the motility and reproduction processes.

Table 19: Description and frequencies of 2007 cohort students' responses for ideas on living characteristics of bacteria

Code	Categories	Pre intervention															Post intervention														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
M	1. Morphology/ Independence																														
	Single-celled organism and reproduce																														√
	2. Independence																														
	Self sustaining																														
	Reproduction																			√				√		√					
N	3. Properties																														
	Cellular structures eg, nucleus, DNA, chromosome								√					√				√									√				
	Metabolism				√		√		√	√																			√		
	Reproduction: binary fission					√						√			√		√		√			√	√		√		√				
	Motility / reproduction	√		√																										√	
	Motility																				√										
O	4. Pathogenic																														
	It infects us.		√							√		√			√																

M: There is an understanding on living characteristics of bacteria

N: There is some understanding on living characteristics of bacteria

O: There is no or little understanding on living characteristics of bacteria

## (SECTION B: CASE STUDIES)

### 4.4 Case Study 1: Student S1

S1 is a 16-year-old female with an O-level aggregate score of 11. She only studied chemistry as a science subject for her O-levels.

#### 4.4.1 Ideas on terminology

Microbiology was basically a subject to study small living things. S1 believed that the organisms existed in the environment and remained invisible. Apart from remembering that microbes were utilised in the production of fermented milk like Yakult drink and cheese, S1 thought most microbes were pathogenic and destructive in nature and caused the flu or cold since microbes like bacteria were found in humans. S1 had not heard of the term 'colony' before and had difficulty in responding. 'Antibiotics' was a kind of medicine to get rid of cold or flu infection. She had no idea as to which type of microbes caused the flu or cold. S1 could not name any microbial organisms at the start of her course but was able to recall *E.coli* and *Sacchromomycetes spp* at post intervention. At the end of her semester, S1 was able to describe the meanings of the terms 'colony' and 'antibiotics' correctly;

Colony: "A lump of large number of bacteria of a single type"

Antibiotics: "Medication that kills off bacteria growth."

#### 4.4.2 Ideas on microbial growth as a living characteristic

At the early stage of her course when S1 was presented with samples of clear stream water, her initial answers were that she had expected to see "*Debris .....like bits of leaves, soil materials*" along with oxygen bubbles in the water. When asked what her thoughts were after 3 days, she replied that "*I'll say that things will be the same.....: It'll be the same as the original...just like that 3 days ago.*"

At post intervention, she maintained that the water would be clear throughout the 3 days. When asked about how 'things' could grow in the tubes, she replied, *"....to see bacteria particles, I think I will....need to cultivate them with a lot nutrients which the water don't have....."* Hence, the reason why she claimed no bacteria could be seen was her perception that the stream water probably did not have adequate nutrients to sustain the growth of the organisms. S1 may not realise the existence of microbes in the water. She had little understanding on 'growth' as a living characteristic of microbes at her completion of her microbiology course.

#### **4.4.3 Ideas on classification of microbes**

Earlier in the semester, microbe to S1 was something small, living and can only be seen with the microscope. She had no information on the size or the dimension. Pollen was however not classified as a microbe since the *".....pollen will become a plant."* Her decision on whether the pollen was a microbe or not transpired from the use of visible large 'size' of the plant and perceived the pollen would develop into one.

S1 regarded the ability to move and respond was an important feature to classify microbial organisms. Her idea was that having a tail or flagellum aided its motility. For instance, the ant was not classified as a microbe since the flagellum, a crucial feature in a microbe was absent.

S1: *.....you (ants) don't have the typical...living characteristics.*

Q: *...What you mean by that?... are you saying that ants don't have the typical...living characteristics, so cannot consider them as microbes*

S1 *The ant don't have the tail.... what you call tail in bacteria used for moving from place to place?*

Q: *Flagella is it?*

S1: *Ya, the flagella*

Q: *What happens when there's no flagella in ants?*

S1: *Then they can't be microbes....I think.*

Her thinking on microbial classification was different at post intervention. Then, she thought an organism could only be classified as a microbe if its DNA

was present. Her argument was that with DNA, only then was it possible for future generations of microbes to maintain its parents' original genetic information upon cell replication. S1 had only some understanding on classification of microbes and her thinking did change within the 'living characteristics' category during her microbiology course. Her ideas did not reflect her knowing that microbes were single cells capable of living independently. S1's understanding on microbial classification did not improve during her study.

#### **4.4.4 Ideas on occurrence of microbes**

At pre intervention, S1 acknowledged the fact that her hands had organisms like bacteria and needed to be washed to prevent food contamination. She referred these microbes as germs, a bacterial type organism. Her argument was that bacteria that were transferred onto her hands each time she touched something like an object, originated from the environment around her. Such an idea was due to an earlier influence from her family.

*"From young we are always reminded by parents and teachers to wash hands because they (hands) are easily dirtied from our surroundings....the dust, the air."*

The student thinks that washing without using medicated soap would only result in physical removal of the dirt and not destroy the organism itself. Her suspicion on the 'bad' nature of the microbes and perhaps paranoia probably may have come from her years of family influences. Her reasoning on why food needed to be cooked and water boiled was due to its exposure to dust and air, the source of microbial organisms.

*"There should be microbes in our food as well, that's why we need to cook them properly...How do they get into our food? The environment then... that the source! .....If it can exist in the air then there must be these microorganisms in the water as well. So one has to boil water to kill the microbes or else you will be sick."*

S1 rationalised that microbes eventually enter the human body from the consumed food and water; and the inhaled air. This lead to the presence of 'good' microbes in the intestine which S1 briefly described its purpose of aiding

food digestion. Later at post intervention, she identified these 'good' bacteria as *Lactobactillus*, which she claimed *"..help to break down food...don't produce harmful byproducts to make us sick."*

Her opinion reversed where microbes located in water and air was concerned.

*" Oh that, they could be dangerous.....that's why we have to wash hands and boil water."*

At post intervention, S1's opinion on her washing of hands did not change as it was intended to destroy the harmful microbes found on her hands. At this stage, S1 argued that microbes could be found everywhere, including her own body. She was more aware on the existence of microbes when compared to her knowledge about location of microbes earlier in the semester. Existence of microbes in human body could also be located at the skin, nose and ear. S1 could not explain the functions of these microbes found there. At one point she even mentioned that the existence of stomach and intestinal microbes began at birth apart from the other source, the digested food. The rest of the organisms she claimed derived from the aerial and water environment around her. At this point, S1's idea on occurrence of microbes in water may not reliable as it contradicts her earlier discussion about stream water where microbes were non existent.

#### **4.4.5 Ideas on living characteristics of virus**

S1's impression on the virus was one that it's round, has hair like structures on its surface and smaller than the bacteria. Virus was harmful in nature but she was uncertain on whether it is an animal or plant cell. She tried to elucidate the confusion by evaluating the virus in a non scientific manner to the concept of animal used by Bell (1981a) and Bell and Barker (1982);

*"Cannot be animals. Animals have legs...snakes don't have legs.....animals have fur.....warm blooded ...give up. I know it can't be animal cells."*

She also took a similar approach to show that the virus was not a plant cell by using the plant concept (Bell, 1981b);

*"No way it's a plant cell. It can't photosynthesize and it's too small...I don't know."*

The thinking of S1 that virus was alive was associated to its ability to inflict sickness on people since dead things were ineffective.

At post intervention, S1 improved her understanding on living characteristics of virus especially on the aspect of reproduction. Her ideas about viral reproduction differed between pre and post intervention. After her microbiology study she understood that virus become inactive or 'non living' whenever it was outside the host cell – a key living characteristic of virus. That would help to partially explain the reason why the virus was neither an animal or plant cell which she attempted to explain earlier in the semester by comparing it to the characteristics of animal and plant cells. At that stage the virus was biologically inert and would be unable to replicate on its own. However, her thinking concerning the association of virus causing diseases and reproduction remained unchanged. Infection of host cells began when the virus injected DNA into it. As more viral particles multiplied *"and replicated with host's DNA"* more cells would eventually get infected.

#### **4.4.6 Ideas on living characteristics of bacteria**

S1's idea of the bacterial shapes included a mixture of thin long to round ones did not change throughout her course. At pre intervention, she thought the bacterium was about 10 times larger than virus and would require a microscope to view the organism. The thinking of S1 that bacteria were living was based on the fact that it could move, reproduce and inflict sickness on people.

*"...If it's dead, it can't move and reproduce."*



The student's thinking on motility was enhanced at post intervention when she spoke on the presence of the flagella which assisted the bacteria in its movement. Her idea of bacterial living characteristic living was that the organism could grow over a period of time and then divided. S1 could not explain the reproduction process except she vaguely remembered how *"It divides itself and keep dividing and becomes millions."* The student at this stage did not recognise that the bacteria could reproduce on its own independently, key living characteristic of bacteria.

However, at post intervention the independent capability of bacteria was still not realised. S1 knew how bacteria reproduced by binary fission. She described the process of how one became two cells and then the two cells became four cells and so forth (Table 19). S1 did not understand the idea behind reproduction as a living characteristic, when she was asked about the involvement of chromosome during cell division.

At pre intervention, S1 thought that bacteria were somehow closely related to an animal or human cells but not a plant cell. Her reason was the structures found in animal cells and bacteria were similar such as the nucleus, DNA and chromosomes. One of the distinct feature between bacteria cells and human or animal cells was that bacteria do not have nucleus while the rest (human, animal and plants) do. She added that it was not a plant cell since it can't photosynthesize. S1 did not realise that certain bacteria like the cyanobacteria could conduct photosynthesis. At post intervention, S1 still had poor knowledge about the cellular structure when she had difficulty in explaining the distinct feature between bacteria with animal and plant cells. She revealed then that animal and plant cells were different due to their different cellular structures. In fact they were rather similar (both are eukaryotes) apart from the presence of chloroplast in plants. During her microbiology course, it appeared she does not have sufficient knowledge about cellular structure of bacteria.

## 4.5 Case Study 2: Student S2

S2 is a 17-year-old male with an O-level aggregate score of 11. He only studied chemistry as a science subject for his O-levels.

### 4.5.1 Ideas on terminology

To S2, the term 'microbiology' was about studying very small living things. He mentioned that he had heard of this term before during his secondary school education. At the end of the semester, his opinion about microbiology includes the study on microbial characteristics like its features, functions and their effects on other living organisms. That meant S2 had a better understanding about microbiology in that the student probably realise its influence and contribution to a larger community of living things in general.

There was no change in S2's description of the 'colony' as a group of microbes lumped together or co-existing together, which he alleged that he would be able to see, throughout the period of the course. He clarified at pre intervention, he would be able to see the 'grouping' but encountered difficulty when asked to draw pictures on colonies. S2 tried to recall science lessons during his early secondary school days and ended guessing with the responses.

S2 regarded antibiotics as a drug for killing the microbes. He appreciated the meaning of antibiotics better at post intervention when he replied that the drug was meant to prevent bacterial infestations. At this time, he was more specific on his response. Throughout the course, the student recognised that microbes could be both 'good' and 'bad'. He related with examples that 'good' microbes "*...can also be used for bread making food, cheese...*" while the 'bad' "*microbes destroy things like our cells in the body....so we get sick*". He said overall, the function of microbes is to breakdown and decay materials.

#### **4.5.2 Ideas on microbial growth as a living characteristic**

S2 claimed that he would not see anything in the test tube of water apart from knowing that oxygen was present. He responded with confidence that the water would be clean reflecting his expectations that there were no signs of any organism in the test tube. When asked what he would expect to see after 3 days, he remarked that it would probably be the same with nothing appearing in the clean water. At pre intervention, S2 did not think on the possible existence of microbial organisms in the test tube which can't be seen with naked eyes. At this early stage of studying microbiology it was apparent S2 had no idea on growth of microbes and hence have little understanding on the concept as a living characteristic.

Post intervention S2 knew about the presence of algae, fungal and bacterial and described its existence in the cloudy or murky regions in the water without offering any explanation. S2 noted that the water will become murky with its *"...inner surface of the test tube will have a smooth and soft layer of jelly-like substance."* and that *"..it takes time for microorganisms to reproduce.."* S2 expected the cloudy region to appear after 3 days since he reckoned it took that long for microbes to multiply.

#### **4.5.3 Ideas on classification of microbes**

During the pre intervention interview on classification of microbes, S2 replied that all small living creatures which required a microscope to see them would be classified as microbes. S2 could not provide a measurement for his idea of size for the microbe. His idea of classifying microbes was along his manner of thinking that as long as living things were too small to be seen and required a microscope, they were classified as microbes. His response which was grouped under the 'size' category failed to correspond or match the established criteria that microbes exist as single cells and were able to conduct their life processes independently of other cells.

Four months later, S2's views about the classification of the microorganisms were still similar and did not change much. S2 applied his idea of size to classify the tiny multi-cellular ant which he concluded was not a microbe as it was large enough to see without the need of a microscope. Though he gave a correct conclusion according to the task criteria, his response in this task was clearly not indicative of a thorough understanding on classification of microbes.

Pre intervention, in the case of pollen, S2 again based his thinking along the size of the organism in his bid to classify them as microbes. Here, he argued that since the pollen was initially small, *"..pollen can actually grows into a plant. And plants are big. You can see them. Microbes will grow but not....to something that's so big."* S2 concluded that the pollen would eventually grow and develop into a plant large enough to be seen without the use of the microscope.

At post intervention, when asked on how he would classify the ant, pollen, skin cell, yeast cell, S2 responded that he would choose yeast cell as a microbe for the simple reason it was a fungi. It was clear that S2 was still not competent and unable to understand how an organism was classified as a microbe. In the case of yeast, S2 did not apply the principle based on independent single cell organism when task with classifying it. S2's reasoning on using the size of organisms at both pre and post intervention illustrated the student's weak conceptual understanding on microbial classification which did not improve after studying the microbiology course.

#### **4.5.4 Ideas on occurrence of microbes**

S2 recognised the fact that his hands were filled with microbes and had to be washed and cleaned to prevent food contamination. At pre intervention, S2 tends to have the impression that microbes were harmful. S2 linked his hands being dirtied due to his contact with everyday things and the environment around him, to contain microorganisms like viruses and bacteria. He viewed the

existence of bacteria all over his immediate environment just as if he was surrounded by microbes. So with his hands constantly in contact with the air he was quite certain of being succumb to the harmful effects of microbial organisms.

*"...You don't wash your hands, you'll get sick....for sure."*

Food and water were other sources where microbes could be found and to prevent him getting sick, he knew that the food needed to be cooked and water boiled to destroy these microbes. S2 hinted that he knew about the occurrence of microbes in his body but had difficulty in explaining why he was not sick. He then attributed it to his immunity.

*"Because, my immunity is strong.....so can't harm me. Maybe the organisms are weak.....They are like my antibiotics. Something like drugs inbuilt in me to fight any microbes."*

It was apparent that S2 regarded antibodies, which played an important part in the immunity as synonymous to the antibiotics. In the earlier part of the interview on terminology, it was seen that S2 looked upon antibiotics as a drug for killing the microbes. At pre intervention, he had no idea how the antibodies in his body came about.

At post intervention, S2 gave prominence to the occurrence of bacteria in the intestines. He said bacteria were constantly breaking things down and there was a better appreciation and purpose of the bacteria in the intestine. S2 gave an example below;

*"In our intestines, lactobacillus aids digestion so that our food is properly broken down and we won't suffer from diseases such as constipation or intestinal congestion."*

The student further explained the breakdown of food materials in the intestine.

Q: ..... what do you think these food materials will be broken into?

S2: Since protein is the main constituent of food materials, I think these microbes breaks them down into amino acids.

S2 also mention the occurrence of housemites on his skin which caused him to itch irritably. He explained using immunity on the reason why he was not sick;

*"This is because microorganisms have specific functions that cause specific reactions to the body. Also, our body is engineered in such that we have our antibodies to help resist the infestation of harmful microorganisms."*

Here, he failed to recognize that housemites were multicellular organisms. It was possible that S2 still may not have understood what a microbe was and had however applied facts or principles based on its microbial characteristics on other situations. Rote learning was apparently present when S2 used reasoning that was out of context.

#### **4.5.5 Ideas on living characteristics of virus**

Pre intervention, S2 thinks the virus is pathogenic. The rationale adopted by S2 was its assumption that only living things were capable of causing an affect which in this case, a harmful one on people.

*" Because people gets sick when they are infected with... the living and not dead virus... It means you're bed ridden, can't get up and function...feeling useless".*

S2 thought the virus was round. He had no idea how small a virus could be measured and thought a microscope would be adequate to help him to see the virus. His impression concerning its shape changed to thorny spherical virus that measured about 0.5 micron later in the semester. S2 also did not realise the requirement of a host cell in order for the virus to become active and exert its effects. That demonstrated the student's lack of scientific knowledge which contributed towards his poor understanding of virus' living characteristics. He believed the virus could breath, feed and reproduce as living things could but yet had difficulty in explaining these 3 processes at pre intervention. The student appeared to struggle to identify the nature of the virus. This 'struggle' in understanding the viral characteristics continued till the end of semester. Post



intervention, it was the presence of genes that lead S2 to belief the virus' capability of living and reproducing;

*"In my opinion viruses are living organisms. Even though they do not have cells they still have genes that allows them to reproduce and evolve.... viruses are classified under micro-organisms...."*

S2 looked troubled when asked to explain what constituted the virus being alive with the possession of genes. The responses were at times incoherent with S2 'togglng' his thinking between living and pathogenic;

*"Although viruses are classified under micro-organisms I think they are just a poisonous agent that modifies and disintegrates living protein cells."*

Realisation on virus' total dependence on its host cell for it to function was absent.

#### **4.5.6 Ideas on living characteristics of bacteria**

At pre intervention, it was recorded that the bacterial shape was that of a rod with its size larger than the virus. He did not know the dimension of bacteria and knew of the necessity to use a microscope for viewing the organism. Nearing the end of the course, S2 assumed the length of bacteria at 0.5 micron and larger than the virus. It was unlikely that S2 had grasped a sense of dimension for bacteria as only earlier, he also reported measurement of virus at 0.5 micron. When he was reminded of that he sounded surprise.

His initially idea of living at the start of semester, was based on the fact that the bacteria move about in the body. Acknowledging that it had no 'legs', S2 reckoned that *"..... It has no legs.....so just follow the blood stream.....Think floated about in our body just like the virus."* His idea of pathogenicity linked his reasoning on the extent of people getting sick to its spread or distribution of bacteria through the works of the blood stream. When asked if the people could still get sick without the use of the blood flow, S2 replied no. This seemed to suggest that bacteria alone would not harm the people. At this initial stage of the microbiology course, there was a sense of confusion in S2.

- Q: *What would a bacteria do without 'legs' in the body if it cannot rely on the blood stream?*
- S2: *Not so sure..... It still must move...I know it is alive.....but people get sick from bacteria.*
- Q: *How do you know?*
- S2: *From my experience and have seen in my family.*

Later in the course, the student viewed about the way the bacteria moved with its tail-like flagella used in propelling the bacteria in the body. The student's response for ideas on the bacterial living characteristics at post intervention shifted towards the presence of chromosomal DNA in the cell. S2's response showed the association between chromosome and binary fission;

*"During binary fission, the chromosomes pass the genetic codes to the bacterial cells to ensure that after cell division the same type of bacteria is being reproduced."*

#### **4.6 Case Study 3: Student S3**

S3 is a 16-year-old male with an O-level aggregate score of 15. He had studied chemistry and biology as science subjects for his O-levels.

##### **4.6.1 Ideas on terminology**

S3 clarified the meaning of the term 'micro' by putting in a numerical value to the microbe's size at  $10^{-6}$ . He had no sense to its dimension and its unit was not included. His meaning on  $10^{-6}$  remains doubtful.

*" Microorganism uh. ....something...that's alive la, then...very small. So until 10 to the power of minus 6."*

Most likely, the unit is in meter. So, at pre intervention, 'microbiology' referred to the study of small living organisms that measured  $10^{-6}$ m. At post intervention, S3 said it was about the study of microscopic living organisms. His idea on microbes at pre intervention was related to his former primary school learning where his earliest introduction to microbe was the plankton. After the microbiology course 4 months later, he changed his view of 'microbe' to include



all living organisms that can't be visually viewed with the naked eye and requiring a microscope to view them.

S3 described what he had done in his secondary school days at one of his biology enhancement programme.

*"...you put in the bacteria inside a agar...thing, you know, you inject it. Then after a while, you take it out then you see the bacteria multiplying..... So and ...that whole bunch right, considered as 1 colony."*

He knew about the accumulation of microbial cells due to reproduction but probably did not realise that that these accumulation of new cells which were identical genetically, actually derived or originated from a single cell. His initially idea on 'colony' is a grouping of microbes without any regard on its origin. His thinking later improved to include the grouping of organisms of the same species living together.

Antibiotics was a type of drug used to combat viruses. He probably based incorrect knowledge of antibiotic on his experience from the medication given to him when he had a bacterial infection. When he was asked about the function of microbes, he used his class experience to derive them. The example he gave was about the degradation of urea, an organic matter into soluble ions by the organism. It was likely that he was referring to brief introduction on microbiology given to his class a week ago about the use of microbes to break down urea, a source of fertilizer, into soluble ions for plant uptake as nutrients. Later at post intervention, S3 understood that the antibiotics were meant for destroy bacteria instead if virus as initially thought.

#### **4.6.2 Ideas on microbial growth as a living characteristic**

S3 claimed that he would not see anything in the test tube of water but thought that something small was probably present in the clear water collected from the stream. He referred those things as microbes and realised the need to use a microscope to view them for confirmation. S3 had no idea that the odour

probably arose due to some microbial activity or processes which would have given him a hint that organisms were present. These odours would become more pronounced after 3 days due to biological processes like anaerobic respiration and fermentation fuelled by the population growth of microbes. Some signs of turbidity indicating microbial was expected after 3 days. S3 commented that, "*I don't think 3 days is long enough to see algae growing yet.*" His argument supporting the presence of microscopic aquatic organisms like algae was only because the water sample was taken from the stream.

#### **4.6.3 Ideas on classification of microbes**

When asked at pre intervention, how he would consider a thing as a microbe, S3 again referred to the earlier answer of classifying any living things as long as it measure at  $10^{-6}$ . He probably did not think that microbes can be larger than a micron like the yeast cell. He was initially able to distinguish between a microbe and a non microbial grouping for the ant (a multi-cellular organism) because under normal circumstances, ants can be observed visually. However, he soon changed his mind and reverted his decision when he was told that the ant size was  $10^{-6}$ . Argument based on independent single cell organism was not used and S3 probably had no idea that a microbe is made up of a single cell and self sustaining. At the beginning of the microbiology study, S3 considered pollen as a microbe based on ideas, that it was living and small in size.

Four months into the formal learning of microbiology, there was some improvement on student's ideas about microbial classification. While still maintaining his earlier ideas of organism being alive and needing a microscope to view it, his idea on the functional independence of the organism supported such improvement. At this point he claimed "*it must be able to live, grow and reproduce*" independently. Argument on the lack of independence was used on pollen and skin cells for classifying them as non microbes. The reason for rejecting ant as a microbe was due to its visibility without using the microscope.

#### 4.6.4 Ideas on occurrence of microbes

S3 referred microbes as 'germs' when the issue of hand washing came up in this instance. Earlier in the interview there was no mention of germs in the discussion. Was there a reason for the negative 'tag' to this term?

He seemed to infer that the germs present in the hands and body originated from the air around him. S3 also thought that the sweaty conditions on his body, like his hands which enhanced the contact with the germs floating about in the air around him. S3 probably thought that the 'germs' were likely to be pathogenic and could make him sick. That could be indicated by his reliance that hand washing with soap would have an antiseptic affect on his hands thus freeing him of the 'germs'.

However, his pathogenic views of microbes were played down with regard to the occurrence inside the human body. Poor understanding on the terminology used during the interview was believed to contribute the inconsistencies of ideas on the presence of microbes in large intestine. His responses about the microbial presence in large intestine were linked to the bile storage in the intestine. In reality, S3 was referring to the organic matter which he termed as 'bile' in the intestine being broken down into ions. The reference was made to the digestive process. At some point during the interview, the student seemed confused and had to be guided back into the discussion.

Further questioning revealed that S3's ideas on occurrence of microbes also included land and sea. When queried on his ideas about microbes in humans, he appeared to associate microbes with dead tissues found at the soles of feet although its purpose of its presence was not discussed.

The student though knew about the presence of microbe in the intestine, he did hint that microbes probably originated from the air outside the body and he explained briefly on the routes such as "*..nostrils, from .....mouth, the ears...*"

taken by the intestinal microbes when entering the body.

S3's view on pathogenicity of microbes was less frequent at post intervention with his description of microbes' point of entry into the human body through the respiratory system and cuts in the skin. He explained that though he may fall ill, there were also intestinal microbes that were beneficial to counteract the bad effects. These intestinal microbes performed its digestive functions by breaking down food materials "...into ions so that they can be transported all over the body" and fight off other bad bacteria. At post intervention, S3 appear to have a better idea on the purpose and function of microbes in the humans.

#### **4.6.5 Ideas on living characteristics of virus**

Student recalled the image of a bacteriophage which had the legged features when asked what the virus looks like. He also described the way the virus injected or transferred the genetic material to host cells. This showed he had come across some information about the shape of a viral particle often shown in books but knows little about the infection mechanism.

*"Virus... from what I know right, it's a 3-legged...it's a 3-legged creature.... Then what this virus do is, they land on your skin,... then they like mosquito..., they inject something then put something inside, then they...run away"*

S3 considered virus as a living thing and did not explain why he thought it was living. He also could not explain whether the virus was an animal or a plant cell.

*"... if the virus is photosynthetic then ....it is able to make it's own food ...if not then most likely the virus... would eat something that is smaller than itself..."*

Unfortunately, being uncertain about viral nutritional requirements and how it derived its nutrients may have lead S3 to be confused about type of cells it belonged to. This uncertainty about the nature of virus improved a little at post intervention when S3 knew there were differences in cellular structures between virus and animal or plant cells but still lack the scientific knowledge in its cellular

structure. *"Virus are neither plants nor animals because they do not have the necessary structure to be classified as either one."* So far, S3's ideas about the living characteristics and knowledge about the virus were insufficient besides it being found in the air and its vague mental image and what it did.

His idea about reproduction was based on his thinking that size has a direct influence on reproduction. The smaller the organism, the faster the progenies were produced. Size dominated his understanding on reproduction. He guessed that virus was smaller than the bacteria at *"...10 to the power of minus 9."*

Q: *Any idea how fast it reproduce?*

S3 :*...faster than the production of bacteria but slower than the speed of light. Because what I think is, things that are smaller reproduce faster, ya reproduce faster."*

This time his idea also involved the virus feeding on the cell at the internal first before reproducing *"..by millions of new viruses in seconds."* He described that the feeding began with the toxins being released which then dissolved the materials in the cell. The virus then absorbed the dissolved materials.

#### **4.6.6 Ideas on living characteristics of bacteria**

S3's idea on the shape of bacteria took different shapes which ranged from spiral, elongated and spherical. Initially in the semester, he believed bacteria was living on the basis that the bacteria reproduced by doubling its numbers. Reason concerning that of a single cell bacterium replicating itself independently, without the involvement of other cells - a key living characteristic of bacteria - was missing from S3 indicating an incomplete understanding.

However, at post intervention the independent capability of bacteria was realised. While S3 knew about the outcome of binary fission i.e., splitting of a single celled organism on its own into two cells, he failed to recognize the similar duplication process of the chromosome occurring concurrently. Such activity was

necessary to ensure the transfer of same genetic material to its daughter cells during binary fission;

*“...process by which chromosomes split looks similar to binary fission, but there is no link because chromosomes split by meiosis and not binary fission. When single celled organisms split by binary fission, each new cell has a complete set of genetic material, whereas a chromosome which splits in half contains only half the original genetic material. when a chromosome splits, it is not reproducing itself as in binary fission...”*

With an incomplete and inaccurate scientific knowledge on binary fission involving chromosomes, it was possible that students would have problems in learning other subjects such as genetic engineering which involved related biological topics like hereditary or genetics.

S3's idea about breathing was the same to that of a human breathing which was through the nose. He realised the difficulty in explaining when he could not use the 'nose scenario' to explain how the bacteria 'breath'. His alternate explanation was the use of osmosis, which had no relevance with regard to oxygen intake in bacteria. That implied the student's poor understanding on concept of respiration, a living characteristic of living organisms. He could only comprehend the 'surface level' of respiration process (to him its breathing) with regard to oxygen being drawn at the nose. S3 did not realise that the intake of oxygen was for metabolic activities and removal of carbon dioxide from chemical reactions occurring at the cellular level.

The student also possessed poor knowledge about the nature of bacteria being a prokaryote and claimed that bacteria has nucleus. In this instance, perhaps this misconception was due to vagueness or unfamiliar on the definition and clarification of such common terminology. S3 too did not recognize the significance for the bacteria to be motile. His description of bacterial motility resembled an animal-like behaviour.

*S3: I would think like the earthworm like that...or caterpillar...*

Q: *They have legs or not?*  
S3: *No legs...*  
Q: *.... Do they have tail?*  
S3: *Some have....not all....*

At post intervention, S3 maintained that the bacterial nutritional needs were obtained by ingestion. *"Bacteria... feed on the virus....on something smaller...engulf and eat whole cells"*. Involvement of other biological processes such as aerobic or anaerobic respiration, oxidation, membrane transport which were needed to facilitate movement of mineral nutrients were not mentioned. There was also no mention on what the nutrients were for.

#### **4.7 Case Study 4: Student S10**

S10 is a 17-year-old female with an O-level aggregate score of 11. She had studied chemistry and biology as science subjects for her O-levels.

##### **4.7.1 Ideas on terminology**

S10 thought that 'microbiology' was about the scientific learning of small living things or organisms. Later at post intervention, her idea about 'microbiology' was to study the invisible microbes targeting on their functions and purposes. Microbes were mainly about viruses while the term 'colony' was a grouping of cells. The term 'antibiotics' did not mean much to her as she admitted that she did not know what it was.

Post intervention, virus was no longer the only microbe S10 knew as the term now includes all tiny cells. She failed to understand that the tiny cells were single cellular organisms that were able to function independently. She now referred the term 'colony' to a group of organism living symbiotically. 'Antibiotics' were antidote to destroy harmful microbes. In general, S10 managed to increase the vocabulary of the terminology but did not quite understand the terms 'bacterial colony' and 'antibiotics'.



#### 4.7.2 Ideas on microbial growth as a living characteristic

S10 had the idea about the death of microbial organisms like plankton due to food competition amongst the organisms. This resulted in the decomposition of organisms when nutrients were inadequate and limited in supply. She had earlier guessed that only plankton would be present in the test tube of water. Her reason was that plankton was an aquatic animal so it made sense to her of its presence. When asked for her opinions on the same test tubes 3 days later, she replied that she would expect the plankton to perish since living things do end up in death.

Competing for limited food was one of the characteristic which living cellular organisms respond to changes in its environment. The limited food at the confined space of the test tube would trigger the plankton to react by competing amongst itself. While it was recognized that such a response (towards changing environment) was an attribute of microbes, S10 did not realise that plankton was a multicellular organism. If S10 had understood that microbes present in the test tube are unicellular, she would know that cell division occurred from a single cell resulting in microbial growth due to an increase in population within a short period.

Post intervention, S10 said that there would not be any sediments at the bottom of test tube at the initial stage but acknowledged the presence of microbes that were too small for her to see. When queried for her views on the test tubes 3 days later, she replied;

*"Nothing much to it... I suppose it's the same...perhaps some algae will grow in the water because it's got light, water and invisible nutrients floating around. The microbes inside would start creating bigger life forms I think. "*

Her response was categorised under 'I don't know' category even though she hinted about the presence of algae in the water since she did not support any idea of growth or increase of organisms when questioned about the 3 days of incubation. She probably was not aware that the algae were capable of undergoing cell reproduction resulting with millions of algae cells which originated



with a single cell to begin with. It appeared that S10 knew little about the way the cell enlarged or escalated in numbers over a period of time which would have contributed towards the visible sediments in the test tube. It was clear that she has little understanding on 'growth' as a living characteristic on algae at post intervention. There was no improvement in understanding for this concept during her 4-month microbiology course.

#### **4.7.3 Ideas on classification of microbes**

To S10, it was the ability to move about and respond, a property in 'living characteristic' category that was thought to be an important feature in classifying microbial organisms. With reference to the ants and pollens, S10 said the ant was too large to be classified as a microbe while for the pollen, it was not considered a microbe due to it being a reproductive cell. S10 then broached the idea concerning its motility when responding in search of food in order to survive;

*"To live, it must move. Useful type of feature for the microbe to have..... like those white cells moving and eating up the germs."*

Later clarification with S10 revealed that the white cells she was referring to was the White Blood Cell (WBC). She mentioned that she saw it on TV where the WBC 'chased' the germs and ate them up. S10 was using WBC as an example of her idea of a bacterium responding by moving about chasing its 'quarry' in the attempt to engulf its food. Most likely, S10 was referring to the amoeba which the protozoa was often featured in primary and secondary biology textbooks. However, understanding the microbial nutrition concept involving metabolic activities which comprised synthesis of new cell materials requiring energy release was lacking.

Post intervention, ideas gathered from S10 on classification of microbes were different to that earlier in the semester. S10 now thought that a living organism could only be classified as a microbe if DNA or nucleic acids were present in the cell. The thinking behind using DNA was to show that living parent organisms were able to transfer its genetic information to the future generation of

cells. The student could not respond to the purpose of transferring the genes. In a sense, S10 had the knowledge but had difficulty in applying it in the proper perspective. She was still using the 'size' category of ideas to classify yeast and skin cells. S10 failed to note that skin cells were dependent on other cells of the same type to function and live;

*"Yeast and skin cells are the only ones I would classify as microorganisms because they are too small to be seen on its own unless seen in a group"*

The thinking behind the idea of a microbe made up of an independent single cell and self sustaining were absent during pre and post interviews. It was unlikely that S10 had a good understanding on concept of classifying organisms into microbes.

#### **4.7.4 Ideas on occurrence of microbes**

S10's ideas on occurrence of microbes were in the surrounding air and surfaces. She believed the reason why she was able to come in contact with both 'good' and 'bad' bacteria were because those microbes could be found in the air and surfaces of everyday common items.

S10: .....hands touch and come in contact with things that are dirty.....like newspaper, money.....coins, notes or food.

Q: Where else can you find germs?

S10: ..... in the air.

S10 reckoned she would fall sick if her immune system, which she regarded as body resistance to germs, was low. Contributing to her immunity, she gathered it was the presence of 'good' microbes which she got from surrounding air. There were little changes on the student's views with regard to occurrence of microbes at the end of her study. She supported the practice of hand washing before meals for the simple reason her hands coming into contact with organisms found in the air and surfaces of everyday common items. Her idea about the damaging nature of microbes appeared lesser towards the end of semester. The knowledge apparently came from her microbiology lessons;

*"I do not know. Maybe nothing, I just read (studied) that most microbes are harmless."*

S10 did have difficulty in attempting to explain why she thought most microbes were indeed safe. For S10 to come to such conclusion, it was plausible that she resorted to recalling of facts concerning the microbes, learnt from the microbiology course without any real understanding.

#### **4.7.5 Ideas on living characteristics of virus**

According to S10, virus was a round shaped living organism. Her idea of the pathogenic nature of virus was connected to her reasoning that disease spread was caused by an increase in viral population. Her rational on pathogenicity was her thinking that that only a living virus can be effective and cause sickness. A dead organism could not cause disease.

At her early semester in 2007, she did not have the necessary knowledge to enable her to understand that the viruses were inactive or inert once they were physically out the cells and thus can't exert its effects. She even claimed that she could see the virus through the microscope and it's cell division similar to that of bacteria. S10 had little understanding on the virus' living characteristics.

Post intervention, S10 described the virus containing nucleic acid surrounded by coat protein. She also said the microscope would not be of any use to view when she made reference to her realization on dimension of the virus being *"The size was just too small"*. For the virus to be alive, she opined that virus did not need to respire or feed. She did not belief that oxygen and nutrients were necessary to sustain it with the availability of other host cells around it;

*"They do not respire..... I do not think so (on virus breathing).....I do not believe they ingest anything other than taking over a host cells nucleus."*

She understood the importance of host cells in enabling the virus to have the ability to produce more copies of itself, an attribute of living. S10 looked as if to have improved her knowledge on virus and was able to apply her knowledge

in explaining the living characteristics surrounding the virus. Her understanding improved at the end of the 2<sup>nd</sup> semester 2007.

#### **4.7.6 Ideas on living characteristics of bacteria**

S10's idea of the shape of bacteria was that of a cigar claiming its size larger than a virus. She was uncertain on its length. The bacteria can be seen under the microscope. Her argument for considering bacteria as living was similar to that of the virus where the bacteria were harmful organisms. Here she thought that its spread of disease was caused by the increase in bacterial population. S10 thought it attacked cells by digesting it and *"...then takes in the food stuff from the cells"*. She could not explain the digestion of cells by bacteria. Most likely it could be the bacteria engulfing the cells as seen in her discussion on microbial classification (section 4.4.). S10 confirmed that the 'food stuff' she was referring to were calcium, iron, sugars and proteins.

Apart from the fact that the bacteria reproduced by dividing, she did not know the significance or its implication. She knew about the division of cells back at secondary school and also learnt it from discovery channel. S10's understanding on bacterial living characteristics was weak.

At post intervention, there were some improvements on her idea about the living characteristics of the bacteria. When commenting on whether the bacteria were alive, S10 answered how bacteria were *"More alive than viruses...."* What she meant was the bacteria were able to *"...move on their own, ...respire and can replicate themselves"*. She realised these properties of living cells i.e., movement, respiration and replication were conducted on its own ability demonstrating the bacteria's ability to be independent. Her thoughts of cell replication involved the process of binary fission where, *"A single-cell organism splitting into two identical single-celled organisms"*. She also explained the association between chromosome and binary fission when she answered about the timely occurrence of DNA duplication during the process of binary fission.

## **4.8 Case Study 5: Student S12**

S12 is a 16-year-old male with an O-level aggregate score of 15. He only studied chemistry as a science subject for his O-levels.

### **4.8.1 Ideas on terminology**

At pre intervention, student S12 thought that the word 'micro' means small while 'bio' provided a hint that it had something to do with cell. He described the term 'microbiology' as the study of small cells. His thought about 'microbiology' remained unchanged at the end of his course. The student's idea of a microbe referred to bacteria which he considered it to be the smallest organisms on earth. S12 admitted he had not seen a bacterial colony before and estimated that each colony consisted of more than 3 million cells. The student does not know what the term 'antibiotics' was and had no clue on its function.

At post intervention, his view of 'microbe' changed with the term now includes all living organisms that cannot be seen by the naked eye. S12's idea on 'colony' was a grouping of bacteria which grew from a single bacterium. He indicated that the cells were of the same species. He also knew that 'antibiotics' was a drug that destroys bacteria. When he was asked about the function of microbes, he knew the organisms caused decay and broke materials down to water, carbon dioxide and glucose.

### **4.8.2 Ideas on microbial growth as a living characteristic**

Pre intervention, S12 expected to see small shrimp-like 'stuff' in the test tube of stream water which he referred to as microbes. There were no responses from S12 to indicate that he knew microbes were actually unicellular organisms. His 'picture' or 'image' of microbe being shrimp-like probably stems from his thinking that the organism was found in an aquatic environment. The shrimp-like microbial organisms would die due to limited food and the competition amongst

the organisms. He said that the microbes devoured each other in the course of competing for food.

S12: *Maybe ...compete with each other right, it'll eat up.*

Q: *Oh, competition is it?*

S12: *Ya. They eat each other up.*

Q: *Oh... alright, so that means there's competition. What do you think they compete for?*

S12: *Food. There are too limited food ...so not all the microbes can survive. Definitely will compete with each other.*

This resulted in the reduction of organisms and S12 did not know the microbial population that survived after 3 days. Thus, his response was animistic when he used 'ball part' figures for the purpose of illustrating the reduction of microbial numbers;

*"Less of them? Maybe less of them. Yah, maybe there's...for example, maybe...before the 3 days got like 10 (10 million), and after the 3 days, there's less than 10 (10 million)".*

The interview also revealed the student's limited knowledge about the reproductive and growth of microbes. If S12 had understood the reproductive capability of the single-celled microbes present in the test tube, he would know on the possible increase in bacterial population. At pre intervention, S12's understanding on the growth as a living characteristic was recorded at its lowest. At the end of the microbiology course, when presented with same questions about the test tube containing stream water, S12 said the, "...solution becomes cloudy from microbial growth" after 3 days. He argued that microbes would respond towards oxygen concentration by reproducing and its activities would be influenced by various oxygen levels.

S12: *Bacterial suspension in the water.*

Q: *Where are colonies being suspended?*

S12: *It depends on the characteristics of the organisms. Meaning that the aerobic ones will be seen floating at the surface of the solution.....If it's an anaerobic, then it be found at the bottom.*

Q: *Why?*

S12: *The surface has plenty of oxygen which the aerobic microbes will require..... The anaerobic will survive and breed at the bottom of the test tube has lesser oxygen.*

At post intervention, the student improved his understanding on microbial growth.

#### 4.8.3 Ideas on classification of microbes

During the pre intervention interview in probing S12 ideas on classification of microbes, he considered any organisms as microbes as long as they require a microscope to be viewed. S12 still had the impression that the microbe should be shrimp-like aquatic organisms. He described that when viewed under the microscope, microbe there should be *"..nothing inside, just plain water or something like that, just plain...plain and just that...that thing itself only."* S12 expressed confusion over classifying the ant and when the interview moved on to the skin cells, he became frustrated at that instant. He stopped abruptly saying instead that it was his 'instinct'.

Q: .... If I tell you that, what you are looking under the microscope are your skin cells, would you consider that as a microorganism?

S12: Yes.

Q: Why is that?

S12: ..(silence)...my instinct

At pre intervention, S12's responses were grouped under the 'size' category of ideas when he failed to match the established criteria that microbes existed as single cells and were capable of functioning independently. Understanding this concept of microbial classification would enable him to classify the ant and skin cells as non-microbial organisms.

Four months into the formal learning of microbiology, a great improvement on microbial classification was achieved moving from the lowest to highest rank of understanding (Table 16). S12's views which now focussed on the functional independence of the organism supported such improvement. S12 classified yeast cell as a microbe citing, *"It's a minute single cell and it can live independently."* As for the non microbial organisms like skin cells and ant, S12 reasoned that, *"Ants are multi-cellular organisms but not a microbe.....Skin cells cannot regenerate and reproduce. It is also a tissue system."* S12 clarified after

the interview that skin cells being part of a tissue can't regenerate as an individual cell. He was familiar with the names of other microbes like *Lactobacillus* and *E. coli*.

#### **4.8.4 Ideas on occurrence of microbes**

S12 agreed that his hands do contain bacteria and needed to be washed before meals in preventing himself from getting sick from food contamination. He said bacteria were transferred onto his hands from the air around him. S12 thought these microbes would eventually enter his body, in particular the stomach, from the inhaled air. He believed that 'good' microbes inside the stomach have a purpose of aiding in digestion where *"They don't like to attack us. They just break down the food we eat"*.

S12 did not appear worried about the presence of 'bad' bacteria causing him harm as he seemed certain that the bacteria in his body are probably more of the 'good' types. According to him, *"As far as I know, the bacteria in ...stomach are good ones."* When he was asked if he had fallen ill before, he replied positively only when he, *"... ate something unclean or something...."* that resulted in him having diarrhoea. He attributed the diarrhoea to the contaminated food and did not make any reference to the presence of microbes in the contaminated food. S12 may not have realised that the toxins which caused the electrolyte imbalance (diarrhoea) were produced by the microbial population fuelled by the nutrients from the digested food in the stomach. It was possible S12 may have a misconception that all the stomach microbes were 'good' since they were suppose to degrade the food in the first place, giving the perception that microbes were not responsible for the sickness.

S12's reason in recommending soap and water for hand washing with the aim to reduce transferring microbial organisms to food showed a more knowledgeable student at the end of semester. He responded that by using tap water alone, more microbes could actually be added since there were also such



organisms in the water. Compared to the early semester when S12 felt more at ease with the 'good' microbes in him, his outlook on microbes was more cautious. He argued that people got sick from either consuming or breathing contaminated food and air was dependent on the type of organisms;

*"Depends on the bacteria some don't last long exposed in air, some wont have any effects unless ingested into the body."*

Though there was no elaboration on his views his thinking seem to suggest the great diversity of microbes. His idea of bacterial occurrence was at the intestine. S12 knew the purpose of microbes in the intestine aiding digestion but could not offer any further explanation as to its benefits from the bacteria's digestive efforts. In general, his idea on occurrence of microbes centres around the human body.

#### **4.8.5 Ideas on living characteristics of virus**

S12's Ideas on virus registered the least understanding. During the interview, S12 revealed his thinking that the virus was a computer virus.

Q: *Are viruses living things?*

S12: *No... No, I don't think so.*

Q: *Why do you say they are not living?*

S12: *Because is, to me right, that word ...to me is computer virus. So it's like somebody send the virus to you.*

He declared that he had little knowledge and understanding about the virus. The interview took S12 sometime to settle down as he had to be reminded that the 'virus' that was being discussed was not IT related. After 4 months of studying microbiology, responses of S12 did not support his understanding on living characteristics of virus. That was due to lack of accuracy in his knowledge. In this case, S12 seemed to think that virus was interchangeable with a bacterium and provides its description to that of a bacterium;

*"..... exists as single cells....Circular or bacilli rod shaped with a lot of surface adherences to other cells ...they possess organelles..... they have flagella or crawl along the surface by adhesion."*

#### 4.8.6 Ideas on living characteristics of bacteria

S12's idea about the shape of bacteria was circular and he regarded it as the smallest thing that lived. S12 believed dead microbes do not cause damage to humans. The bad publicity which microbial diseases generate may have influenced his opinion on the harmful nature of bacteria.

“Q: .... *most bacteria that you know of, are they good or bad...to humans?*

S12: *Bad. I heard there's stuff...like bird flu, ...and all the bad stuff..*”

S12 believed that there were also 'good' bacteria found in the stomach. His idea of nutrition involved the bacteria 'grabbing' the food and then digesting it. The process resembled that of phagocytosis. The bias views of S12 concerning the 'bad' bacteria resulted on the emphasis placed on the destructive nature of the bacteria. Such one sided opinion would lead to poor understanding on living characteristics of bacteria.

At post intervention, S12 did not to realise the independent capability of bacteria. However, he set the bacteria apart from other cells, due to its fast reproduction process unique to microbial organisms. S12 referred this process as binary fission “.....*a method or replication where a cell becomes 2 cells and then later each produce 2 more cells. It doubles each time they produce.*” S12 could not respond when questioned about the association or relevance between living and the duplication process which involved a range of metabolic processes. His idea on bacterial nutrition contributing towards living bacteria improved when compared to the early semester where phagocytosis was suggested. Instead of engulfing the food as first thought at pre intervention, he explained that enzymes were used to break down complicated food structures like starch, protein or fats. He then used starch to illustrate his understanding whereby starch was digested down by enzymes into smaller sized glucose for possible absorption into the cell. There was a slight improvement on understanding living characteristics of bacteria.

## 4.9 Case Study 6: Student S15

S15 is a 17-year-old female with an O-level aggregate score of 15. She had studied chemistry as a science subject for her O-levels.

### 4.9.1 Ideas on terminology

S15 regarded 'microbiology' as a subject about observing living things under the microscope. Her idea on the subject later changed to study of small living cells at the end of semester. Early in the semester, S15 considered microbes as living things (mainly bacteria) which caused diseases in humans. Whenever assistance was needed, she was given hints to help her along. When asked if yeast was also a microbe, S15 replied that yeast was a cooking ingredient and non living thing.

S15: *Oh...yes...used for cheese ..right...Oh cheese yeast is a microbe.!*

Q: *What do you think it was?*

S15: *Thought its something like some cooking ingredient.*

Q: *You didn't know it's alive?*

S15: *No...not really*

Her views on 'microbe' changed at post intervention, which now included all living organisms that required a microscope to see them. S15 appeared more familiar with the terminology towards the end of her study. For example, "colony" which she thought was people colony at pre intervention, could now be described correctly;

*"A very large family or group of organisms...of the same species, that are living together."*

S15 appreciated the meaning of antibiotics better at post intervention when he realised that these were medicines meant to destroy bacteria. Earlier in the semester, she thought it a kind of drug.

#### 4.9.2 Ideas on microbial growth as a living characteristic

Pre intervention, there was no mention of the growth and reproduction of the organism by S15. Instead, she spoke on the idea about the death of microbial organisms like plankton and algae due to food competition amongst the organisms. This resulted in her reasoning that organisms decomposed due to low availability of nutrients from the limited supply in the test tube of stream water.

The interview also revealed contradiction in S15's views. That occurred when S15 described algae death due to lack of food but when reminded that algae could actually synthesised their own food, she appeared doubtful on her views. S15 did not realise that her knowledge about the lack of food was correct but she failed to understand that the 'food' in this instance refers more appropriately to sunlight in which algae had to compete for its energy source for photosynthetic process. This was partially due to lack of proper scientific knowledge and poor conceptual understanding of photosynthesis which required her to apply knowledge when seeking a sensible solution to a problem.

Besides the death of plankton and algae, S15 reckoned that it was not possible for the organisms to reproduce within 3 days.

*Q: So during those 3 days...do you think it reproduces and grow really fast?*

*S15: Time is too short for it to grow. No way.*

*Q: Sure the numbers can't increase?*

*S15: No ..they will not grow...3 days..too short to see any significant growth...the tube will be the same.*

The interview also revealed the student's limited knowledge about the reproductive capability of microbes at the start of her course. Such lack of awareness on the importance of microbial reproduction would lead to poor understanding of the living characteristics of the organism. It was surprising that at the end of the course, S15 thinking or opinion about microbial reproduction had not change. Though she acknowledged the existence of microbes (in this

case algae) in water, she did not seem to realise the rapid growth which microbes could conduct within the 3 days;

*"Yes, there is algae. There is probably plenty of microscopic aquatic life living and growing in the water, since it came from a stream, but I would only be able to see them with the help of a microscope. I don't think 3 days is long enough to see algae growing yet."*

Her thinking in this case did not support the reproductive proliferation nature of microbes, a living characteristic of microbes that contributed toward the growth of the microbial population. If S15 had understood that microbes present in the test tube were single-celled, she would have recognised that the rapid cell division, occurring from a single cell would result in growth due to an increase in population within a short period of 3 days.

#### **4.9.3 Ideas on classification of microbes**

When probing S15's ideas on classification of microbes, she gave examples of bacteria and virus where they cannot be observed with their naked eye. S15 did not classify pollen as a microbe as she said the pollen could not move. When asked to explain further with regard to classification, she looked confused and eventually concluded that all she knew was that a microscope was needed and microbes were capable of moving. S15 classified the mite, a multi-cellular insect, as a microbe because a microscope was required to see it. On the classification of skin cells, she said, *"No.....skin cells don't go around infecting people. Microbes causes sickness and skin cells do not cause an infection unlike microorganisms."*

Her idea of classifying microbes was as long as the small living things moved and required a microscope to view them, they would be classified as microbes. S15's responses which were grouped under the 'size' category of responses, did not match the established criteria.

At post intervention, apart of the earlier thinking of using the microscope to view the motile tiny living things, she now included the microbe's ability to reproduce on its own as another idea suggesting microbes' independent property. On motility, S15 responded without providing scientific reasoning, that all living things must move. S15 did not classify pollen as a microbe as she said the pollen was a gamete and involved in plant reproduction. On the classification of skin cells, she could now recognise that skin cells were not microbes as the cells formed part of a multicellular skin tissue. The ant was not a microbe for the simple reason it could be observed without the need of a microscope. Though she did not use appropriate scientific argument or demonstrate an understanding while classifying the ant (a multi-cellular organism), she did however manage to give the correct answer. In this case S15 knew the answer but not necessary understood it. According to Brumby (1982), students do face difficulty in an 'unfamiliar' context where the work was done in a non laboratory environment. Under such circumstances, they knew the answer and possessed the knowledge but could not use or apply them.

The application of using size or dimension as a criterion to classify microbes was still an influential idea at both pre and post intervention. In the case of yeast cells, they were classified as microbes for being a single cell. Overall, S15 showed some understanding on classifying microbes at the end of course.

#### **4.9.4 Ideas on occurrence of microbes**

For hygiene purposes, S15 agreed that hands had to be washed and cleaned to prevent her from getting food poisoning. She thought that her *"....hands are constantly exposed to the environment ...the air...they touch the surface on everyday things...Bacteria are everywhere."* S15 also knew microbes could be found inside the stomach for aiding digestion. She also made reference of the 'good' microbes in the stomach to the beneficial bacteria used in commercial fermented milk products;

*"It helps in the digestion.....you know like yakult drink where there plenty of good bacteria."*

S15 knew superficially that 'good' bacteria was advantageous for her digestive system but did not fully understand how it came about. Perhaps, it could be just the bacterial population of the 'good' and 'bad' bacteria. S15 did not appear worried about the occurrence of 'bad' bacteria in her body with its possible harmful affects as there were also the 'good' bacteria to counter them. During the interview she was asked where the stomach bacteria came from. Her reply was, *"Originally it's already there!"* hinting that the bacteria was there at birth. She also added that the stomach bacteria located at birth were probably 'good' ones or else the baby would probably get sick. As for the origin of the 'bad' bacteria, S15 suspected industrial pollutants as the source. *"These dirties the environment and these bacteria ends up in our bodies when we breath the air,"* she said.

Post intervention, S15's opinion on her washing of hands did not change as it was intended to minimise the introduction of contaminated food and contaminants into her body. The idea on occurrence of microbes shifted to a wider location. It now includes other living organisms, soil and ocean as locations where microbes could be sourced from. She had obtained this information from the school's library.

S15 could appreciate the function of intestinal microbes in breaking down large food material into simpler particles called ions. The ions were then absorbed directly into the body cells. The microbe's degradative nature was also used by S15 in her explanation of microbial occurrence in the soil. Dead plant materials especially the leaves and roots; and animal waste were decomposed into nutrients by soil microbes. These nutrients then served as a source of fertilizer for the plants.

#### 4.9.5 Ideas on living characteristics of virus

At the early stage of her course, virus to S15 was round like a ball. She had read in the newspaper about diseases such as SARS, AIDS and bird flu that were caused by viruses. She did not know how small a virus was but suspected that it was smaller than the bacteria. S15 thought the microscope would help her identify the virus organism. In reality, a microscope was unable to aid in observing the virus. When describing the reproduction of virus, she provided an inaccurate account on how the virus would *"Just divide...2, 4, 8, 16 and so forth"* like how bacteria would double its cell numbers. Her lack of scientific knowledge would contribute towards her poor understanding of virus' living characteristics. S15's reason why the virus was a living thing was based on the disease outbreak caused by SARS, AIDS and the bird flu. The rationale adopted by S15 was its assumption that only living things are capable of causing a harmful affect;

*".....that's why it's deadly! If dead then they shouldn't make us sick."*

At post intervention, S15's knowledge surrounding the viral structure was still inaccurate. She described the virus having a cell wall and believed it can be observed under a microscope. S15 considered the virus' ability to grow, reproduce and die as its living characteristics. The student could not explain how the reproduction which resulted in millions of viruses being replicated could occur. She had the thinking that the virus feed on the cell by first breaking the cell wall and then proceeded towards 'sucking' the protoplasm. Overall, S15 showed little understanding about the virus. She did not demonstrate any appreciation that viruses would be inactive and cannot reproduce when it was not in the host cell.

#### 4.9.6 Ideas on living characteristics of bacteria

The thoughts and descriptions of bacteria without any 'tails' or 'fins' attached to its surface convinced S15 of the bacteria moving about *"...like an amoeba. Slimy, slippery."* She believed the bacteria were round in shape and most likely were 'bad' bacteria like the SARS and bird flu. When questioned



about his thoughts on what made the bacteria a living thing, S15 replied that it was the ability of the bacteria to move about in people, fish and animal. She also associated the bacteria's movement with infection. Things like people, fish and animals could be infected with bacterial diseases but she was uncertain if plants could get infected.

In a bacterial infection, the bacteria appeared to be feeding on the cells. She then described how the bacteria infect the cells.

Q: *How do they attack the cell?*

S15: *Bacteria move in on the cell. The cell is like the food. It suck in ..like absorbs the food around it. Or the food diffuses into the bacteria.*

Q: *What happens when the food is absorbed into it?*

S15: *The food is digested...The food gets broken down further into soluble stuff.*

Q: *Isn't the food already broken down like already soluble?*

S15 : *Yes, but still not soluble enough.*

Such feeding behaviour reflected the animalistic nature of human beings where food was first ingested and then digested. S15 has little understanding on bacterial living characteristics.

At post intervention, S15 commented that bacterium was a “..single-celled organism with a cell membrane...” which “...live, respire, grow, reproduce and can also die.” She singled out reproduction as a living feature for bacteria. When asked why, she answered bacteria were the only organisms that can survived on its own. The ability to “...reproduce by binary fission, and reproduce by millions of new bacteria....” at a rapid rate also gave it the advantage to survive. S15 understood the mechanism of binary fission.

## **- CHAPTER 5 -**

### **DISCUSSION**

In the study of students' ideas towards understanding the nature of microbes, steps were taken to determine the 2005 cohort's existing knowledge on the terminology, classification and occurrence of microbial organisms via written pretest. Post intervention interview was also used to probe the 2005 cohort's ideas on 'living', growth and classification of microbes.

For 2007 cohort students, pre and post intervention interviews were conducted to probe ideas about understanding of microbiology concepts at the beginning and end of the 4-month microbiology course respectively. Table 20 listed the frequencies at each interview and summarised the overall categories of understanding for combined responses to definition of 'living' in organisms, growth and classification of microbes, obtained from cohorts of 2005 and 2007. Overall categories of understanding for combined responses to living characteristics of virus and bacteria for cohort 2007 were shown in Table 21. Such initial part of the discussion would deal with the overall categories of understanding for combined responses from all the students interviewed (cohorts 2005 and 2007). This would give a general perspective on the students' understanding for both cohorts. The changes and developments of individual student's understanding for the various concepts of microbiology over semester 2 were discussed as case studies in section 5.8. That dealt with the individual development or changes of their respective understanding of ideas on the microbial concepts.

Table 20: Overall categories of understanding for combined responses to 'living' in organisms, growth and classification of microbes (n=15)

Code	Categories of understanding	'Living' in organisms		Growth of microbes				Classification of microbes			
		2005 cohort		2005 cohort		2007 cohort		2005 cohort		2007 cohort	
		Post Semester 1*	Post Semester 2 <sup>#</sup>	Post semester 1*	Post semester 2 <sup>#</sup>	Pre semester 2	Post semester 2	Post semester 1*	Post semester 2 <sup>#</sup>	Pre semester 2	Post semester 2
X	Have an understanding	5 (71.4%)	2 (25.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	3 (42.9%)	2 (25.0%)	0 (0.0%)	6 (40.0%)
Y	Have some understanding	2 (28.6%)	4 (50.0%)	7 (100.0%)	5 (62.5%)	0 (0.0%)	8 (53.3%)	0 (0.0%)	2 (25.0%)	3 (20.0%)	4 (26.7%)
Z	Have little / no understanding	0 (0.0%)	2 (25.0%)	0 (0.0%)	3 (37.5%)	15 (100.0)	7 (46.7%)	4 (57.1%)	4 (50.0%)	12 (80.0%)	5 (33.3%)

\* 7 students were interviewed in that semester

# 8 students were interviewed in that semester

Table 21: Overall categories of understanding for combined responses to living characteristics of virus and bacteria of 2007 cohort (n=15)

Code	Categories of understanding	Living characteristics of virus		Living characteristics of bacteria	
		Pre intervention	Post intervention	Pre intervention	Post intervention
X	Have an understanding	0 (0.0%)	5 (33.3%)	0 (0.0%)	4 (26.7%)
Y	Have some understanding	0 (0.0%)	4 (26.7%)	11 (73.3%)	11 (73.3%)
Z	Have little / no understanding	15 (100.0%)	6 (40.0%)	4 (26.7%)	0 (0.0%)

## 5.1 Terminology

It was believed that familiarity with the terminology would add confidence to its knowledge application. Alcamo (2001) viewed that constant usage would contribute towards its familiarity and context. This improved their understanding and knowledge in microbiology. Students from both semesters in 2005 cohort had similar idea about microbiology. To them, 'microbiology' was about the study of small living things like bacteria and viruses. Typical responses of students on their understanding of the term 'microbiology' were;

*"Study of living things or bacteria at microscopic level"*

*"Study of microorganisms about small cells"*

*"Learning about microbes and bacteria"*

Such ideas were also found in 2007 cohort at pre intervention. Their ideas about 'microbiology' then progressed to thinking involving biological functions and benefits of manipulation of microbes at post intervention. Such functions and benefits included digestion of large molecules, production of genetically modified antibiotics and cloning of organisms. At the end of the course, almost all 2007 cohort students understood what the term 'microbiology' meant (Table 22). Their views could be summed up by Summers' (2000) broad definition of microbiology which include the study, *".....of the living objects.....below the limits of normal human visual acuity .... also includes the study of properties of these objects...example, the metabolic processes,.....and the products of microbial activity."* (p. 678)

Explanation from most 2005 students on the term 'microorganism' or 'microbes' concerned the use of microscopes on tiny living cells and organisms especially that of virus, bacteria and fungi. Thus, students' initial idea of microbes was associated with the small physical size and that contributed towards the use of microscope to examine these organisms. Though most students could offer some explanation about what a microorganism was about, only 8 (7.1%) semester 2 students and none from semester 1 could respond appropriately on idea about its morphology that microbes were made up of single cell organisms.

Less than 6% of semester 1 students had ideas which concerned the living cell capable of surviving and reproducing on its own.

Like the earlier 2005 cohort, ideas relating to the physical sizes and use of microscopes seemed to be unanimous among the 2007 cohort students. They also expressed difficulty in giving their ideas on sizes or dimensions of microbes as similarly observed by Simonneaux (2000) on her fifth-form French students. Only 1 student provided a measurement of  $10^{-6}\text{m}$  as the size to be considered as a microbe. At post intervention, students' idea of a microbe was still based on the need of a microscope. Towards the end of semester, the number of students with some understanding of microbes (code Y in Table 22) for cohort 2007 declined from 8 to 5 as these students still had the idea that the invisible organisms would require a microscope to view them. At the same time, students who had little understanding about microbes increased by 2 students to 9 (code Z). Only S8's idea of a microbe came close to the view of most microbiology text books that of a single celled or clusters of cells that were self sufficient (Dreyfus and Jungwirth, 1989).

Table 22: Overall categories of understanding for responses to terminology of 2007 cohort

Code	Category description	Pre intervention	Post intervention
X	An understanding on microbiology	9	13
Y	Some understanding on microbiology	6	2
Z	Little/no understanding on microbiology	0	0
X	An understanding on microbes	0	1
Y	Some understanding on microbes	8	5
Z	Little/no understanding on microbes	7	9
X	An understanding on bacterial colony	0	8
Y	Some understanding on bacterial colony	6	7
Z	Little/no understanding on bacterial colony	9	0
X	An understanding on antibiotics	1	12
Y	Some understanding on antibiotics	3	3
Z	Little/no understanding on antibiotics	11	0

On the term 'bacterial colony', none of the 2007 cohort students understood its meaning at pre intervention. About half of the students interviewed had never heard of the term and knew little about it. Post intervention, there were improvement with 8 code X students being able to explain its meaning. By then, there were no students categorized with its lowest level of understanding.

About 73% of students did not know what an antibiotic was at the start of their course. The rest thought it was some kind of a drug with most of them not knowing its target. However, at post intervention, understanding on the term 'antibiotic' was found to be accurate on 12 students (80%) who emphasized bacteria in their explanations as the target for the antibiotics. One student (S4) even mentioned specific enzymes (kinases) and proteins (receptors) and DNA which the antibodies would bind to. Though S4 did not explain the effects of such binding, he argued that it concerned the permeability of cell membrane (diseased cells). Responses from S4 reflected the presence of rote learning. It was not surprising to note that some students thought that antibiotics were also meant to attack virus. Such incorrect biological fact was also found to exist in adults. A survey about public knowledge of biological science, conducted on 1033 British adults (more than 15 years old), showed that only 70% knew antibiotics attacked bacteria (Lucas, 1987). Thus, this misconception concerning the application of antibiotics could be found in both the young and adult.

From the data gathered from 2005 and 2007 cohorts, students appeared to improve their understanding on the commonly used terms 'microbiology', 'bacterial colony' and 'antibiotics' at the end of their 4-month microbiology course. This however did not appear to be so for the term 'microbe'. The majority of the students still did not have a proper understanding or at least a definition, of what a microbe was. It would envisage that students would have problems studying microbiology and understanding the microbiological concepts without first knowing the proper meaning to the term 'microbe'.

Hilge and Kattman's (1999) acknowledged that microbiological terms must be properly understood when researching on students' conceptions of microbes. Such clarification would eventually assist the students' learning process. This was also reflected in Simonneaux's (2000) research in biotechnology education with regard to students' notion of immune system to microbes where she interviewed them by targeting on the terminology. In that study, students were able to discuss ideas about the immune system when they knew something about the terms and what they meant.

## **5.2 'Living' of Organisms**

Although 15 students of 2005 cohort, who volunteered for this study were given the freedom to explore their ideas about the general living characteristics of organisms, the interview questions did provide some guidance (as hints) which would be of use to some students who needed assistance. The semi-structured interview was worded carefully to allow students more latitude to express themselves.

The most popular general ideas on living characteristics of organisms gathered from 2005 cohort were on the categories of 'metabolism' and 'growth'. Five and 2 students from semester 1 and 2 respectively had the highest category of understanding about 'living' of organisms at post intervention (Table 11). Ideas on 'living' under 'metabolism' category concerned nutritional aspects of food and water being consumed by living things. Other ideas associated with nutrient consumption were those that concerned waste production (CO<sub>2</sub> and water) through the breaking down of food, and respiration. Hilge and Kattmann (1999) observed in their interviews with German students about their conceptions of microbes, regarded cellular metabolism as a property as living. The responses gathered in this study were similar to 'living' characteristics of Brumby (1982) which include growth, reproduction, respiration, response, motility, excretion and nutrition. Perhaps, it was not surprising to note that ideas relating to nutrient consumption were frequently mentioned by the older Ngee Ann students since

nourishment for 'living' things was known to be easily understood by primary students (Looft, 1974). Semester 2 students had some understanding in the 'growth' category. According to them, water and nutrients were necessary for the size of substance to change and gain weight, indicating growth and therefore it was alive. Their idea of growth lack scientific explanation in that there was just the mention of cell expansion and cell division without the ideas of incorporating or assimilating of nutrients into cells and its requirement for energy, thus were placed in code B.

On the 'movement' category, S6 (semester 1) demonstrated her understanding through her response that being able to move would reveal that the 'lump of soft substance' was living (Table 11). The information gathered displayed her reasons that living things could move in response to a stimuli like food. Piaget (1929) cautioned against such interpretation involving movement of objects especially from the ideas of young children. It was believed that children were too young to form logical opinion or accumulate adequate knowledge to fully understand the concept of living (Carey, 1985).

In Lucas *et al.*, (1979) assessment of students' understanding of 'living', behavioural ideas associated with trait like movement were also detected. In the same study, smaller proportions or sub-categories of physiological activities like respiration, growth and even blood were also recorded as ideas on the 'living' concept. In this research, 1 student claimed that a living organism must contained blood for it to be alive. However, possession of such weak scientific knowledge did not contribute significantly towards understanding living characteristics as he later could not explain why a plant lives despite the absence of blood in it.

It was expected that at this stage of their post secondary education where most biotechnology students are in their mid to late teens, their thinking and understanding on biological concepts would tend to be more scientific (Bell and



Barker, 1982). Unfortunately this did not turn out to be so. In this regard, the students could not amalgamate the concepts together for instance linking the relationship between nutrients and respiration to illustrate substantive understanding (Roberts, 2001). The findings showed that students' ability to understand the concept of 'living characteristics' were ideas derived mainly from categories of 'metabolism' that illustrated nutrient consumption, respiration and waste producing activities; and 'respond to stimuli'. These ideas were also found in Brumby's study on characterization of living and non living things (Brumby, 1982). Though the student responses were gathered according to Wragg's (1984) concept of reliability where same interview questions were applied on 2 different student groups on different occasions, there appear to be diversity on their understanding of 'living' in organisms (Table 20). Such diversity of responses which was detected in all 3 categories of understanding failed to obtain similar results. This may probably be due to the small sample size obtained from each semester.

### **5.3 Occurrence of Bacteria**

#### **5.3.1 Microbes seemed to be everywhere**

Young students seem to relate better to the concept of what a microbe is if they knew about its physical presence or occurrence (Roland *et al.*, 2005). The need to visually observe the organisms from where they were found would help the students to acknowledge the existence of microbes. Roland *et al.* (2005) noted that they did not realise the existence of microbes around them. The occurrence of microbes would provide additional information in students' understanding of microbes.

At least 63% of 2005 cohort had conception that bacteria were harmless and not pathogenic. This idea was developed based from their reasoning that if bacteria were indeed harmful, everyone would be infected with bacterial infection and falling sick daily. Most of the arguments and thinking were related to personal experience that they themselves did not fall ill since they came in

contact with bacteria around them. Below are examples of some typical responses from 2005 cohort;

*"Many will be sick if organisms are not harmless.."*

*"People will be falling sick everyday due to bacteria if they are harmful....."*

*"Microorganisms are everywhere and I am not sick."*

(2005 cohort)

Dreyfus and Jungwirth (1989) considered that students under those circumstances probably;

*"....do not use the scientific knowledge they have been taught, but stick to their out-of-school perceptions of phenomena or concepts."* (p. 50)

Though the arguments above represented viewpoints that were associated more of non-classroom learning than classroom learning, such personal experience would strengthen their notion of harmless bacteria found around them. The researchers further argued that the nature of such knowledge was likely to be non-functional due to lack of conceptions or meanings. To counter that, it was suggested that if students were taught meaningfully in school based on the right conceptions. This would reverse the use of non-scientific or non-functional knowledge by the students.

My findings of 2005 cohort having considered bacteria as harmless was not in agreement with Nagy, (1953), Maxted (1984) and Wallace (1986) where children and teenagers associated diseases with microbes. Perhaps it could be due to the age factor as Ngee Ann biotechnology students were older than those of Maxted, Nagy and Wallace, thus were more mature and capable of acquiring more credible views and knowledge via personal experiences (White and Gunstone, 1992).

About 60% of semester 2 students agreed that healthy people do carry bacteria. Why did the remaining 40% think there were no bacteria in healthy people? Written responses from this group of students showed that while they

acknowledged the presence of bacteria in the intestine of healthy people, half of them did not explain their rationale of having bacteria only in sick people. Perhaps, there was a misconception here that bacteria were only bad and harmful to humans. Majority of semester 1 students thought that healthy humans had bacteria especially the beneficial types in them. Their ideas also included the belief that they had immunity to protect them against harmful bacteria. Some even thought that immunity and antibody production were caused by the presence of bacteria in the body. Two-third of 2005 cohort was of the opinion that bacteria occurred everywhere and the beneficial bacteria did occur in humans especially in the intestines. This was in disagreement to Roland *et al.* (2005) where they reported that high school students failed to notice the existence of microbes around them.

### **5.3.2 Microbes in human intestine**

In 2007, almost half of the students interviewed at pre intervention, believed that microbes were located in the human intestine. The other half acknowledged the occurrence of microbes in the 'environment and food' category. All the students agreed that their hands were contaminated with microbes. Students remarked that the dust and air were filled with germs or microbes. Hence, their reason for washing their hands before meals was to avoid food contamination. That suggested students were aware on the likelihood of microbes being transferred to them along with diseases. Even Pasteur avoided physical contact and handshaking to prevent any transfer of diseases onto him (Raichvarg, 1995). The acknowledgements on the dangerous implication on not having their hands washed were in agreement with United Nations first Global Handwashing Day celebrating 2008 as the International Year of Sanitation (ST, 2008). In the report, the UN recommended hygienic practices of hand-washing with soap to remove microbial organisms and prevent killer diseases. S4 remarked on how easy it was for him to make 'contact' with organisms;

*".... the dust and air around me will come in contact with my hands...you know when I swing my hands...it will come in contact, so the dust, plenty in the air, land on my hand. So with dust you*

*have bacteria. Dust is not clean anyway so will have these things. With dust you also have air....kind of together right?"*

It was surprising that none of the 2005 students mentioned that microbes occurred on their hands apart from intestinal microbes. Perhaps, it was due to the different questions used for 2005 cohort (written pretest) and 2007 cohort (pre interview) when attempts were made to probe their ideas for occurrence of microbes.

While pre intervention students knew about the location of microbial organism in their body like lungs, stomach and intestine, many contributed the environment outside their body as the microbial source. Apart from microbes being found in food and water S8 added that the microbes in his lungs originated *"from the air we breathe and the air gets polluted because the environment is polluted from the industries."* Others thought of the desert location as their idea of occurrence. For example, S14 argued that the desert is *"A logical place...so large and no one disturbing it so the bacteria will find it easier to breed and spread. With the sand storm... the sand .....will carry the organisms to all the cities around the world. So ...in Singapore we'll also get it."* The general 'feel' about students' ideas of occurrence appeared to indicate microbes were everywhere. A study by Simonneaux (2000) reported that 3 of her 10 students interviewed also believed that microbes especially bacteria were located everywhere including the soil.

The next major locations where microbes were found were probably the stomach and intestine. They did not know how the bacteria came about in the intestine. S7 suggested that perhaps the bacteria were already there when he was a baby. He even associated the waste excreted by the baby as an effect from the bacterial activity;

*"....when we are born, there already these bacteria in us. See the waste that comes out from the baby is always stinky and nasty."*

(S7)

The existence of microbes in the stomach and intestine at birth was also found in S1 and S11 at post intervention. S4 and S13 believed they had inherited the microbes from their parents. When questioned how the microbes had occurred in his body, S4 replied, *"Some from the environment, some from transfer during birth, others (i.e in intestine) from mother."* S13 mentioned that he *"Inherited them at birth."*

Students S9, S11 and S13 spoke of the bacterial action in the intestine and agreed that microbes digest food via some means of breaking down large food into smaller ones. Understanding on the digestion process remained doubtful. For instance, the thinking of S11 on digestion develops around the physical means of engulfing when she gave an example of an amoeba *"....engulfing the food and breaking into small pieces."* S13 however, does not know what will happen to the smaller bits of food that have been broken down.

The idea of bacteria occurring 'everywhere' as seen in 2005 cohort was also observed on 7 post intervention 2007 students. They were more knowledgeable and understood that microorganisms were easily produced and disseminated everywhere. Other ideas on the occurrence of microbes include seat and floor surfaces, soil and the ocean. Students in both 2005 and 2007 cohorts knew microbes were most likely to be found in the intestine and involved in the digestion process. However, they displayed limited understanding on the concept of digestion and offered little explanation.

## **5.4 Microbial Growth**

### **5.4.1 Influence of oxygen on microbial growth**

At post interviews in 2005, there was no evidence that 2005 cohort understood the concept of growth. Instead, students were of the opinion that the growth of microbes was associated with the presence of oxygen. Majority of the students interviewed from both semesters had the notion that oxygen was critical in encouraging microbial growth. They were able to interpret the different growth

response by explaining the cloudiness or location of bacteria colonies (test tube surface or bottom) in the test tubes. They further explained that the degree of cloudiness and location of bacterial colonies was associated with the microbial ability to grow at various levels of oxygen. Colonies at tube surface were termed as aerobes due to the active growing of microbes at surface locations with rich oxygen content. Microbes that were able to survive and grow without the need of oxygen were termed anaerobes. The comments provided by 2 students below typically summarised their inferences at post interview;

*"Floating on top of tube shows its aerobic and at the bottom its anaerobic."*

*"Bacterial growth occurring at the broth surface is aerobic since more oxygen is available. At the broth bottom, presence of sediments indicate anaerobic bacteria."*

(Semester 1, 2005 cohort)

Seven students (4 semester 1 and 3 semester 2) from 2005 cohort knew that not all organisms needed oxygen to live and grow. They could explain the rationale behind their simple experiment to prove that microbial growth was possible in presence and absence of oxygen. Thus, their ideas on microbial growth were about creating living conditions by manipulating oxygen levels (Table 12).

Microbes occurred as 'black things' or pellicles at test tube surface and sediments at the bottom or 'cloudiness' indicated microbial presence. Such method was obtained from a standard test employed for culturing microbes in broth as described in Bergey's manual (Brown, 2005). During the interview, there was little evidence on the misuse or misunderstanding of terms concerning 'aerobic' and 'anaerobic' from the students and they knew the descriptions of the different types of respirations well.

They however, lacked the substantive understanding which linked physiological activities or biochemical reactions like fermentation or enzymatic

reactions which elucidate the effects of oxygen towards growth. Furthermore, ideas about the generation of energy needed for growth, was also not mentioned to indicate its association with oxygen requirement. So, students only had some understanding on microbial growth (code Y) and failed to discuss their significance of their responses such as why different groups of microbial organisms (aerobes and anaerobes) have different oxygen requirements for growth. To demonstrate their understanding, clarification of these responses were vital (Driver *et al.*, 1994). It was highly likely that students' responses and opinions to microbe's different oxygen requirements were recalled from a laboratory practical where they learnt about biochemical characterisation of microbes, conducted a week before the interview.

Semester 1 students had a better understanding on microbial growth than semester 2 in 2005. Both 2005 and 2007 cohorts at post intervention had at least half of its students in code Y category of 'having some understanding' (62.5% for 2005 cohort and 53.3% for 2007 cohort). None of the students from both cohorts however, understood that 'growth' in microbes concerned cell production from a single parent cell (code X).

Two students of 2007 cohort had ideas about the growth being influenced by the concentration levels of oxygen. They were able to relate growth behaviour seen from the test tube and revealed the different metabolic diversity in microbes towards oxygen. With regard to this, S12 said;

*"It depends on the characteristics of the organisms. Meaning that the aerobic ones will be seen floating at the surface of the solution.....If it's an anaerobic, then it be found at the bottom....The surface has plenty of oxygen which the aerobic microbes will require..... The anaerobic will survive and breed at the bottom of the test tube has lesser oxygen."*

Such observations were also noted on 7 students at post intervention 2005 cohort. They all believed that microbial growth was influenced by oxygen concentrations. Such ideas indicated that existence of metabolic diversity

towards different oxygen levels was another living characteristic of microbes. Such characteristics allowed the microbe to adapt and respond to its environment. This observation also deviates from the conventional notion that all living things require oxygen to grow.

#### **5.4.2 No idea on occurrence of microbes in water**

At pre intervention, all the 15 students had none or little understanding on 'growth' in microbes. One of the factors was that they did not think and also had no knowledge, on occurrence of microbes in the stream water in the first place. Such response came as no surprise as most students of 2007 cohort interviewed at the early stage of the study expected microbes to be present in the air and digestion tract of humans. That was shown in the responses of students when they said that they would not expect anything to grow after 3 days since nothing was introduced into the test tube. The genuine response of the students of not knowing anything about living organism in the water was probably realised when gasses like oxygen and carbon dioxide were thought by S9 to exist in the test tube instead. The student did not even realise that the disappearance of the gasses was due to metabolic activity of the microbes.

S9: *Nothing inside but there will be gasses..Yes, just gasses like oxygen and carbon dioxide.*

Q: *.....What do you expect to see in 3 days time?*

S9: *The gasses disappear. They disappear into thin air.....The gas will travel from the test tube to the outside.*

Q: *Could it be the gasses disappear because some other things use them up?*

S9: *No, you don't have anything in there (in test tube) so how can anything use the oxygen then? Make sense that it diffuses into thin air.*

#### **5.4.3 Competition for nutrients**

Of the few students who knew about the presence of microbes like plankton and algae, there was no mention of the growth and reproduction of the organism. Instead, their idea was about the decomposition and 'cannibalism' of organisms due to nutrient competition. S6 commented that, *".....it has only*



*limited food, so the algae will compete for food and those that don't have enough will die....so decompose."* Similar argument was also found in the plankton (thought to be a microbe) by S10 where she said, *"The plankton will compete for food with each other... don't have enough ...the remainder plankton dies and decompose."*

S12 mentioned of microbes devouring each other when competing for food.

*S12: Maybe ...compete with each other right, it'll eat up.*

*Q: Oh, competition is it?*

*S12: Ya. They eat each other up.*

*Q: What do you think they compete for?*

*S12: Food.*

Such an anthropomorphic description of microbes 'killing each other' for the limited food available resembled the notion of survival for the fittest commonly applied to the animal kingdom. Such views of 'killing' and 'eating up' of other cells were also documented in students' conceptions of virus (Simonneaux, 2000)

#### **5.4.4 Microbes need more than 3 days for growth and cell replication**

The next factor was the students' lack of knowledge that microbes were capable of growing rapidly through its cell replication process. Some students had suspected about the existence of the microbial organisms but did not think that the stream water would be a breeding medium for microbes to multiply and that the organisms were capable of undergoing cell division producing multiple generations of microbes within 3 days. The time period required for cell replication could range from minutes to hours depending on the type of organisms (Madigan *et al.*, 2003). S11 did not make any reference to production of more microbial cells apart from her earlier acknowledgement of cells in the test tube.

*Q: ....You said earlier microorganisms growing inside*

S11: *Yes, I know so...now it is still clear.*  
 Q: *Are there microbes in there?*  
 S11: *Yes,...*  
 Q: *What happens during the 3 days?*  
 S11: *Don't know...*

Even after S3 detected the strange scent from the water due to microbial respiration or fermentation contributed by the vast population of microbes, he still had no idea on its presence;

Q: *..... will you see anything inside?*  
 S3: *No .. Cannot see, got one strange odour ....*  
 Q: *.....do you still think there's living things inside, after 3 days?*  
 S3: *Living things inside there...I think there is....*  
 Q: *Will you see anything inside?*  
 S3: *Don't think so....*

Four months later, at post intervention, 8 students had gained idea on microbial growth as a living characteristic and were able to understand something about the microbes itself (code Y). None of the students from 2007 could properly understand the concept 'growth' according to the criteria. Seven (46.7%) students were still classified in the lowest category of understanding (code Z) having little understanding on the growth concept of microbes at the end of semester 2 (Table 20).

While the views of a couple of students in code Z category, remained unchanged at post intervention maintaining no growth of organisms throughout the 3 days, there were students who knew about the presence of microbes especially the algae but their thinking did not support any idea on proliferation of the algal organisms. At post intervention, the 4 students shared the common reason that algae needed longer period to reproduce. Such misconception can be seen in the views of S15 where she claimed that *"Yes, there is algae.....don't think 3 days is enough to see it (algae) growing yet."*

The other 8 students with ideas about microbial growth could associate the cloudiness of the water with the reproduction of the microbes. S9 explained that the solution “....turn a bit cloudy,....the microbes inside will replicate and produce waste” while S7 explained the short life cycle of microbes and its multiplying effects reflecting some understanding in growth. However, there was no indication in their argument that they fully understood the growth concept that concern identical cells being produced from a single parent cell.

Q:     *So fast? Within 3 days?*

S7:     *You know microbes can divide every 20 min....so after so many generations definitely the solution will have visibility of such cloudiness. With those millions of cells in there, bound to make the water dirty.*

## **5.5     Classification of Microbes**

### **5.5.1   Microbes were small living cells**

Less than half of semester 1 students (2005 cohort) classified nerve cell as being a microbe. Although they have the knowledge about the cellular characteristics of nerve cells, students considered nerve cells as microbes and failed to distinguish between the dependent nature of nerve cells (eukaryotic cell) as part of a multi-cellular tissue and independent nature of a single-celled microbe (normally a prokaryote). The remaining semester 1 students considered nerve cells as eukaryotes and larger than microbes. Microbes were capable of living independently and smaller than nerve cells. Half of the students in semester 2 classified nerve cell as a microbe and based their reasons (as in semester 1) that nerve cells cannot live independently and considered as part of tissues. That suggested that even though 2005 cohort students possessed the subject knowledge about nerve cells (knowing its characteristics), they failed to exercise proper scientific reasoning when classifying the nerve cells. The basis for their poor conceptual understanding in classification of organisms could probably be their thinking of an association existing between a ‘cell’ and ‘its ability to live’ regardless of its independence. That meant their thinking was probably that as long as an organism was small, like a cell and had the ability to

live, i.e. whether on its own or dependent on similar cell types around it, the cell (in this case a nerve cell) was classified as a microbe. Such observation was in agreement with Maxted (1984) where 12-13 year-old children basically regarded microbe as small and living without providing satisfactory reasoning. Thus, it seemed even older students at the polytechnic had difficulty in explaining their views of a microbe.

### **5.5.2 Incorrect and inadequate scientific knowledge**

Approximately one third of 2005 cohort classified red blood cell (RBC) incorrectly as microbes. Explanations on cellular characteristics that were based on its functional, structural and reproduction aspects seemed inaccurate indicating students' poor substantive understanding in classifying the RBC. For example, RBC could not reproduce or undergo cell division which a microbe could. Inaccurate facts about its structure from semester 1 students portrayed cells containing nucleus and ability to move independently although RBC had no flagella to aid in its motility. Thus, it appeared students applied scientific knowledge incorrectly to differentiate whether RBC was indeed a microbe.

Similar incidence on wrong application of factual knowledge was noted when classifying the pollen during pretest 2005. More students in both semesters at pre intervention thought that pollen was a microbe even though they knew that pollen was not capable of functioning, or survive on its own and it was part of a reproductive system. Was it due to students' existing knowledge about the pollen being inadequate in supporting their understanding when classifying the pollen? That may be true but if they had understood the criteria behind the concept in classifying the organism i.e., subsistence of microbes as single cells and its ability to conduct their life processes independently, organism with complicated structures like the pollen could be classified successfully. However, for these criteria to be applied student's subject knowledge must be scientifically correct and sufficient which in this instant was inadequate. Thus, they could not understand the concept when classifying the pollen.

There was consistency in 2005 cohort's responses for both semesters when classifying fungi and algae, showing reliability on their ideas. There were some confusion on microbial colony which was an aggregation of microbes were mistaken as individual microbes. Such thinking contributed to the algae being wrongly classified as non microbe due to the visible green algal colonies.

The 2005 cohort had inadequate subject knowledge especially on algae, RBC and pollen, and this prevented the 'correct' judgmental response according to the task criteria involved in the concept of microbial classification. White and Gunstone (1992) referred such subject knowledge as statements where the students' scientific knowledge and ideas relating to the concept were incomplete. Although with adequate subject knowledge students must also be able to apply its relevance with proper scientific reasoning as seen in the case of classifying nerve cells.

The tendency of students to "box up" technical or subject knowledge and their lack of ability to process knowledge with weakness in reasoning contributed to their inability to solve a problem (i.e., classification of organisms). Such was a situation where students were presented with an unfamiliar problem (e.g. classify RBC) and they applied facts learnt from one familiar context (e.g. nerve cell) without realising differences in its living characteristics.

This would suggest that they had poor substantive understanding when attempting to classify algae, nerve cells, RBC and pollen at the beginning of both semesters in 2005. Pekmez *et al.* (2005) had argued on the necessity to have facts and concepts to allow substantive understanding to support proper explanations required in problem solving. The inadequate knowledge which cohort 2005 possessed would therefore lead to poor substantive understanding and wrong classification of organisms. However, fungi seem to be the only organism where both student groups could understand well in classifying them.

### 5.5.3 Microscopes and size of microbes

At post intervention 2005, students' still associated the use of microscopes with 'sizes' and 'morphology' of organisms when classifying living things as microbes. These ideas involved the microscopic examination of physical structure and dimension of cellular organisms, characteristics that Bauman (2007) recommended as the most practical approach for classifying organism. Other laborious ways include;

*"....differential staining characteristics, growth characteristics, microorganisms' interactions with antibodies....nucleic acid analysis, biochemical tests...."*

(Bauman, 2007 p.115)

With 8 students (53.3%) showing little or no understanding on the concept, adopting the 'size' criteria, it can be said that students' understanding on microbial classification was lacking. Using the ant as an example, most students agreed that the ant was not a microbe with the reason being it could be visually observed without the microscope;

*"No, we can still see it with our naked eye without a microscope.... microorganism needs to be observed under the microscope."*

(S1)

*"Because I think it's more than 1 micron....well... ..you don't need a microscope to see an ant."*

(S7)

A dust mite was however classified as a microbe by S15 respectively because she could not see it with her eyes. S15 had no idea on microbial classification when she confirmed that the dust mite was a microbe even after acknowledging that it is a multi-cellular organism. Perhaps she had no knowledge on the fact that microbes were single-celled organism.

S15: *Dust mite.....I can't really see very well, as far as I know. They are microorganism.*

Q: *Dust mites, is it made up of unicellular organism or is it mutilcellular organism, in your opinion?*

S15: *Multicellular.....*

Q: *So, even though its a multicellular organism you still consider it as a microorganism?*

S15: *Yup.*

In both instances, both the ant and dust mite were multicellular organisms, hence they were not microbes. Their naïve interpretation on how organisms were classified as microbes by describing them as small is just knowledge without any understanding. There was an incident where the thinking from S6 seemed to suggest that the microbe and molecules were similar in size. The student had no perception on the relationship between the microbe and molecules and that microbe itself was made up of molecules. Dreyfus and Jungwirth's (1989) found that some of their 16-year-old biology students also had such conceptions about cells. Their survey revealed students' ideas about the cell being smaller than protein and carbohydrate molecules which it was actually made up of.

Presence of rote learning was also detected from the interviews especially from S11 (2005 cohort) where she demonstrated her textbook factual knowledge by going into the 'depth' or 'details' of a microbe. Such manner of studying could prevent students from applying their knowledge for other situations of a different context. The ant example demonstrated S11 knew it was a non microbe but could not substantiate an appropriate explanation for her decision. Instead, she provided the nitty-gritty details about the microbes. Thus, learning about the microbe would be more meaningful if the nature about microbes could be better understood by students if fundamental criteria of it being single cellular and independent functioning were highlighted.

#### **5.5.4 Model on conceptual areas needed in understanding the nature of microbes**

The case of S13 was interesting as it demonstrates the thinking process which S13 adopts in deriving her solution unlike student 11 where facts were probably memorized. Student 13's thinking process was similar to the concept model (Fig. 1) developed from the gathered literature about understanding microbes. S13 revealed that to learn and understand the nature of microbes,

ideas about the living characteristics present in things alive, must first be well understood to differentiate the living and non living things.

Q: *How would you tell me that..... it is a microorganism?*

S13: *..have to see whether it is.. living or not...maybe.... try growing it on a plate... agar plate. After examining it under microscope.. ..Then should be able to tell if it is living or not. If it looks like bacteria ..known bacteria..*

Having the organism plated out on an agar to encourage growth and reproduction would demonstrate its living characteristic and establish it as living. The following step of examining it under the microscope enabled S13 to classify if the organism was of a microbial nature i.e., a single-celled organism and therefore a microbe, or multicellular organism. In this instant S13 did not achieve a sound understanding on microbial classification, as her ability to classify was based on bacteria recognisable to her "*If it looks like bacteria ...known bacteria.*" She applied a similar argument on the pollen. Though she had incorrect fact about pollen initially, she then considered the possibility of it being a microbe after confirming its living status via its living characteristic of reproduction. The way S13 learnt about pollen was similar to the pathway of the concept model for understanding the nature of microbes.

Q: *How about flower pollen. Is it a microbe?*

S13: *No...if I am not mistaken..I don't think pollen is a living thing...pollen..no...I wouldn't consider.*

Q: *.....so you wouldn't consider pollen as a microorganism because it is not living ...*

S13: *Ya.*

Q: *If you have a pollen that is happen to live .?.*

S13: *If it can reproduce, then...it should be classified living already what...then possible as a .micro organisms.*

This approach adopted by S13 outline a possible alternate route for new students to learn about unknown microbes apart from conventional 'diving head on' captured in introductory facts-filled chapters normally found in popular microbiology textbooks by Alcamo (2001) and Bauman (2007) that featured core topics such as;

*"....General Properties of Microorganisms - Origins of*



*Classification; The Five Kingdoms; The Three Domains; Bacterial Taxonomy; Nomenclature; and Size Relationship.”*  
(Alcamo, 2001 p. 53)

*“Cell structure and Function - ....Prokaryotic and Eukaryotic Cells...External Structures of Prokaryotic Cells....Cytoplasm of Prokaryotes.... External Structures of Eukaryotic Cells....Cytoplasm of Eukaryotes....”*  
(Bauman, 2007 p. 55)

These traditional approaches found in recommended general microbiology text books contained introductory core topics or themes recommended by the American Society for Microbiology (ASM). Even the current topics taught at Ngee Ann Polytechnic (NP) seemed to be influenced by the American syllabus with 5 of NP's 7 topics (Table 3) having similarities to theme 1 of the ASM's core concepts (Table 23) (Bishop, 2000).

Ngee Ann's current microbiology syllabus emphasised much on microbial diversity and cell structure and function. What was needed perhaps was teaching students more about concepts associated with living characteristics of organisms. So, ideas concerning living characteristics present in living things could be established first during the early part of the course to allow students to be familiar with scientific meanings on 'living' before dwelling on whether the organism belonged to prokaryotes or eukaryotes. Thus, these topics should focus instead on the concepts of 'living' which at the moment it was taken for granted that all students would know and understand what 'alive' was all about.

Table 23: Core themes and concepts recommended by the American Society for Microbiology (ASM) for an Introductory Microbiology Course\*

<b>Theme 1: Microbial cell biology</b>
Information flow within a cell Regulation of cellular activities Cellular structure and function Growth and division Cell energy metabolism
<b>Theme 2: Microbial genetics</b>
Inheritance of genetic information Causes, consequences and uses of mutations Exchange and acquisition of genetic information
<b>Theme 3: Interactions and impact of microorganisms and humans</b>
Host defence mechanisms Microbial pathogenicity mechanisms Disease transmission Antibodies and chemotherapy Genetic engineering Biotechnology
<b>Theme 4: Interactions and impact of microorganisms in the environment</b>
Environmental pressure for survival Adaptation and natural selection Symbiosis Microbial recycling of resources Microbes transforming environment Harnessing of microbes for productive uses
<b>Theme 5: Integrating thesis</b>
Microbial evolution Microbial diversity

\* Source: Bishop (2000)

Explanations on their understanding of classifying organisms as microbes were scanty with many providing descriptive answers instead. Such descriptions on microbial classification were at most just prescribed knowledge without any understanding and were possible that students may have been learning without proper perception (Deadman and Kelly, 1978). With more than two thirds of students interviewed in 2005 cohort showing little and some understanding (codes Y and Z) on the concept, it can be said that students' understanding on classification of organisms as microbes was lacking at the end of study (Table 20). There was no improvement in conceptual understanding of microbial classification for the 2005 cohort.

Just like the 2005 cohort, majority of the 2007 cohort at pre intervention, used the size factor to classify organisms as microbes showing their lack of understanding. Response from S15 illustrated the poor grasp of the concept;

S15: *...since I can't see the tiny things, so I will need a microscope....so that I can see them.*

Q: *How about if I give you a mite, a kind of insect and you can only see them clearly under a microscope will you consider it as a microbe?.*

S15: *Yes, I would say so....since I can only see it with a microscope.*

The students had no sense on the dimension of microbes even though size was a main consideration when it came to classification. Only S3 (2007 cohort) had a notion as to how large a microbe was. None of the responses at pre intervention thought of the microbe as a singled celled organism. At that stage, only the plankton, a multicellular organism was mentioned. This reflected the extent of their understanding where knowing the basis of classifying organisms into microbes is concerned. Being too reliant on the fact that organism must be very small posed a danger of a belief that all specimens observed under the microscope would be a living thing. That was observed in S6 (2007 cohort) during pre intervention where the student admitted she would not be certain if the speck of dust was actually dust itself. This could be solved if S6 had assessed the living characteristic of the 'dust' for its cellular structures and movement to ascertain if it living or non living as shown in Fig 1. Once this was done, S6 could then decide if further classification into microbes was warranted.

#### **5.5.5 Movement of microbes**

Other important factors in microbial classification were the ideas about movement and response in 'living characteristic' category. Reasons from 2007 cohort S1, S5 and S10 were about the organism's need to search for food for its survival. The response below by S5 illustrated his rationale for their idea on movement;

*"A microbe cannot stay still. It has to move in search of food. It's an important characteristic of a living organism."* (S5)

The students' idea of microbe responding to food as a living characteristic illustrated their possession of 'common knowledge' which Dreyfus and Jungwirth (1988) considered as acceptable knowledge used suitably and correctly by majority of the students. There is a misconception that microbes do not contain chlorophyll at all. Initially, S4 derived such idea from inaccurate scientific information that chlorophyll containing cells would eventually become a plant;

S4: *As long as it is not a plant cell and that's small, it can be called a microbe. If it is similar to animal cells, then it s OK.*

Q: *How so?*

S4: *Animal cells do not contain chlorophyll, plant cells do..so that's the difference.*

Q: *So if a cell do not contain chlorophyll, it is then classified a microbe?*

S4: *Yes.*

Q: *And..if it contains chlorophyll?*

S4: *It will not be a microbe. The plant cell will also grow up to become a tree and plant, so it is big. It can be seen. Microbes will not grow to something so large that it can be seen.*

Such incorrect scientific information leading to misconception was shown to prevent understanding on classification of microbes.

Four months later, at post intervention of 2007 cohort, 'size' was still one of the dominant categories of ideas for microbial classification. At that stage, such responses with the lowest category of understanding were reduced to 5 students compared to 12 at pre intervention (Table 20). While the code Z students still rely on the microscope to classify organisms into microbes, generally they were able to classify ant, pollen, yeast and skin cells accordingly. There was an increase of 1 student to a total of 4 students at post intervention with some understanding on classification of microbes (code Y). They had ideas in the 'living characteristics' category which were based on its ability to respond and reproduce. S4 used the characteristics of reproduction and response to illustrate his thinking that microbe is a dynamic living thing.

One fifth of students considered movement as ability to respond when they were asked to assess a rock if it was alive (Brumby 1982). However, movement in the scientific sense may not be acceptable as seen from Piaget's (1929) work with 9-year-old children where they believed things that moved (e.g. moving cars) were actually alive (Driver *et. al.*, 1994). Even older students (18-20 years) had the idea that fire was alive because it moved (Brumby, 1982). S4 established the organism as living but his understanding about the nature of microbes was incomplete due to his failure to classify organism into microbe or non microbe according to the concept model (Fig. 1).

#### **5.5.6 Presence of DNA in microbe**

Post intervention of cohort 2007 students S1, S10 and S11 in code Y answered that DNA or nucleic acids should be present in the organism if it was to be classified as a microbe. They reasoned it needed to transfer the characteristics of the parent cell to future generations during cell division. The following was the reasoning provided by S11 when asked to explain the relevance of DNA.

*"Q: Can you explain why or the reasons behind your action of classifying them?"*

*S11: Micro of course, as you know it means small and using the name organism will also means living thing, therefore must consist of have DNA*

*Q: Why is DNA necessary in living thing?*

*S11: It's the material necessary for all living things to pass on to the next generation like during its replication to give more of it's .....babies to have same features as parents. Also, non living things don't have DNA"*

Just as S4 used characteristics of reproduction and response to establish something as a living organism, S11 applied the presence of DNA in microbe as a living characteristic. Application of molecular technology was used to develop further detailed classifications and characteristics of other bacterial organisms in particular that of archaebacteria (Woese *et al.*, 1978). Venville and Donovan (2007) when using gene and DNA to study the concept of inheritance of year 2

biology students found that they were able to distinguish between living and nonliving things. Through the use of the concept model to know more about the nature of microbe, S11's understanding of microbial classification was hampered due to her failure in distinguishing independent single-celled organism from the rest during the task of microbial classification. These students in the 'living characteristics' category would have a proper conceptual understanding of microbial classification if they had facts and knowledge on the microbe's morphology and its conduct of independent biological processes.

For 2007 cohort, the understanding on classification of microbes improved after 4 months of formal study. Ideas of responses in categories of 'morphology and independence', most relevant towards an understanding on classification of microbes were found in 6 students (code X) while no students with that category of understanding were registered at pre intervention. Ideas were mainly about students thinking of cells capable of self growth and reproduction. In the 'morphology / independence' category, S7 regarded 'living entity' a criterion for his idea on microbial classification. He established a biochemical criterion using the presence of DNA to discriminate between living and non living.

- Q: *How would you classify a "thing" or consider it as a microorganism?*  
S7: *A thing can't grow, replicates. It has no DNA, doesn't require food  
A microorganism needs all these. It is also small and very tiny.*

Once having determined the 'thing' as living, S7 then classified it by explaining the significance of 'living entity' with its reference to a single-celled organism that provided the cell its self sustaining properties unlike the individual skin cells forming a tissue. He supported his argument using the yeast cell;

*"Yeast, as an example....unicellular and it a living entity by itself whereas things like skin cell also unicellular, but then it doesn't consist of a living entity by itself as it is part of a larger multi-cellular organism....."*  
(S7)

It appeared that the student's thinking process needed in understanding the nature of microbes was along the pathway on conceptual areas shown in the

concept model. Difficulties encountered along the pathway may diminish students' efforts in knowing the nature of microbes if both concepts, the living characteristics and classification of microbes were not properly understood.

## **5.6 Living Characteristics of Virus**

### **5.6.1 Viruses were harmful**

The students interviewed had vague impressions about the nature of virus. Table 21 showed that all 15 students had poor understanding on the living characteristics of virus at the beginning of semester for 2007 cohort. The virus was regarded as living and pathogenic. Students associated the thinking that the viral organism must be alive in order to inflict its toxicity and harmful outcome on people;

S13 offered more details on the 'infection' when he commented on the virus attaching itself to the cells using their suckers *"..to begin attacking the cells after landing on the surface"*. S2 commented that, *"It (virus) lands on the cells and then eats up the cells"*. Such dramatic illustration of virus latching onto the cells with its deadly intentions to destroy them summed up their thinking that virus was basically an active destructive organism in which its influence could only be realised if it was alive. They also did not realise that virus were acellular and needed to be in the presence of a host for its infection stage.

Looking at the students' reasoning process, it was likely that layman's knowledge through the interpretation of events on SARS and bird flu which sometimes were influenced by the media, cannot be ignored. One recent UNICEF news article reported on the killer diseases of microbes;

*"An estimated 5,000 children die daily from diarrhoea, but half of those deaths could be prevented if they washed their hands with soap before meals and after going to the toilet....."*

(ST, 2008 p. A22)

Such report above was bound to influence students' idea about microbes especially on its pathogenicity as its living characteristics. This was especially so when 'new students do not have adequate knowledge to help them make an informed judgment. Thus, when learning about the virus with the hope of knowing more about its nature, current scientific knowledge together with students' personal experience could be used to explain their reasoning or thinking behind their idea.

Taking into account of their personal experience was important as it allowed any preconceive idea to be corrected. In this instance, This was the case where S12 had no knowledge about a biological virus in which his idea of virus was IT linked. Being able to appreciate student's educational background who has not done any biological studies, the computer virus was the only viral-related topic he has been exposed to. One would expect him to experience difficulties in understanding about the organism. S12 will be discussed in greater detail under the section 'Case Studies'. (see section 5.8)

### **5.6.2 Misconceptions and lack of scientific knowledge**

Respiration was a process students had a problem grappling with. S7 and S9 thought oxygen was needed for virus to live but could not offer an explanation on its physiological functions. They reasoned that since the viruses occurred in air, they were constantly being exposed to the air so 'breathing' by absorption of air into its cell was most sensible. Similar idea was also obtained from Simonneaux (2000) where virus 'breath' in oxygen through the membrane and cytoplasm. It was most likely that they both resorted to using their 'common sense' showing their inadequate understanding on viral living characteristics. Haslam and Treagust (1987) noted that their secondary students had a misconception that respiration was breathing. In this research 'breathing' was not an act of inhaling but probably was just a simple term applied by them to describe surface absorption. None of the students realised or could associate it with the requirement for oxygen for the generation of energy from food indicating



students' idea about the physiological function of oxygen was also missing. It would come to no surprise that younger students would also have problem in understanding the respiration concept. Such complex physiological process proved too much for Leach's 11-year-old students where they too had no idea on the role of oxygen except for the fact that they knew it kept the animal alive (Leach *et. al.*, 1992). Apart from the use of 'breath' to refer or mention the respiration process in bacteria, so far the students' ideas about respiration were different to that of the inhale–exhale phenomena recorded by Arnaudin and Mintzes (1985).

Students also had the misconception that virus replicated by binary fission like the bacteria. They thought that the persistent existence of microbe was due to its ability to divide rapidly which a student associated the rate of reproduction with size. Here, S3 reckoned that the virus production was *"...faster than the production of bacteria but slower than the speed of light. Because what I think is, things that are smaller reproduce faster."*

At post intervention, students' expression of ideas of viral living characteristics has been occasionally anthropomorphic. They mentioned that during nutrition when virus feed, it 'absorbed' and 'sucked out' cellular materials and when it reproduced, 'spare parts' or cellular components from the cell were utilised. Some of the ideas which the students had which lead to poor understanding in living characteristics of virus (code Z) were due to lack of accuracy in their scientific knowledge. Description of virus having circular or rod shape coupled with presence of organelles, contributed to their thinking that virus and bacteria were related. Such observation was also reported by Simonneaux (2000) where students regarded viruses to be identical to bacteria. Other ideas linking the difficulty in learning about the virus in particular its living characteristics concerned the students remembering the symmetrical shape or image of virus rather than knowing the reasons behind features of living entity.

Adamo (1996) applied the viral icosahedron model to assist students to learn the subject but found it only useful for understanding its structural concepts.

### 5.6.3 Virus were dependent organisms

After 4 months of study, there was an improvement on understanding the living characteristics of virus. Five (33.3%) students were in the highest category of understanding (code X) while 4 (26.7%) students had some understanding (code Y) on the concept. There only 6 (40.0%) students with little understanding on viral living characteristics compared to 15 students 4 months earlier. No students were found to have ideas associating the virus being a pathogenic agent where it was a main idea of students at pre intervention.

Under code X, the students understood that to generate more viral particles which is a trait of living, they knew host cells had to be present. S4 and S8 shared similar views about the virus being an inert lifeless cell. According to S4, viruses were not living, when *"They are outside, but when inside the cell, it is then. ...able to reproduce"*. S8 said *"They need to be in other organisms so that it can reproduce"* hence, virus was unable to reproduce independently; S13 confirmed such views that replication of viral DNA can only be done if it *"Reproduce in other cells"* since it needs *"....other cells' DNA to carry out reproduction"*.

Students placed under category Y developed some understanding on the 'living' virus by realising that virus contained either DNA or RNA, a property unique to virus only. However, they omitted the necessity of the virus to be in another cell (host) and probably thought that DNA inside the capsule was adequate for it to replicate itself. Students tend to believe that DNA alone was sufficient to make the virus come alive since the genetic materials were fundamental for replication or reproduction;

*"In my opinion viruses are living organisms. Even though they do not have cells they still have genes that allows them to reproduce and evolve."*  
(S14)

This suggested they understood the importance on the presence of genes in living things.

## **5.7 Ideas on Living Characteristics of Bacteria**

### **5.7.1 Bacteria as pathogenic 'animal'**

At pre intervention for 2007 cohort, students' main category of ideas on living characteristics of bacteria were about bacterial 'properties' and 'pathogenic' effects. Table 21 showed the overall categories of understanding of combined students' responses where 26.7% of students had little understandings on the living characteristics of bacteria. According to S10, the bacterial main living characteristic was its potential to reproduce, destroy and damage body cells. He said that, *".....the bacteria reproduce and just like the virus make us sick. It also destroys things..... When we infected with bacteria, think our body also gets destroyed.....like a decay with cells getting damaged."* Ideas on characteristics like movement and nutrition were associated with the pathogenicity of bacteria. S3 however, thought that the bacteria moved by crawling along the walls of the intestine like some kind of worm. The description of bacteria floating about in the body since the organism did not have any legs was documented from S2. With regard to pathogenicity, S2 reasoned the extent of people getting sick to its spread or distribution of bacteria through the works of the blood stream.

Similar reasoning was also found in S15 where the student associated bacterial infection with its ability to move to the site of infection by sliding. Once, at the site, bacteria appeared to be feeding on the cells by an animalistic manner of 'sucking' the cellular materials. S15 attempted to use 'easy words' to explain his idea of cell decomposition or decay caused by the bacterial feeding action. The danger in using such 'easy words' when describing scientific processes was that it may lead to other misunderstandings or misinterpretations. In this case, the 'sucking' which come across as a form of feeding may lead to an idea of ingestion taking place instead of bacterial infection. It may also hamper the understanding on bacterial nutrition at a later stage. Such descriptions of feeding

and movement which were associated with daily animalistic habits, gave the students an impression of the nature of an 'animal' at work in their body. Even Carl Gustav Ehrenberg in his 19th century observations with improved microscopy, was convinced that his drawings of bacteria and protozoa actually reflected the characteristics of miniature organisms or 'animals' complete with stomach (Summers, 2000).

S12 used the judgment that dead things do not cause damage let alone actively attacking human cells. Point of infection was also mentioned at the interview where the student said that bacteria could enter the human body "*...through the nose, .. skin, ...the mouth*". During the interview, discussion of ideas about the self sustaining trait of the independent single cell bacterium was absent.

#### **5.7.2 Binary fission of bacteria**

Twenty percent of the students in code Y had the idea of cell replicating through binary fission, one of the students' ideas on living characteristics of bacteria. Do they understand the significance of the bacteria reproducing by doubling its numbers? At pre intervention, Students did not realise that their description of a single cell bacteria replicating itself independently, without the involvement of another cells, was a key living characteristic that was different to other cellular organisms. Their understanding about such characteristic only centered on the outcome of the doubling effect and did not appear to recognise the reason behind the replication process. Still, they linked the rapid spread of bacterial disease to the reproductive capability of the organism that contributed to the increase in bacterial population.

Only 3 of the 15 students appeared to know the function of chromosome and were aware on the continuance of life through the transfer of genetic materials to daughter cells during cell division. The rest could not identify its relevance and 1 student thought chromosome would only duplicate during

meiosis. Elsewhere 9<sup>th</sup> grade biology students were noted for their knowledge on the principles of cell replication but did not realise that hereditary information (parents' DNA) was being transferred to new cells at the same time (Dreyfus and Jungwirth, 1988). That was not surprising considering the fact that understanding the idea of inheritance was indeed a complex concept for students to grasp (Wood-Robinson, 1994; Lewis *et al.*, 1997). Difficulties in understanding genetic concepts were not only confined to secondary students. Even older university students had difficulties in studying this biological science concept. In Lenton and Turner's (1999) work on conceptual understanding of genes and evolution involving 60 student-teachers, many did not possess adequate knowledge.

### 5.7.3 Use of anthropomorphic terms

Usage of anthropomorphic terms was commonly used by students to describe their thinking on concepts of life (Brumby, 1982) and microbes (Simonneaux, 2000). Students' vague ideas on nutrition and respiration associated them with bacterial living characteristics were filled with anthropomorphic terms. With regard to nutrition, S6 said *"It (bacteria) absorbs nutrients by soaking it up of nutrients using enzymatic reaction."* The 'soaking' of nutrients represented the absorption mechanism which to student like S8 was how he perceived the bacteria to *"consume food"* leading to an *"....increase in size"*. Response from S4 was scientifically incorrect when he attempted to explain bacterial nutrition in the stomach. His view was that bacteria 'fed' by absorbing the food into the cell before digesting them. The reasoning was akin to that of a human feeding whereby food was ingested into the body before the digestion process. Such reasoning using the human example would lead to misunderstanding of bacterial nutrition. Ingestion of food was also found on S11's argument on digestion process. The student focused on the physical mechanism of 'engulfing' the food during nutrition and this may cause misinterpretation of the digestion process and hinder their understandings. Proper use of scientific term and explanation on the enzymatic reactions and absorption of nutrients would avoid such misunderstanding.

It must be acknowledged at this point absorption of organic materials like protein, carbohydrates and lipids did occur in heterotrophic microbes where complex molecules were broken down and resynthesized to form other bacterial components. This meant that bacteria could for instance ingest lipid and break it down to fatty acids in the cytoplasm (intracellular digestion) for subsequent synthesising of phospholipids necessary for building up the cell membrane. During the interview, none of the students provide responses leading to discussion about intracellular digestion. Further inaccuracies were found in code Y category when S9 tried to explain respiration to link it as a living characteristic of bacteria. In this instant, the osmotic process (for controlling water movement in cells) was used in his attempt to explain the transport of oxygen in bacteria. S9 also failed to understand that respiration supplied energy essential for bacterial growth and reproduction. When asked why was oxygen required, he responded, *"..to let the bacteria to live"*.

After 4 months of study, there was an improvement on understanding the living characteristics of bacteria. Four (26.7%) students were in the highest category of understanding (code X) while 11 (73.3%) students had some understanding (code Y) on the concept. There were no students with little understanding on bacterial living characteristics compared to 4 students in that category earlier in the semester of 2007 cohort. Similar to the case of virus, there were no students still holding on to ideas associating the bacteria being a pathogenic agent. Responses from at least 10 students mentioned the reproduction process as their idea on living characteristics of bacteria. Most students knew how the binary fission functions.

#### **5.7.4 Presence of DNA in bacteria**

Ideas on the bacterial living characteristics at post intervention shifted towards the presence of DNA in the cell. That was due to the influence of the chromosome during cell division which enables the daughter cells to contain the

same genome as the parent. Students did encounter difficulties in describing the function of chromosome and its relevance during cell replication. Few students however, had some understanding on the need to have the chromosome replicated apart from the division of the cell itself in order to enable the transfer of genetic information from parent cells to daughter cells upon cell division thus maintaining the characteristics of the previous cell. This was referred to as continuity where *"The origin of every cell is a previous cell"* (Dreyfus and Jungwirth, 1989, p. 54). Such issues concerning inheritance and genetics were commonly acknowledged as difficult topics to comprehend by 16-year-old students (Lewis *et al.*, 2000)

High degree of self sustainability in bacteria was illustrated by S6 when he said that its functional activities perform under such circumstances were 'normal';

*"They are able to respire, and do all the normal things like reproduce, feeding...quite independently....you see that's the way of sustenance."*  
(S6)

The term 'nucleus' seem to cause some doubt about the students understanding concerning the bacteria. In explaining the events of cell replication involving the chromosome, 3 students (S6, S7 and S8) mentioned that the chromosome was enclosed within the nucleus of the bacteria. Such description was scientifically incorrect as bacteria do not have nucleus and absence of such structure was a special feature for the bacteria. Perhaps it was easier to visualise and explain the doubling and division of DNA within a confine border of the nucleus during cell division. Such complexity encountered during the discussion on living characteristics of bacteria suggested that knowledge alone was not adequate to learn about the organism if the knowledge could not be applied appropriately.

#### **5.7.5 Energy requirement**

On the issue of nutrition, only 3 students had the idea that food was needed for the living bacteria to move and reproduce; and recognised it as a

characteristic of living (Table 19). They probably thought that food was needed because bacteria was a living cell just as young children were found to have associated energy with living things (Solomon, 1983; Bliss and Ogborn, 1985). However, they did not fully understand that the food provided the nutrients necessary for generation and utilisation of energy for biological activities such as those of movement and reproduction. Thus, they were both categorised in code Y with some understanding on the characteristics of bacteria. Solomon's children knew that energy was needed for movement of humans. To NP's students, they related nutrition to a simple notion of how humans needed to feed or eat in order to live and move about. There was no discussion about purpose or storage of energy in bacteria.



## 5.8 Case Studies: Development of Ideas of 6 Students

Summary detailing the 'picture' on the development of ideas as the 6 students began their microbiology course at the beginning (pre intervention) and end (post intervention) of the semester was tabulated in Tables 24 and 25.

## 5.9 Terminology

Table 24 showed the individual changes between the categories of understanding for responses to terminology. The term 'microbiology' was the easiest to understand while 'microbe' proved to be the most difficult among the 4 terms. At pre intervention, responses on the term 'microbiology' centre around the study of small living things. Response from S2 typically provided a general explanation that 'microbiology' was about studying *"Small living organisms that are so small that you cannot see with naked eye."* S3 was more specific in his idea on the topic;

*"Biology is the study of living organisms. ...micro is the study of things on a micro scale. something times 10 to the power minus 6."*  
(S3)

He was probably referring to the measurement of micron ( $10^{-6}$  m) but was not certain on its meaning behind it or comprehended the dimension of the scale. Only S15 moved up from code Y to X at post intervention as she realised that it was about studying living things of cellular nature. The rest maintain their adequate understanding on 'microbiology' throughout their study.

At pre intervention, students at code Y realised that 'bacterial colony' was an accumulation of microbial cells due to reproduction. At that early stage in the semester, there was no evidence to suggest their idea of cell accumulation consist of only one type. Subjects of Maxted (1984) regarded the various sizes of colony as a sign of microbial growth but did not know that the colony was built upon an accumulation of identical cells. Students S1, S12 and S15 from code Z admitted that they do not know anything about the terminology and attempted to guess. Speculations included the term being associated with people colony (S15)

and accumulation of millions of cells linking his argument to “...cells being together...becoming a group...” (S12). S1 had no idea what the term ‘bacterial colony’ meant. At post intervention, these 3 students together with S3 (code Y) moved up to the highest category of understanding (code X) where they accurately explained their idea of new genetically identical cells that were derived from a single cell about ‘bacterial colony’. There were no changes in development in the ideas on ‘bacterial colony’ from S2 and S10 who maintained their category understanding at code Y.

None of the 6 students knew the purpose of antibiotic at the start of their course. At the lowest category of understanding, both S10 and S12 had never heard of the term. The rest had incorrect knowledge that it was some kind of a drug against flu, cold or virus. Confusion over the function of antibiotics was also documented by Prout (1985) where 21% of his 15-year-old students do not know what antibiotics were. Fewer than 9% of the 54 students interviewed knew that the common cold was caused by virus. So it was not surprising to note that all 6 students at Ngee Ann initially had no knowledge on antibiotics. At post intervention, all students (except S10) placed the emphasis of bacteria in their explanations as the target for antibiotics to destroy. That suggested 5 students at code X had a good understanding on ‘antibiotics’ while to S10, it was some kind of a remedy for harmful organisms. Simonneaux (2000) noted that her students were able to relate better to the concept of immunology after knowing what ‘antibiotic’ meant.

For the term ‘microbe’, no students could understand the term even after 4 months of studying microbiology. Three students’ understanding on ‘microbe’ worsened and moved down from Y to Z at post intervention. Their idea of microbe was still based on the need of a microscope to view them. Only students S1 and S2 managed to gain some understanding (code Y) on what the microbe is about. No students attained the proper description and understanding of the term microbe according to the established criteria. The main ideas on microbe

seemed to involve the physical sizes and viewing of organisms with microscopes. All 6 students failed to understand and appreciate that microbes were single cellular organisms capable of functioning independently. The term 'microbe' proved to be the most difficult scientific terminology for students to understand amongst the 4 selected terms.

Table 25 showed the individual changes between the categories of understanding for responses to microbial growth, microbial classification; and living characteristics of virus and bacteria. At least 4 students had little understanding (code Z) on each of the 4 conceptual areas shown in Table 25 at the beginning of semester for 2007 cohort.

### 5.10 Ideas on Microbial Growth

At pre intervention, all 6 students had none or little understanding on 'growth' in microbes (code Z). S1 did not realise that living organisms do live in stream water. When probed further by hinting on the possible growth of living things in the water, S1 said the water will probably have "*some nutrients...chemicals like some ions.*" And she maintained that there would not be anything else in the water "*...besides the fish*". Her 'fish' remarks reaffirmed her thinking that there were no other living things growing in the water apart from the aquatic creatures. Thus, at pre intervention, S1 has no idea concerning the growth of microbes.

S10 and S15 knew about the presence of plankton and algae, but there was no mention of the growth and reproduction of the organisms. Instead, their ideas were about the decomposition and 'cannibalism' of organisms due to nutrient competition. S10 contributed the death of plankton to the lack of food in the test tubes leading to the plankton competing for the limited food;

*"The plankton will compete for food with each other... don't have enough ...the remainder plankton dies and so decompose."*  
(S10)

*"Possibly they died and decompose...so it'll be smelly..... Not*

*enough food..so they died and rot”.*  
(S15)

Students' lack of knowledge that microbes were capable of growing rapidly through its cell replication process also contributed towards their poor understanding. Here, S3 had suspected on the existence of the microbial organisms but did not think that the stream water would be a breeding medium for microbes to multiply within 3 days. He had no idea that his proposed 'strange' scent from the water was an indication of metabolic processes like respiration or fermentation contributed by the vast population of microbes. The fact that nothing was introduced into the test tube made it more compelling for the students to think or expect nothing growing during the 3 days.

At post intervention, only S2 and S12 had gained some idea on microbial growth as a living characteristic and able to understand something about the microbes itself (code Y). S2 knew that microbes could grow in the test tube but still did not fully realise the rapid proliferation and short reproductive cycle of microbes that manifest itself into layers of jelly-like material within just 3 days. S2 could not explain the occurrence of such substance and mentioned, *“Not sure, it just grew.”* S12 observed colonies floating at the surface and those organisms were aerobic in nature since more oxygen was available at the surface. He also explained that colonies seen at the bottom of the tube were anaerobic where lesser oxygen content existed. These anaerobes would survive and reproduce at the bottom of the test tube causing the cloudiness of the test tube solution. The student's justification was based on their thinking of microbial's response to different levels of oxygen, indicating metabolic diversity towards oxygen which exist in the microbes. Elsewhere, agar colony sizes were used by students as an indication on their idea of bacterial growth (Maxted, 1984).

In category code Z for little understanding, S3, S10 and S15 expected microbes to be present but did not realise much of the tremendous ability of the organism to multiply and divide rapidly in such a 'short period' of 3 days. Their

lack of appreciation and scientific knowledge on the rapid replication of the microbial cell, a living characteristic of microbes, remained unchanged at post intervention. Such misconception can be seen in the views of S15 where she claimed that *“Yes, there is algae.....don’t think 3 days is enough to see it (algae) growing yet.”* There was no change in the development of S1’s understanding since she still placed greater importance on having adequate nutrients to maintain suitable growing environment for the organisms without recognising the production of new cells derived from rapid cell division.

### 5.11 Ideas on Classification of Microbes

At pre intervention, 4 students had little understanding on classification of microbes. None of the students regarded microbe as an independent singled celled organism. Instead, they classified organisms as microbes if they were too small to be seen with their naked eyes, requiring the use of microscope. Responses from S2 and S15 typifies their thinking on ‘size’ and points to the fact that living organisms (both unicellular and multi-cellular) were microbes if a microscope was used to view them since they were too small to be visually observed. S3 showed that he based his decision to classify things as microbe according to its physical dimension, resorting to the use of a microscope. Students’ woes in microbial classification were further contributed by their limited scientific knowledge. For example, when asked whether pollen with the size of a micron, was a microbe, S3 replied;

*“Yes ...cause I know that the pollen, ... can actually divide. Then the pollen can actually, be used for you know... fertilization. Yes, the pollen can be a microorganism. “*  
(S3)

S3 failed to realise that pollen would only undergo cell division but only after fertilisation (with another cell) unlike microbes where they were capable of reproducing on its own via cell division without the involvement of another cell. His understanding on microbial classification was limited at this stage. S12’s idea of a microbe was a simple ‘transparent’ feature with movement of fluid in the ‘plain’ shrimp-like organism. The fluid movement was probably the cell’s

cytoplasm. Though there was no mention that the shrimp-like organism was single-celled, for a student who had not studied biology before, his portrayal of microbes quite accurately resembled organisms seen under a microscope. He recalled his experience having seen it on TV. According to White and Gunstone (1992), such memory or 'episode' do contribute towards S12's understanding of microbes though the quality of understanding were also dependent on other dimension such as facts, images (mental representations of sensory perceptions) and intellectual skills. However, such experience failed to assist him to classify skin cells, ant and yeast appropriately at pre intervention.

Ideas about movement and response using the flagella were important living characteristic when classifying microbes. S1 and S10 rationalised on the organism's independence in searching for food for its survival. They demonstrated some understanding on classification of microbes (code Y). Their idea of microbe responding to food as a living characteristic illustrated their possession of 'common sense' which Dreyfus and Jungwirth (1988) considered as 'common knowledge' used by the majority of their students.

Four months later, there were no changes in categories of understanding on responses to microbial classification for S1 and S10 though their ideas differ from pre intervention. S1 and S10 in code Y answered that DNA or nucleic acids should be present in the organism if it was classified as a microbe. They explained the necessity of maintaining the characteristics of the previous cell by transferring the genetic material to future generations during cell division. Only S2 remained at code Z with the lowest level of understanding on this concept. He still maintained his idea under the 'size' category.

He derived his 'size' idea of microbial classification by analysing the terminology itself by breaking it up into prefix and suffix and then combining the meanings of the sub terms.

- Q: *Can you explain why or the reasons behind your action of classifying them?*
- S2: *Micro means extremely small. So, organisms that are living but extremely tiny and can only be seen under a microscope fits the word 'Microorganisms'.*

Such method of making sense of an unknown terminology by analysing it part-by-part to derive its meaning was also conducted by teenage French students when they had no clue what 'pathogenic agent' was (Simonneaux, 2000). Understanding on classification of microbes improved for S3, S12 and S15 when they moved up to code X from Z. Their ideas relate to category of 'independence'. Ideas were mainly about students thinking of microbial cells capable of self growth and function without involving other cells. S3 by now realised that pollen and skin cells were dependent on other cells for them to function and hence classify them as non microbes. While S3, S12 and S15 still maintained their earlier ideas of organism being alive and needing a microscope to view it, S12 now had additional arguments that a 'thing' should be considered a microorganism if, *".....it is capable of self growth and reproduction."* S15 also did recognise that such independent ability to reproduce was not present in the pollen which she considered it as one of the gamete needed for fertilisation. She was able to explain that skin cells were part of a multi-cellular tissue making a skin cell unable to function on its own.

## **5.12 Ideas on Living Characteristics of Virus**

### **5.12.1 Linking pathogenicity to nutrition and reproduction**

All the students had little understanding on the living characteristics of virus at beginning of their study (Table 25). At that stage, most of their ideas (S1, S2, S10 and S15) were about the pathogenic effects the virus had on people (Simonneaux, 2000). They all thought of virus as a living organism as they adopted the thinking that dead things were not capable of causing harm to people. Such views could be seen from S1 and S10;

*"Its mean that its poisonous...its alive. It must be. No way it'll make people sick if its dead."* (S1)

*"Viruses are causing so much diseases and it easily spread. .... Diseases like the bird flu, last time we had SARS.. ..Yes, If it's dead then its not active...so..when alive the virus can do its damage to the people and make them sick and also spread the disease by reproduction. If it's dead then cannot reproduce. That will cut out the infection. How nice to have dead virus, then it can't make people sick."* (S10)

Students' views on pathogenicity of virus could perhaps be linked to nutrition and reproduction which according to Brumby (1982) are characteristics of living things. During the interview, S1 explained and demonstrated how a virus fed by wrapping around its prey. The feeding was a necessary attribute for the virus to live;

*(demonstrating his arms wrapping around an imaginative object).  
"...sort of squeezing the enemy. Gets dissolve and absorbed into the virus."*

In the case of reproduction, S1 later described that perhaps the;

*"baby virus just comes out from female viruses... It grows from inside the virus then comes out from the surface of the virus... the virus gives birth like an animal except they come out from the body all over....like the "the Gremlin movie".*

Such birth spurts of 'baby virus' from the 'female virus' do indicate the speed in which the virus spread its harmful effect on the host. It can be seen that S1 possibly perceived her ideas of 'live' virus by associating its pathogenicity with the concepts of nutrition and reproduction.

### **5.12.2 Inaccurate scientific knowledge**

Misconception that a living virus caused sickness posed a possible hindrance on students' understanding on the virus and learning of microbiology. They did not have the knowledge that virus were acellular, appeared 'dead' and thus not biologically active when located outside their host cell (Alcamo, 2001; Madigan *et al.*, 2003). It became alive and caused disease only in the presence of a host cell. Students also did not realise that the virus' ability to reproduce and function was highly dependent on the host cell which was vastly different to the



independent nature found in bacteria. Hence, poor scientific knowledge on the characteristics of virus added further confusion to the learning.

Such poor knowledge was recorded from S3 and S12 (code Z) where S3 described viral reproduction of a single cell divides into 2 and sharing the same chromosome number. This process occurred instead in bacteria and not in virus. S12 thought the virus being discussed was the computer virus and often had to be guided back to the interview proper. He could not comprehend the thought of 'microbial' virus behaving like a living organism where reproduction occurred inside the host cell. Without any knowledge to help him understand something he had no idea on, he admitted having to rely on his 'instinct' as a last resort.

Q: .... what makes you think they are living, if you see it under a microscope?

S12: See if it can move around or something.

Q: So you expect movement, to say that a particular virus is living?

S12: I don't think so. Cause I don't think virus looks like a living thing.

Q: What's your reason for saying that virus is not living?

S12: Cause...instinct.

Q: Instinct. ... ..if I were to ask you what do you think of virus, what's the first thing that comes into your mind?

S12: Computer virus?

Q: .... Do you know how a virus reproduces?

S12: Not sure.

Understanding this concept of the virus proved to be difficult for S3, S12 and S15. Although ideas differed at post intervention, their category of understanding remained unchanged at code Z. S12 appeared to think that virus contained cellular structures such as organelles and flagella which otherwise were commonly found in bacteria. His limited knowledge of the virus contributed to the poor conceptual understanding of living characteristics in virus. The close resemblance between the virus and bacteria was also reported by Simonneaux (2000) where some of her students thought the 2 organisms were identical and occasionally use the terms interchangeably.

As observed in S1 at pre intervention where idea of pathogenicity was linked to nutrition and reproduction, similar thinking was also recorded for S3 and S15 at post intervention. Although, the nutrients were possibly being used to supply energy required for the reproduction process, no explanation was provided with regard to this phenomena. Hence, it was unlikely that S3 understood the significance of the association between nutrient absorption with reproduction. In addition, S15's poor knowledge about the virus morphology like claiming it to have cell wall and able to be seen under a microscope, further contributed towards the poor understanding of the viral living characteristics by influencing his ideas about nutrition and reproduction. For example with regard to the cell wall, after the initial disintegration of the cell wall, S15 alleged that *".....they .....fed on a cell, ..... use the 'spare parts' to make new viruses."* Clarification with S15 after the interview showed that 'spare parts' meant the glucose, generated from the degradation of cell wall. The glucose was probably meant to supply energy for the reproduction of new viruses.

### **5.12.3 Virus requires a host cell to function**

At post intervention, S2's level of understanding improved by one level to code Y. His opinion was that genetic materials allowed virus to reproduce and evolve making it adaptable to exist in any environment. S2 did not realise that the existence of genes alone does not tantamount to its reproductive capability or its pathogenic effect. For these 2 phenomena to occur, the virus must be located in the host cell and thereafter relying totally on the host cell's metabolic activity.

S1 and S10 had the greatest improvement in understanding the living characteristic of virus, progressing from code Z to X after 4 months of studying microbiology. They understood that to create more viral particles which are a trait of living, they knew host cells had to be present which without it renders the virus being an inert lifeless cell. According to S1, the viruses *"infect hosts and use the host's body system to multiply."* Comparable arguments were also given by S10 where the student explained the function of the host cell in allowing the virus to

*“...inject their nucleic acids into the host cell for it to begin replication process”.* By being dependent on host cells, she aptly puts it that virus *“...are more like parasites...”*

## **5.13 Ideas on Living Characteristics of Bacteria**

### **5.13.1 Linking pathogenicity to nutrition**

Similar to the responses on virus, 4 students (S2, S10, S12 and S15) with ideas about the harmful effects the bacteria had on people, had little understanding on the living characteristics of bacteria (code Z) at beginning of their study. All the students did not know that bacteria could replicate itself independently, without involving other cells - a key living characteristic of bacteria.

S2's idea of bacteria's living characteristic was pinned on the microbes' ability as a pathogen to human using the flow of the blood stream. His responses about 'living harmful bacteria' were contributed partly from past experience of him or his family members being ill from bacterial infection. S10 associated the ability of bacteria to increase in bacterial numbers and only living bacteria were harmful. Such characteristic of inflicting damage or decay onto other cells were synonymous to that of virus;

*“..the bacteria reproduce and just like the virus makes us sick. It also destroys things....when we infected with bacteria, think our body also gets destroyed....like a decay with cells getting damaged.”* (S10)

There is a possible association between bacterial infection and bacterial nutrition. According to S15, digestion which was integral to the infection process, was conducted inside the cell after the materials were 'suck' or diffuse into the bacteria. In fact, digestion normally occurred on the external of the bacteria and the soluble digested nutrients were then absorbed by the bacteria. Incidences of intracellular digestion were also mentioned by S3, S10 and S12 where bacteria initially engulfed the food in a phagocytotic manner. S3's idea of the bacteria's nutritional requirements of it getting its food by engulfing or 'grabbing' other

smaller organisms such as the virus, did not change throughout the course of study. Though his conception of microbes obtaining nutrients by means of a physical mechanism surrounding its 'food' did contribute some understanding toward the living characteristic of bacteria, such understanding did not improve and remained unchanged at the end of the microbiology course. Compared to pre intervention where anthropomorphic terms were used to describe the idea of nutrition i.e., food 'grabbed' and digested internally, S12 could now explain digestion using enzymatic action on starch. At post intervention, his notion of digestion now occurs outside the bacteria and followed by absorption of smaller sized 'food' like glucose into the cell. S12 did not fully understand that the nutrients generated from the enzymatic reactions were necessary for utilisation of energy for cellular movement and reproduction. Their idea about the phagocytotic mode of nutrition could hinder the understanding of bacterial nutrition since most of the digestive processes involved enzymatic reactions on the outside of the cell.

Why was damage causing organisms which in this study involved virus and bacteria, were assumed by students to be pathogenic as a living characteristic? *"Because bacteria attack humans. If they are not living things, how did they attack humans?"* Such was the typical logic-based type of response recorded from S12 when asked why bacteria were living things. Though this research did not pursue it further as a research question, the misconception of living microbes equating to disease outbreak could possibly mislead students to belief or interpret that all living microbes caused disease or damage cells while dead microbes do not. Students S1, S2, S10 and S15 had such idea during the early stage of their course. It has now been established by the scientific community and published by microbiology text books that majority of microbes were not pathogenic (Alcamo, 2001; Bauman, 2007; Madigan, 2003).

Other ideas on cellular properties which included combination of reproduction through binary fission and motility capabilities were observed from

S1 and S3 (code Y). Description of bacterial reproduction by division and motility assisted by the flow of blood in the human body was recorded from S1. She concluded that disease spread was contributed the circulatory system;

*“...it needs the help of blood flow to distribute the bacteria. That’s how the infection can be so fast to infect our whole body.”*

(S1)

Since S3 merely described the process of binary fission, evidence indicating his understanding of a single cell bacterium replicating itself independently, without the involvement of other cells, was missing. It was unlikely that he knew the function of the flagella which was necessary for the bacteria to move in the moist environment found in the body. S3 thought that bacteria moved by crawling along the walls of the intestine like some kind of worm.

Throughout S1’s study in microbiology, her ideas about the living characteristics of bacteria focused more on its reproductive property. Of the 6 students involved in the case studies, only S1 and S3 did not improve their understanding, remaining at Y after the completion of microbiology course in 2007 (Table 25). At the end of her study, S1 still could not understand the relevance between chromosome and the division process. Her thoughts about the chromosome was just simply a “..*piece of DNA, with many genes*”. S1 also needed to increase her factual scientific knowledge on cellular structures of bacteria, animal and plant cells if she was to improve her understanding on the living characteristics of bacteria and prevent any misconception of bacteria being similar to animal cells.

There were no students in code Z, the lowest category of understanding at the end of microbiology study. Two students, S2 and S12 progressed upwards to code Y from Z, improving their understanding on living characteristics of bacteria. S2 explained his rationale starting with the description of chromosome “..*a thread-like structure that contains genes codes (DNA) and control functions*”. S2 claimed the chromosomal control extended to that of binary fission where the

daughter cells were exactly alike to that of the parent at the same time containing the same genome.

**5.13.2 Association between DNA replication and binary fission**

After 4 months of study, 2 students were located in the highest category of understanding (code X) bacterial living characteristics. S10 and S15 made the most progress in their understanding from code Z (Table 25). S10 was aware of the bacteria's independence and had a good understanding on the living characteristics of the bacteria. She was also able to reason the association between DNA replication and binary fission which ensured equal distribution of genetic materials.

While S15 knew about the independent capability of bacteria, she also showed understanding on the relevance of chromosome replication during cell division. was encountered. Hence, S15 could comprehend the linkage between chromosome and binary fission. To maintain the progeny of bacterial cells having the same genetic makeup S15 responded that;

*"The chromosomes must be multiplied into two copies first. When this is done, each chromosome can then be distributed to each bacterial cell so that when binary fission is completed, all 2 cells would have a copy each."*

S15 demonstrated an understanding on living characteristics of bacteria. She was the only student to include her thinking that a single cell could maintain its survival independently and by generating its progeny at a fast rate, the bacteria had the means to maintain its continuity for survival purposes.

**5.14 Reliability and validity**

Repeatability and consistency of results or data refers to its reliability. Validity refers to a measure which the test is supposed to determine. For internal validity, it sets out to explain a phenomenon which is supported by the data collected (Cohen *et al.*, 2000). Did the intervention cause the students'

understanding to progress or decline, establishing an internal validity? Student ideas collected from the pre and post intervention did indicate the improvements for some concepts for 2007 cohort. That was supported with the case studies' results that featured students' development of ideas after their microbiology course. However, it felt that the internal validity for this research may be compromised as there was no control group in both 2005 and 2007.

As for external validity, which refers to the extent in which the data be generalized to a larger population, Cohen *et al.* (2000) suggested that it allowed the researchers to view the respondents' honesty and the accuracy of its information. To increase the validity of the interview, conscious efforts were made not to form expectations.

The interview questions were formulated to elucidate students' ideas on microbiology concepts that constituted towards understanding the microbes. In cohort 2005, the post interview questions attempted to obtain student ideas on living characteristics and classification of microbes. Knowing what the students think and understand about these 2 ideas was fundamental in making sure that these concepts were not 'missed out' or 'misunderstood' when learning topic 1 'Introduction to Microbiology'.

The questions were posed in such as a manner so as to invite responses from the interviewees and provide them an opportunity to demonstrate their understanding of microbiology concepts. White and Gunstone (1992) took the notion that understanding a concept was both dependent on levels and types of knowledge (eg. intellectual, motor skills, propositions and memories). They argued that these 2 factors dictate the ability to understand and its quality of understanding. With these insight, White and Gunstone regarded interview as the most 'sincere' method of gathering someone's understanding;

*"Understanding of the concept is a function of a set of knowledge....understanding improves as the amount of knowledge increases... Its purpose is to bring forth as much*

*as possible of what the person knows about the concept, for that knowledge to be analysed to yield measures or impressions of the person's understanding."*

(White and Gunstone, 1992 p. 85)

It could be assumed that the questions used in this study do have internal validity as it attempted to measure what it was developed to do. However, the reliability of the interview may perhaps be compromised because of its non-anonymity possibly contributing to a lack of honesty (Burns, 1997). On the other hand, its negative impact may not be significant as it was made known to the students that their feedback actually would help future students by improving the teaching of microbiology that have an impact on their understanding of microbiology concepts. This implied that it can be reasonably assumed that their interview responses were indeed valid. Lastly, students were assured of their confidentiality as no personal particulars were recorded. It would be reasonable to assume that once the students felt assured that their identity were protected and their microbiology grade remained unaffected, greater truthfulness in their responses would be obtained thus, maintaining the validity of this study. The students were also reminded that they could use phrases like *"I am not sure....I don't really know"* to avoid them coming up with responses to suit the interviewer so as to make the whole session more pleasant.

Though the number of students participating in the case studies may be small to provide some reliability to the results in detecting any development or improvement of ideas as their microbiology course, it does however, elucidate their ideas or misconceptions on the various microbiology concepts that may have contributed towards their poor understanding.

### **5.15 Limitations of the Study**

This study was a descriptive research and the author acknowledged the limitations of this study. The microbiology students were selected only from Ngee Ann Polytechnic and not from other polytechnics in Singapore. Hence, the

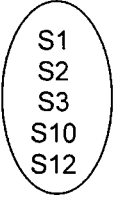
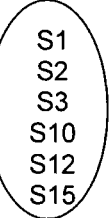

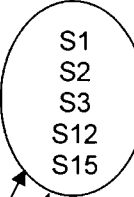

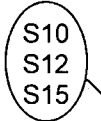
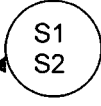


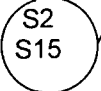

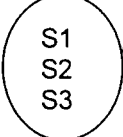
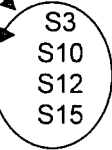
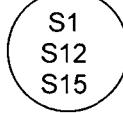
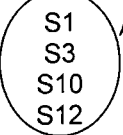


students sample was not a true representative of the biotechnology student population. Interpretation of results on a whole was also restricted.

The 6 student volunteers involved in the case studies had O-level aggregate scores of 11-15 and their respective O-level results may not be indicative of their academic ability. Thus, when high and low achievers were selected to provide a good 'coverage' for their ideas, in many ways that was done in an arbitrary manner. Though this study did not seek the students' understanding of microbes based on their academic ability, future studies could ensure the inclusion of low, medium and high achievers to avoid any discrimination.

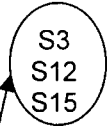
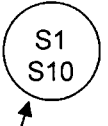
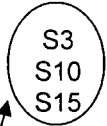

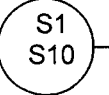
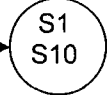
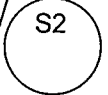
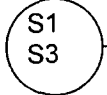
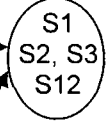
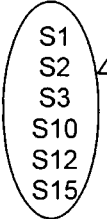
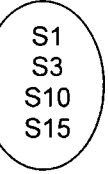
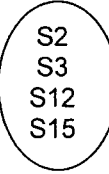
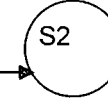
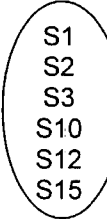
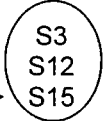
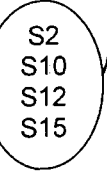
The study is also restricted by the duration of the intervention due to the operational constraints of Ngee Ann's academic timetable. It is reasonable to argue that longer interventions will produce more noticeable results.

Table 24: Individual changes in categories of understanding for responses to terminology of 6 case studies of cohort 2007

Code	Microbiology		Microbes		Bacterial colony		Antibiotics	
	Pre intervention	Post intervention	Pre intervention	Post intervention	Pre intervention	Post intervention	Pre intervention	Post intervention
X								
Y								
Z								

X: There is an understanding on the terminology  
Y: There is some understanding on the terminology  
Z: There is no or little understanding on the terminology

Table 25: Individual changes in categories of understanding for responses to microbial growth, microbial classification; and living characteristics of virus and bacteria of 6 case studies of cohort 2007

Code	Microbial growth		Microbial classification		Living characteristics of virus		Living characteristics of bacteria	
	Pre intervention	Post intervention	Pre intervention	Post intervention	Pre intervention	Post intervention	Pre intervention	Post intervention
X								
Y								
Z								

X: There is an understanding on the growth, classification, living characteristics of virus and bacteria

Y: There is some understanding on the growth, classification, living characteristics of virus and bacteria

Z: There is no or little understanding on the growth, classification, living characteristics of virus and bacteria

## **- CHAPTER 6 -**

### **CONCLUSIONS**

#### **6.1 General Conclusions**

Majority of 2005 cohort considered microbes as small living organism requiring the microscope to view them. Use of size criteria to classify organisms as microbes was unreliable and could be a factor in preventing students from understanding microbiology concepts during the early stage of pursuing their diploma in biotechnology. It was observed that 11.6% of 2005 cohort semester 2 students did not consider single celled algae as microbes because they could recognise the green colouration of algal population. Generally, 2005 cohort thought that most bacteria were harmless and ubiquitous especially in the air and intestinal tract, based on their belief and personal experience that they did not fall ill daily. However, cohort of 2007 students interviewed individually was aware on the existence of harmful microbes but not overly concern on the affects which the organisms bring. They believed the 'good' microbes would colonise the body and inhibit the growth of 'bad' microbes minimizing the harmful effects on them. Students seemed to view virus as a more dangerous organism than bacteria. They associated virus pathogenicity with its living characteristics and their idea was partly influenced by bad media reports and limited scientific knowledge. Ideas of living were mainly about the respond of organisms to move towards stimuli, i.e. food, and nutrient consumption. Such ideas were associated with metabolic activities like respiration and growth. However, there were little explanations on the respective metabolism except knowing the outcome like production of waste and weight gain.

Amongst the terms 'microbiology', 'antibiotics', 'microbe' and 'bacterial colony' students had most difficulty in understanding 'microbe'. Their ideas of 'microbe' were that of a small tiny organism, invisible to the eye which required a microscope to examine it were found in all cohorts of 2005 and 2007. During the discussion on microbes, students' ideas normally related it's physical dimension.

They had little scientific knowledge on what a microbe was when they first began studying microbiology. The students were most familiar with bacteria and virus as microbial organisms. Less than 8% of 2005 cohort had appropriate idea that microbes were single celled organisms while about 6% of students had idea about its independence. There was no improvement on students' understanding of microbes. Responses on the terminology identified the term 'microbe' as the least understood microbiological term amongst the students. This reflected the difficulty students had when learning about the microbes.

Overall, only 40% of 2007 cohort had good understanding on microbial classification at post intervention. Their understanding was based on the thinking that the living organisms were able to grow and replicate as independent organisms. They could also identify that these attributes were present in yeast, a microbe and absent in other non-microbes like the skin cell, pollen and an ant. Understanding on microbial growth improved slightly for 2007 cohort but there were no students in with sound understanding on this concept as a living characteristic.

Students believed that microbes could be found everywhere predominantly in the air and intestinal tract. However, there was evidence to suggest that they did not realise on the presence of microbial organisms in water.

#### **6.1.1 Failure to interrelate biological functions**

Students could not interrelate with the various ideas surrounding the living characteristics of virus and bacteria. Students' understanding of biological concepts was limited with ideas confined to a specific concept and such weakness prevented its association with other biological processes. Cellular division via binary fission and respiration were two such biological processes which students failed to relate to other biological functions. In reproduction, students were able to describe binary fission and recognise it as a living characteristic of bacteria. But they were still unable to explain the relationship

between chromosome and binary fission. In the case of respiration, students knew organisms needed the intake of oxygen or air to live. Beyond that, they failed to understand the influence of oxygen on the oxidation of nutrients resulting with the release of energy necessary for microbial reproduction, growth or movement.

There was no evidence to indicate that students were able to interrelate the cellular functions of respiration and reproduction which contributed toward understanding the living characteristics of bacteria. Possession of inaccurate scientific knowledge had also lead to a weakened understanding of concepts. Ability to interlink ideas of respiration and reproduction would contribute towards their understanding on the living characteristics of bacteria and effective learn better about the nature of microbes.

#### **6.1.2 Limited scientific knowledge impede understanding**

Lack of scientific knowledge about cellular characteristic in particular its functional and structural aspects of cells contributed towards erroneous understanding on classification and living characteristics of microbes. Students did not know that virus is acellular and not biologically active outside a host cell. Their poor knowledge particularly about the virus morphology such as claiming it to have cell wall and being able to be see it under a microscope, further contributed towards the poor understanding of nutrition in virus. As such with the ability to comprehend the size of virus, students would then be able to reject the common notion of virus engulfing cell for its nutritional needs. Students had most difficulty in understanding the concept of microbial growth. None of the students interviewed from cohorts 2005 and 2007 realised that microbial growth concerned the production of cells from a single cell. Factors inhibiting the understanding of growth were their lack of knowledge on occurrence of microbes in water, nutritional requirements and rapid cell division.

## **6.2. Case Study Conclusions**

Students interviewed from the 2007 cohort managed to familiarise and apply the terminology correctly but some had not quite understood the meanings. Antibiotics were thought to be medications that destroyed a broad-spectrum of microbes which included viruses instead of the targeted bacteria. Of all the terms tested, the term 'microbe' proved to be the most difficult to grasp for all the 6 students interviewed.

### **6.2.1 Limited scientific knowledge impede understanding**

Adequate knowledge about the organism being single celled with independent functioning of biological processes would have helped students' understanding of biological concepts and hence the learning of microbiology itself. It was evident that such idea was missing during the interviews about the microbe. Instead, students' thinking about the microbe seemed to involve the physical sizes of organism and viewing of organisms with microscopes. From the case study, all 6 students at post intervention failed to gain a better understanding that microbes were single cellular organisms capable of functioning independently. Students had difficulty in understanding the term 'microbe' and knowing its meaning. This would have an adverse affect on application of knowledge and hampered their ability to explain scientifically the classification of organisms like those of the nerve cell, RBC and pollen. Perhaps the popular and 'old' criteria of a microbe being small cells and needing a microscope may have hindered the students understanding on the concept of a microbe.

The significance of accurate scientific knowledge was also seen where knowledge deficiency caused poor conceptual understanding in the living characteristics of virus especially in the biological processes of nutrition and reproduction. Furthermore, limited scientific knowledge may have encouraged the use of anthropomorphic expressions in explaining the ideas behind the

concepts and bring about new literal meanings which may misconstrue the scientific principles involved. Hence, scientific knowledge is necessary since it provides the explanation and in doing so displace both misconceptions and myths.

### **6.2.2 Pathogenic bacteria and virus**

Individual changes on categories of understanding to living characteristics of virus and bacteria revealed that 3 students had considered these 2 organisms as pathogenic. The concepts of microbial growth and living characteristics of virus were found to be most difficult to understand for the students. The weak understanding of microbial growth were due to students' deficiency of knowledge and awareness on the nature of microbe being able to undergo rapid cell division during reproduction and its occurrence in water or aquatic environment. The students tend to link pathogenicity of microbe to nutrition and reproduction where living characteristics of organisms were concerned. From their ideas on bacterial and viral living characteristics, it was apparent they 'equate' the fact that these 2 organisms were alive since it was able to damage the cells. Damaged cells as an outcome were then thought of as a source of nutrients which promote further spread of infection by the production of more bacteria or virus. Their idea about the phagocytotic mode of nutrition could also lead to potential misunderstanding of bacterial nutrition which was needed in learning about bacterial growth and metabolism.

### **6.3 Misconceptions**

Results from cohorts 2005 and 2007 showed that students' understanding about microbes was further marred by the misconception of ideas which the students had. Until reasons for such misconception of students' ideas on microbes' harmful nature were identified and misconception corrected, it was not likely that student learning and their ability to understand the microbial properties and their applications will improve. Misconception will continue to be one of the stumbling blocks in the students learning of microbiology. Even graduates are



known to continue to misunderstand biology concepts after attending formal training (Willson and Williams, 1996). Though the microbiology students' prior misconception cannot be totally 'unlearned', judging from the responses gathered in this investigation, understanding on certain conceptual areas such as bacterial and viral characteristics, microbial classification and some microbiological terms could be improved, to some extent, by classroom teaching.

Listed below were the common misconceptions uncovered in this investigation

1. Microbes were small organisms or cells and invisible to the eye which required a microscope to examine it.
2. Bacteria and virus were mainly destructive in nature and cause decay of materials and diseases in living things. The spread of bacterial diseases was linked to the reproductive capability of the organism that caused the increase in bacterial population.
3. Virus was characterised as a living organism due to the presence of DNA which lead students to think that virus was capable of carrying out its metabolism on its own which was scientifically incorrect.
4. Students did not realise that microbes require a short period of time (minutes to hours) to undergo cell replication. Students with such knowledge had a misconception that 3 days were not adequate for microbes to multiply. This would have an affect on their understanding of cell growth and microbial population.

#### **6.4 Concept Model for Understanding the Nature of Microbe**

When learning the concept of microbial classification, there was an over reliance on the assumption that all tiny specimens observed under the

microscope would be living. This could be resolved if students were to assess the living characteristics of the specimens for characteristics such as cellular structures, DNA and movement according to the steps described in concept model for studying the nature of microbes. Once this was done, further classification on whether the specimen was a microbe could then be determined according to criteria that microbes were single-celled organism independent for sustaining its living processes. Using the proposed concept model for studying the nature of microbes (Fig. 5), students would have a higher success of classifying organisms into microbes. Being able to classify microbes successfully using the concept model could perhaps help students to be more aware and better understand and study the complex nature of microbes. Adequate scientific facts and knowledge on the microbe's morphology, living attributes and its biological processes would further enhance students to understand microbes better.

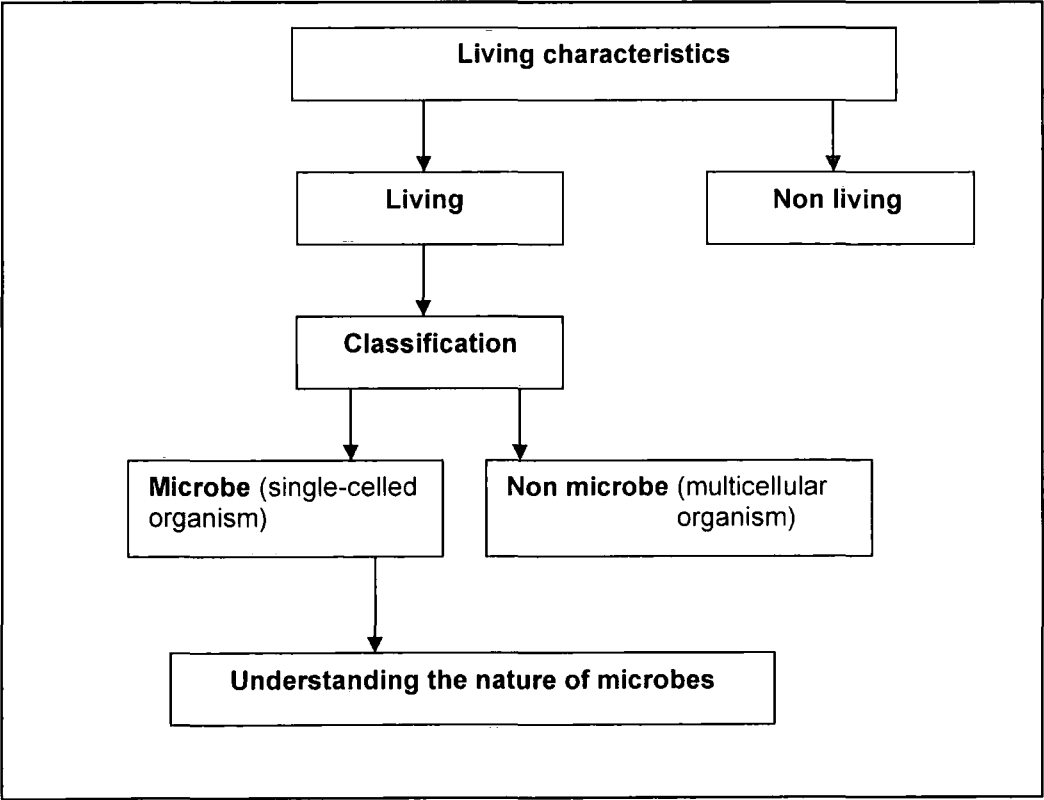


Fig 5: Proposed concept model for understanding the nature of microbes

## **6.5 Occurrence of Microbes**

Students' ideas on the occurrence of microbes were similar across both cohorts of 2005 and 2007. Students believed they were constantly in contact with bacterial organism as it could be found everywhere around them in the environment. Majority of students agreed that healthy people do carry bacteria and acknowledged the presence of bacteria in the intestine of healthy people. Students also realised that the microbial organisms found in their lungs, stomach and intestine, originated from the environment outside their body. The aquatic environment like those from the river was 'overlooked' as a source of microbes.

## **6.6 Implication on Teaching**

Teachers teaching biology-related subjects such as microbiology have since realised that to improve the understanding of scientific concepts or ideas which in many instances were complex in nature, basic ideas needed to be taught separately and later developed to derive an overall coherent framework linking each concept.

In preparing to teach students with little science or biological background in the topic microbial diversity, instructors ought to bear in mind students may well have knowledge about small and minute organisms but unfortunately these are not indicative of their ability to thoroughly understand what the concept i.e., microbial classification implies. This knowledge could be of a 'non-functional' nature where a lack of awareness of the meanings of the scientific contents could contribute towards poor understanding of the concept learnt. This can be seen in the studies involving organisms such as nerve cells, RBC and pollen grains. So for students to study microbiology and know more about the nature of microorganisms, students must, in the early stage of study, be taught a proper way to make a distinction between organisms that are microbial and those that are not.

The misconception that microbes were pathogens just because it was alive may hinder or narrow their learning on microbiology. So for Ngee Ann

biotechnology students learning microbiology many of whom do not have secondary biology, it was therefore important to ensure that perhaps the concept of living be taught early in the microbiology course to provide them a foundation and prevent the misconception that all microbes were pathogenic when learning about the organism. The current microbiology syllabus does not include any lesson on living concepts and it was assumed that all students had understood the concept of living.

Students needed to understand and study microbes as single cellular organisms capable of biological functioning in an independent manner instead of the popular opinion of small invisible organisms which required a microscope to examine it. Though it may sound trivial, only when students were able to distinguish microbes from non microbial organisms by examining their living characteristics and classification, students would most likely be misled and misunderstood the real nature of microbes. Perhaps then, students would not think of microbes as 'germs' which were only capable of destruction and disease causing.

Two-thirds of the 2007 cohort students held the opinion on binary fission being a living characteristic in bacteria, a prokaryote which differentiate it from other eukaryotes at the end of the study. With students' familiarity about the replication process, it was perhaps reasonable to introduce the concept to students early during the course as compared to the current syllabus where cell division was dealt in detail (in topic microbial growth) toward the end of the course (Table 3). By introducing this topic early, perhaps it would also enhance the conceptual understanding of microbial growth which students had most difficulty in amongst the conceptual areas tested. Furthermore, by associating it with other biological processes such as respiration, students would perhaps 'piece' together and 'see' its connectivity between all these biological processes. In preparing to teach cell division, students must recognised the duplication of

the chromosome during the cell replication which enabled the transfer of equal genetic materials to daughter cells.

The focus and structure of the microbiology module needed to be modified so that students could be taught about concepts associating with 'living' at the early phase of studying microbiology. With an understanding on the concept of living, students would be able to acquire the ideas of a single cellular organism capable of independent biological or metabolic processes. They would then have the skills to understand the concept of microbial classification. By following the pathway of the proposed concept model, perhaps then students would be able to understand the nature of microbial organism.

### LITERATURE CITED

Adamo, J.A. (1964) The effect of temperature on the phenomena of thixotropy. *Science Bulletin*, 7(2), 1-8

Adamo, J.A. (1996) The anatomy of the icosahedron. Absts Annual Meeting ASM Atlanta GA 93, 102

Adamo, J.A. (1999) Teaching the methodology of science: The utilization of microbial model systems for biometric analysis. Annual Meeting of the American Society for Microbiology, Chicago, Illinois, May 30–June 3

Alcamo, E. (2001) *Fundamentals of Microbiology*, 6<sup>th</sup> edition. Jones and Bartlett.

Arnaudin, M.W. and Mintzes, J.J. (1985) Students' alternative conceptions of the human circulatory system: A cross age study. *Science Education*, 69(5), 721-733

Baird, J.R. and Mitchell, I.J. (1986) *Improving the quality of teaching and learning: An Australian case-study – The Peel Project*, Melbourne: Monash University

Bauman, R.W. (2007) *Microbiology: With diseases by taxonomy*, 2<sup>nd</sup> edition Pearson Benjamin Cummings. San Franscisco

Beck, U. (1986) *Risikogesellschaft: auf dem Weg in eine andere Moderne*, Frankfurt am Main: Suhrkamp Verlag.

Bell, B.F. (1981a) When is an animal, not an animal? *Journal of Biological Education*, 15(3), 213-218

Bell, B.F. (1981b) What is a plant? Some children's ideas. *New Zealand Science Teacher*, 31, 10-14

Bell, B. and Barker, M. (1982) Towards a Scientific Concept of 'Animal'. *Journal of Biological Education*, 16(3), 197-200

Bishop, R.H. (2000) Education in Microbiology, In: Lederberg, *et al.* (Editors) *Encyclopedia of Microbiology*, 2<sup>nd</sup> edition. 2, 156-159 New York: Academic Press

Black, P.J. (1993) Formative and summative assessment by teachers. *Studies in Science Education*, 21, 49–97

Bliss, J. and Ogborn, J. (1985) Children's choices of uses of energy. *European Journal of Science Education*, 7(2), 195-203

Bowers, B.C. (1989) Alternatives to standardised educational assessment. ERIC Digest. Available: [http://www.ed.gov/databases/ERIC\\_Digests/ed312773.html](http://www.ed.gov/databases/ERIC_Digests/ed312773.html)

Brekke, S.E. (2002) True scientific literacy for all students. *Teachers.Net Gazette*, 3(6) 5p.

Brown, A.E. (2005) *Benson's Microbiological Applications: Laboratory Manual in General Microbiology*, 9<sup>th</sup> edition. McGraw-Hill

Brumby, M.N. (1981) Learning, understanding and 'thinking about' the concept of life. *Australian Science Teachers Journal*, 27(3), 21-25

Brumby, M.N. (1982) Students' Perceptions of the Concept of Life. *Science Education*, 66(4), 613-622

Brumby, M.N. (1984) Misconceptions about the concept of natural selection by medical biology students. *Science Education*, 68(4), 493-503

Brumby, M.H. Garrard, J. and Auman, J. (1985) Students' perception of the concept of health. *European Journal of Science Education*, 7, 307-323

Bryant, S.L. and Timmins, A.A. (2000) Using portfolio assessment as an innovation to assess problem-based learning in Hong Kong schools. In: Tan, O.S., Little, P., Hee, S.Y. and Conway, J. (Editors) *Problem-based learning: Educational innovation across disciplines*. Singapore: Temasek Centre for Problem-based Learning.

Bryce, T.G.K., McCall, J., MacGregor, J., Robertson, I.J. and Weston, R.A.J. (1983) *Techniques for the Assessment of Practical Skills in Foundation Science*, London, Heinemann.

Buckley, M.R. (2002) *The Global Genome Question: Microbes as the Key to Understanding Evolution and Ecology*, American Academy of Microbiology, October 11-13, Florida. 18p.

Camp, W. (1990) Participation in student activities and achievement: A covariance structural analysis. *Journal of Educational Research*, 83, 272-278

Campbell, DT and Stanley, IC (1963) Experimental and quasi-experimental designs for research on teaching. In: N. Gage (Editor) *Handbook of Research on Teaching*, Chicago. Rand McNally, 171-246

Carey, S. (1985) *Conceptual Change in Childhood*, MIT Press, Cambridge, Mass.

Carlson, R.O. (1965) *Adoption of educational innovations*, Eugene: Centre for Advanced Study of Educational Administration, University of Oregon.

Chen, P. (2001) Speech by Mr Peter Chen, Senior Minister of State, Ministry of Education and Ministry of Trade & Industry, at the ground-breaking ceremony for Ngee Ann Polytechnic's phase V development on 17<sup>th</sup> January 2001

Cheung W-L and Ravinder, S. (2003) A tale of two cities: Education responds to globalization in Hong Kong and Singapore in the aftermath of the Asian Economic Crisis. *Asia Pacific Journal of Education*, 23(1), 43-68

Clarkburn, H., Beaumont, E., Downie, R. and Reid, N. (2000) Teaching biology students transferable skills. *Journal of Biological Education*, 34(3), 133

Cohen, L. and Manion, L. (1994) *Research Methods in Education*, London: Routledge

Cohen, L., Manion, L. and Morrison, K. (2000) *Research Methods in Education* 5<sup>th</sup> edition, London: Routledge/Falmer

Coleman, J.S. (1966) *Equality of educational opportunity*. (Report No. OE-3800). Washington, DC: National Centre for Educational Statistics

Coles, M. (1997) Science education – vocational and general approaches. *School Science Review*, 79(286), 27-32

Darling-Hammond, L. (1997) *The right to learn: A blueprint for creating schools that work*. 1<sup>st</sup> Edition. Jossey-Bass.

Darling-Hammond, L. (1999) Teacher quality and student achievement: Are view of state policy evidence. Centre for the Study of Teaching and Policy, University of Washington. Available: <http://www.ctpweb.org> 48 pp.

Deadman, J.A. and Kelly, P.J. (1978) What do secondary school boys understand about evolution and heredity before they are taught the topics? *Journal of Biological Education*, 12(1), 7-15

Delors, J. (1996) *Learning: The treasure within*. Report to UNESCO of the International Commission on Education for the Twenty-First Century. Paris: UNESCO. 85-111

Denscombe, M. (2000) Social conditions for stress: young people's experience of doing GCSEs. *British Educational Research Journal*, 26(3), 361-374

Dreyfus, A and Jungwirth, E. (1988) The cell concept of 10<sup>th</sup> graders: curricular expectations and reality. *International Journal of Science Education*, 10(2), 221-229



Dreyfus, A and Jungwirth, E. (1989) The Pupil and the Living Cell: A taxonomy of dysfunctional ideas about an abstract idea. *Journal of Biological Education*, 23(1), 49-55

Driscoll, M.P. (1994) *Psychology of learning for instruction*. Needham Heights, MA: Allyn & Bacon.

Driver, R., Squires, A., Rushworth, P. and Wood-Robinson, V. (1994) *Making Sense of Secondary Science: Research into children's ideas*, Routledge 210p.

Duit, R. (1993) Research on students' conceptions: developments and trends. Paper presented at the 3<sup>rd</sup> International seminar on Misconceptions and Educational Strategies in science and Mathematics. Cornell University, Ithaca, USA, 1-4 August 1993.

Duit, R. Treagust, D. and Mansfield, H. (1996) Investigating student understanding as prerequisite to improving teaching and learning in science and mathematics. In: *Improving Teaching and Learning in Science and Mathematics*, Editors: Duit R and Fraser, B. pp. 17-31 New York, USA, Teachers College Press

Education Statistics Digest (2006) Ministry of Education, Singapore

Edwards, R. (2000) Lifelong learning, lifelong learning, lifelong learning. In: Field, J. and Leichster, M. (Editor) *Lifelong Learning; Education Across the Lifespan*. London: Routledge and Falmer. 3-11

Ekborg, M. (2003) How student teachers use scientific conceptions to discuss a complex environmental issue. *Journal of Biological Education*, 37(3), 126-132

Elliott, S.N. (1995) Creating meaningful performance assessments. ERIC Digest. Available: [http://www.ed.gov/databases/ERIC\\_Digests/ed381985.html](http://www.ed.gov/databases/ERIC_Digests/ed381985.html)

Engel, C.E. and Wood-Robinson, C. (1985) How Secondary Students Interpret Instances of Biological Adaptation. *Journal of Biological Education*, 19(2), 125-130

Environmental Literacy Council.  
Available: <http://www.enviroliteracy.org>

Etheredge, S and Rudnitsky, A. (2003) *Introducing students to scientific inquiry: How do we know what we know?* Boston: Pearson Education

Field, J. (1997) The European Union and the Learning Society: Contested Sovereignty in an Age of globalisation. In: Coffield, F. (Editor) *A National Strategy*

*for Lifelong Learning*. Department of Education: University of Newcastle Upon Tyne. 95-111

Fisher, L.E. (1996) Writing to facilitate learning in microbiology. Paper presented at the American Society for Microbiology Undergraduate Microbiology Conference. Baton Rouge, L.A. May 17-19. 8p.

Friedler, Y., Amir, R. and Tamir, P. (1987) High school students' difficulties in understanding osmosis. *International Journal of Science Education*, 9(5), 541-551

Garfield, J., delMas, R. C. and Chance, B. L. (1999) The Role of Assessment in Research on Teaching and Learning Statistics. Paper presented at the AERA Annual Meeting Montreal, 1999

Garrahan P. and Stewart P. (1992) *The Nissan Enigma: Flexibility at Work in a Local Economy*. London: Mansell. pp.58-118, 140-145

Gerber, S. (1996) Extracurricular activities and academic achievement. *Journal of Research and Development in Education*, 30(1), 42-50

Gibbons, M. (1974) Walkabout: searching for the right passage from childhood and school. Available: <http://www.selfdirectedlearning.com/walkabout.html>

Giraud, G. (1997) Cooperative Learning and Statistics Instruction. *Journal of Statistics Education* 5(3)

Goh, C.T. (1997) Speech by Prime Minister Goh Chok Tong at the opening of the 7<sup>th</sup> International Conference on Thinking on Monday, 2 June 1997, at 9.00 am at the Suntec City Convention Centre Ballroom. Shaping Our Future: Thinking Schools, Learning Nation

Gopinathan, S. (2001) Globalisation, the state and education policy in Singapore. In: *Challenges Facing the Singapore Education System Today*, (Ed: Tan J., Gopinathan S. and Ho W.K.) Prentice Hall, Pearson Education Asia

Gott, R. and Duggan, S. (1995) *Investigative Work in the Science Curriculum. Developing Science and Technology Education*, Buckingham: UK. Open University Press

Gott, R. and Duggan, S. (2003) *Understanding and Using Scientific Evidence*. London: Sage.

Grubb, W. N., Davis, G., Lum, J., Plihal, J. and Morgain, C. (1991) *"The Cunning Hand, the Cultured Mind": Models for Integrating Vocational and Academic*

*Education*. Berkeley, National Centre for Research in Vocational Education. (ED 354283)

Guardabassi, L. (2000) *The use of Acinetobacter spp. as bacterial indicators for monitoring antimicrobial resistance in aquatic environments*. Ph.D. thesis.

Guardabassi L. and Dalsgaard A. (2002) Occurrence and fate of antibiotic resistant bacteria in sewage. Department of Veterinary Microbiology. The Royal Veterinary and Agricultural University, Environmental Project No. 722, 71 pp

Haefner and Zembal-Saul (2001) *Engaging in Science as Inquiry: Prospective Elementary Teachers' Learning in the Context of an Innovative Life Science Course*. Paper presented at the Annual Meeting of the American Educational Research Association. Seattle, April 10-14, 26 pp.

Haney, J.J. and McArthur, J (2002) Four case studies of prospective science teachers' beliefs concerning constructivist teaching practices. *Science Education*, 86, 783-802

Harlen, W. and Qualter, A. (1991) Issues in SAT development and the practice of teacher assessment. *Cambridge Journal of Education*, 21(2), 141-152

Harlen, W., Gipps, C, Broadfoot, P. and Nuttal, D. (1992) Assessment and the improvement of education. *The Curriculum Journal*, 3(3), 215-230

Haslam, F. and Treagust, D.F. (1987) Diagnosing secondary students' misconceptions of photosynthesis and respiration in plants using a two-tier multiple choice instrument. *Journal of Biological Education*, 21(3), 203-211

Hilge, C. and Kattmann, U. (1999) The significance of microbes for biology teaching – A study of scientific and students' conceptions. *Proceedings of the 2<sup>nd</sup> International Conference of the European Science Education Research Association (ESERA), Research in Science Education: Past, Present and Future*. 31 Aug – 4 Sept, Germany. 3 pp.

Hitchcock, G. and Hughes, D (1995) *Research and the Teacher: A Qualitative Introduction to School-based Research*, 2<sup>nd</sup> edition, Routledge,

Holloway, J. H. (2000) Extracurricular activities: The path to academic success? *Educational Leadership*, 57(4), 5 pp.

Holtzhausen, S. (2001) Triangulation as a powerful tool to strengthen the qualitative research design: The Resource-based Learning Career Preparation

Howe, C., Rogers, C. and Tolmie, A. (1990) Physics in the primary school: peer interaction and the understanding of floating and sinking. *European Journal of Psychology of Education* 5(4), 459-475

Hornby, A.S. (1989) *Oxford Advanced Learner's Dictionary of Current English*. (Editor: A.P. Cowie) 4<sup>th</sup> edition. Oxford University Press

Hubbard, R.S. (1994) How effective is self-directed learning at generating successful learning experiences and what is its role within higher education? Paper presented at the Annual Meeting of the Teachers of English to Speakers of Other Languages (March 8-12) Baltimore, Maryland. 9 pp.

Hutchinson, N.L., Freeman, J.G. and Fisher, C. (1993) *A two-year cohort study: Career development for youth with learning disabilities*. Paper presented at the annual meeting of the American Educational Research Association, Atlanta, Georgia.

Hutchinson, N. L. (1995) Performance assessments of career development. ERIC Digest. Available: <http://ericae.net/edo/ED414518.htm>

Inhelder, B and Piaget, J. (1964) *The early growth of logic in the child*. Routledge and Kegan Paul

Jacobi, D. (1993) Lexique et reformulation intradiscursive dans les documents de vulgarisation scientifique, CNRS, INaLF, Vocabulaires technoscientifiques et dictionnaire de langue, *Lexicologie française*

Jaeger, R. (1978) About educational indicators. In: Shulman, L.S. (Editor) *Review of Research in Education* 6, 276 - 315

Jansen, T. and van der Veen, R. (1996) Adult education in the light of the risk society. In: Raggatt, P., Edwards, R. and Small, N. (Editors) *The Learning Society: Challenges and Trends*, London: Routledge, 122-135

Jarvis, T. and Pell, A. (2002) Effect of the challenger experience on elementary children's attitudes to science. *Journal of Research in Science Teaching*, 39(10), 979-1000

Johnson, P. and Gott, R. (1996) Constructivism and evidence from children's ideas. *Science Education*, 80(5), 561-577

Johnstone, A.H. and Mahmoud, N.A. (1980) Isolating topics of high perceived difficulty in school biology. *Journal of Biological Education*, 14(2), 163-166

Kass, H. and Macdonald, A.L. (1999) The learning contribution of pupil self-directed building activity in science. *Science Education*, 83, 449-471

Kell, C. and Van Deursen, R. (2002) Student learning preferences reflect curricular change. *Medical Teacher*, 24(1), 32-40

Kempa, R. (1986) Assessment in science. Cambridge Science Education Series, Cambridge, Cambridge University Press

Kuech, R., Zogg, G., Zeeman, S. and Johnson, M. (2003) *Technology rich biology labs: Effect of misconceptions*. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching. Philadelphia. March 2003. 14 p.

Lam-Kan, K.S. (1985) *The contributions of enrichment activities towards science interest and science achievements*, Unpublished Master's Thesis, University of Singapore

Lam, P.K. and Lam, Y.K. (2001) Comprehensive Biology for 'O' level Science 2<sup>nd</sup> edition. Marshall Cavendish

Lankard, B.A. (1992) Integrating academic and vocational education: Strategies for implementation. *ERIC Digest* No. 120, 7 pp.

Lee, Y.C and Ng P.H. (2004) *Hong Kong primary pupils cognitive understanding and reasoning in conducting science investigation: A pilot study on the topic of "keeping warm"*. Asia-Pacific Forum on Science Learning and Teaching. 5 (3) article 8. (Dec 2004)

Leach, J., Driver, R., Scott, P. and Wood-Robinson, C. (1992) *Progression in conceptual understanding of ecological concepts by pupils age 5-16*. Centre for Studies in science and Mathematics Education, University of Leeds

Lenton, G. and Turner, G. (1999) Student-teachers' grasp of science concepts. *School Science Review*, 81(295), 67-72

Levin, H.M. and Kelly, C. (1994) Can education do it alone? *Economics of Education Review*, 13/22, 97-108

Lewis, J. and Wood-Robinson, C. (2000) Genes, chromosomes, cell division and inheritance--Do students see any relationship? *International Journal of Science Education*, 22 (2) 177-195

Lewis, J., Leach, J. and Wood-Robinson, C. (2000) What's in a cell? – young people's understanding of the genetic relationship between cells, within an individual. *Journal of Biological Education*, 34(3), 129-132

- Lim, Linda (2004) The future of biologics manufacturing in Singapore. *Innovation*, 5(1)
- Lofty, J.S. (1993) Can Britain's national curriculum show America the way? *Educational Leadership*, 50(5), 52-55
- Looft, W.R. (1974) Animistic thought in children: understanding 'living' across its associated attributes. *Journal of Genetic Psychology* 124, 235-240
- Lovell, C.R. (2000) Diversity, microbial. *Encyclopedia of Microbiology* 2<sup>nd</sup> edition. 2, 55-70 Academic Press
- Lovell, K (1968) In: Lunzer, E.A. and Morris, *Development of human learning*. J.F. Staples Press
- Lucas, A. (1987) Public knowledge of biology. *Journal of Biological Education*, 21(1), 41-45
- Lucas, A.M., Linke, R.D. and Sedgwick, P.P. (1979) School children's criteria for "alive": a content analysis approach. *Journal of Psychology*, 103, 103-112
- Lum, H.K. (2001) *Biology: The Living Science*. Longman
- Madigan. M.T, Martinko, J.M. and Parker, J. (1999) *Biology of Microorganisms*, 8<sup>th</sup> edition, Prentice-Hall International, Inc
- Madigan. M.T, Martinko, J.M. and Parker, J. (2000) *Brock Biology of Microorganisms*. 9<sup>th</sup> Edition, Prentice-Hall International, Inc.
- Madigan. M.T, Martinko, J.M. and Parker, J. (2003) *Brock Biology of Microorganisms*. 10<sup>th</sup> Edition, Prentice-Hall International, Inc.
- Marsh, H. (1992) Extracurricular activities: Beneficial extension of the traditional curriculum or subversion of academic goals? *Journal of Educational Psychology*, 84(4), 553-562
- Massey, M. (1989) States move to improve assessment picture. *ACSD Update*, 31(2), 7
- Maxted, M.A. (1984) *Pupils prior beliefs about bacteria and science processes: their interplay in school science laboratory work*. MA thesis, University of British Columbia
- McKane, L. and Kandel, J. (1998) *Microbiology: Essentials and Applications*. 4<sup>th</sup> edition, McGraw-Hill, Inc.

McKenzie, D.L. and Padilla, M.J. (1986) The Construction and Validation of the Test of Graphing in Science (TOGS). *Journal of Research in Science Teaching*, 23(7) p571-79

Ministry of Education (1998) *The desired outcome of education*. Singapore

Mintzes, J.J., Wandersee J.H. and Novak, J.D. (2000) *Assessing Science Understanding: A human constructivist view*. San Diego, CA, USA, Academic Press

Mintzes, J.J., Wandersee J.H. and Novak, J.D. (2001) Assessing understanding in biology. *Journal of Biological Education*, 35(3), 118-124

Modi, M. Konstantopoulus, S. and Hedges, L.V. (1998) *Predictors of academic giftedness among US high school students: Evidence from a nationally representative multivariate analysis*. Paper presented at the conference of the AERA, San Diego, CA. (ED 422356)

MOE <http://www.moe.gov.sg/cpdd/syllabuses.htm>

Mok, K.H. and Lee, H.H. (2003) Globalization or Glocalization? Higher education reforms in Singapore. *Asia Pacific Journal of Education*, 23(1) 15-42

Nagy, M.H. (1953) The representation of germs by children. *Journal of General Psychology*, 83, 227-240

Natapoff, J.N. (1978) Children's views of health: a developmental study *American Journal of Public Health* 68, 995-1000

National Commission on Educational Excellence (1983) *Nation at Risk* (Washington DC: US Government Printing Office).

NP (2000) *Report of the study team on academic system and structure*. Ngee Ann Polytechnic 14 pp.

Osborne, R.J. and Gilbert, J.K. (1980) A method for investigating concept understanding in science. *European Journal of Science Education*, 2, 311-321

Osborne, J.F., Simon, S. and Collins, S. (2003) Attitudes towards science: A review of the literature and its implications. *International Journal of Science Education* 25(9), 1049-1079

Palmore, E. and Luikart, C. (1972) Health and social factors related to life satisfaction. *Journal of Health and Social Behaviour*, 13, 68-79

- Papageorgiou, G. and Johnson, P. (2005) Do particle ideas help or hinder pupils' understanding of phenomena? *International Journal of Science Education* 27(11), 1299-1317
- Parson, S. (1990) Lifelong learning and the community school. In: Poster, C. and Kruger, A. (Eds) *Community Education in the Western World*. London, Routledge
- Patton, M.Q. (1990) *Qualitative Evaluation and Research Methods*. Newbury Park: SAGE Publishers.
- Pekmez, E.S., Johnson, P. and Gott, R. (2005).Teacher's understanding of the nature and purpose of practical work. *Research in science and technological education*, 23(1), 3-23
- Piaget, J. (1929) *The Child's Conception of the World*, New York: Harcourt, Brace
- Piaget, J. (1952) *The Origins of Intelligence in Children*, NewYork: International University Press
- PISA (2003) Programme for International Student Assessment. Framework for 2003. Paris: OECD, PISA. Available: <http://www.pisa.oecd.org>
- Prout, A. (1985) Science, health and everyday knowledge. A case study about the common cold. *European Journal of Science Education* 7(4), 399-406
- Qualter, A. Strang, J. Swatton, P. and Taylor, R. (1990) *Exploration: A Way of Learning Science*. Oxford. Blackwell.
- Raichvarg, D. (1995) *Louis Pasteur – L'empire des Microbes*. Decouvertes Gallimard
- Roberts, R. (2001) Procedural understanding in biology: "the thinking behind the doing". *Journal of Biological Education*, 35(3), 113-117
- Roberts, R and Gott, R. (2000) Procedural understanding in biology: how is it characterised in texts? *School Science Review*, 82(298), 83-91
- Roland, S., Bahr, M., Olendzenski, L. and Patterson, D.J. (2005) Switch on Micro\*scope! *Science Teacher*, 72 (2), 44-46
- Ryman, D. (1974) Childrens' understanding of the classification of living organisms. *Journal of Biological Education*, 8(3), 140-144
- Samavedham, L. (2006) Teaching students to think: a matter of engaging minds. *SDTL Brief*. Centre for Development of Teaching and Learning. National University of Singapore July 9(2), 1-3



Scherer, M. (2006) The challenge to change. *Educational Leadership*, May, (63) 8, 8

Screen, P.A. (1986) The Warwick Process science project. *School Science Review*, 72(260), 17-24

Shavelson, R.J. McDonnell, L.M. and Oakes, J. (1991) What are educational indicators and indicator systems ? *Practical Assessment, Research & Evaluation*. 2(11), 4 pp. Available: <http://ericae.net/pare/getun.asp?v=2&n=ll>

Shepard, L.A. and Smith, M.L. (1986) *Flunking Grades: Research and Policies on Retention*. New York: Falmer Press.

Simonneaux, L. (2000) A study of pupils' conceptions and reasoning in connection with 'microbes', as a contribution to research in biotechnology education. *International Journal of Science Education*, 22(6), 619-644

Smeets, P.M. (1974) The influence of MA and CA and the attribution of life and life traits to animate and inanimate objects. *Journal of Genetic Psychology*, 124, 17-27

Solomon, J. (1983) Messy, contradictory and obstinately persistent: a study of children's out of school ideas about energy. *School Science Review*, 65(231), 225-233

Spring, J. (1998) *Education and the Rise of the Global Economy*. Mahwah, NJ: Lawrence Erlbaum Associates.

ST (2000) *The Straits Times*, 2 April, p. 7

ST (2007) *The Straits Times*, 5 Dec, p. 27

ST (2008) *The Straits Times*, 16 Oct, p. A22

Stiggins, R.J. (1987) NCME instructional module on design and development of performance assessments. *Educational Measurement: Issues and Practice*. (Fall) 33-42

Strauss, V. (2006) Report calls for improvement in K-8 science education. *Washington Post* 22 Sept p. A09

Strauss A. and Corbin J. (1990) *Basics of Qualitative Research: Grounded Theory Procedures and Techniques*. Sage

Summers, W.C. (2000) History of Microbiology, In: Lederberg, *et al.* (Editors) *Encyclopedia of Microbiology*, 2<sup>nd</sup> edition. 2, 677-697 New York: Academic Press

Tairab, H.H. and Khalaf Al-Naqbi., A.K. (2004) How do secondary school science students interpret and construct scientific graphs? *Journal of Biological Education* 38 (3) 127- 132

Tan, S.C., Yeo, A. C. and Lim, W. Y. (2005) Changing epistemology of science learning through inquiry with computer-supported collaborative learning. *Journal of Computers in Mathematics and Science Teaching*, 24(4), 367-386

Teo, C.H. (2002) Speech by Radm (NS) Teo Chee Hean, Minister for Education and Second Minister for Defence at the Launch of the Academy of Principals, Singapore (11 Jan)

Thomas, D. (1987) Semiotics: The pattern which connects. *American Journal of Semiotics*, 5, 291-302.

Tight, M. (1998) Education, education, education ! The vision of lifelong learning in the Kennedy, Dearing and Fryer reports. *Oxford Review of Education*. 24, 4 pp. 473-485

Today (2006) *Today*, 18 Oct, 26-27

Toh, K.A., Yap, K.C., Lee, S., Springham, V. and Chua, P. (1996) Developing curriculum in Singapore : teacher-academic partnerships. *Journal of Curriculum Studies*, 28(6), 683-697

Toh K.A., Ho B.T., Wan, Y.K. and Ang, D. (2004) Science Teachers' Perceptions: Similarities and Differences in the U.S., England, Singapore and Japan. *Asia Pacific Journal of Education*, 24 (1), 1-11

Tuijnman, A. (1991) Emerging systems of recurrent education. *Prospects* 21, 1, 17-24

Tytler, R. Duggan, S. and Gott, R. (2000) Dimensions of evidence, the public understanding of science and science education. *International Journal of Science Education*, 23(8), 815-832

Tytler, R. Duggan, S. and Gott, R. (2001) Public participation of an environmental dispute. Implications for science education. *Public Understanding of Science*, 10, 343-364

Venthan, A. M. (2006) An Insight into Secondary Science Education in Singapore Classrooms. M Ed Thesis, Nanyang Technological University

Venville, G. and Donovan, J. (2007) Developing Year 2 Students' Theory of Biology with Concepts of the Gene and DNA. *International Journal of Science Education*, 29(9), 1111-1131

Villavicenzio, R.R. (1981) The concept of health: A preliminary investigation among secondary school students in the Philippines. Monograph no. 20. Science Education Centre, University of Philippines, Diliman, Quezon City.

Wain, K. (1991) Lifelong learning: a duty to oneself ? *Journal of Philosophy of Education*. 25(2), 273-278

Walker, J.M. and Cox, M. (1995) *The Language of Biotechnology: A Dictionary of Terms*. 2<sup>nd</sup> edition, American Chemical Society, Washington, DC

Wallace, V. (1986) Children's understanding of microorganisms: Pupils' understanding of science. College of St Paul and St Mary, Cheltenham, now Cheltenham and Gloucester College of Higher Education

Wandersee J.H., Mintzes, J.J. and Arnaud M.W. (1989) Biology from the learner's viewpoint: A content analysis of the research literature. *School Science and Mathematics*, 89, 654-668

Watson, R. Goldsworthy, A. and Wood-Robinson, V. (1999) What is not fair with investigations? *School Science Review*, 80(292), 101-106

Wellington, J. (1989) *Skills and Processes in Science Education*, London: Routledge

Werner, C.M. (1994) *The development of generic competencies in Australia and New Zealand*. National Centre for Vocational Education Research.

White, R. and Gunstone, R. (1992) *Probing Understanding*. London: Falmer Press

Wicks, M. (2000) An enthusiast's view of lifelong learning. *Individual Learning News*. Available: <http://www.lifelonglearning.co.uk/iln/j2-16.htm>

Wiggins, G. (1989a) Teaching to the (authentic) test. *Educational Leadership* 46(7), 41-47

Wiggins, G. (1989b) A true test: Toward more authentic and equitable assessment. *Phi Delta Kappan* 70(9), 703-713

Williamson, B (1998) Lifeworlds and learning, essays in theory. *Philosophy and Practice of Lifelong Learning* (Leicester NIACE) pp. 17-32

Willson, M. and Williams, D. (1996) Trainee teachers' misunderstandings in chemistry: diagnosis and evaluation using concept mapping. *School Science Review* 77(280) 107-113

Wiskin, C. (2004). International science teachers programme. *Eis* Feb,10-11

William, D. (1993) Validity, dependability and reliability in National Curriculum assessment. *The Curriculum Journal*, 4(3), 335-350

Woese, C., Magrum, L. and Fox, G. (1978) "Archaeobacteria." *Journal of Molecular Evolution* 11 (3): 245-51

Wood-Robinson, C. (1994) Young people's ideas about inheritance and evolution. *Studies in Science Education*, 24, 29-47

Woolnough, B.E. (1991) Setting the scene. In: Woolnough B.E. (Editor) *Practical Science*, Buckingham, Open University Press

Wragg, E. (1984) Conducting and analysing interviews In: Bell, J. Bush, T., Fox, A., Goodey, J. and Goulding, S. (Editors) *Conducting Small-Scale Investigations in Educational Management*, London: Harper and Row

Wragg, T. (2002) Interviewing. In: Coleman, M and Briggs A.R. (Editors.) *Research Methods in Educational Leadership and Management.*, 143-158 London: Paul Chapman.

Yim-Teo, T.H. (2004) Reforming curriculum for a knowledge economy: The case of technical education in Singapore. *Education that Works: The NCIIA 8<sup>th</sup> Annual Meeting*, 18-20 March

## APPENDIX

### **Appendix 1: Pre Interview Transcript of Student 3 (S3) of 2007 Cohort**

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**Ideas about:** Terminology

#### **Pre interview Q1**

##### Term 'Microbiology'

The student clarified the meaning of the term 'micro' putting in a numerical value to the microbe's size at  $10^{-6}$  and probably use the definition and knowledge learnt from school and apply them by heart as he could not put an idea to its dimension since no unit was included. His meaning on  $10^{-6}$  remains doubtful.

*"Biology is the study of living organisms. ...micro is the study of things on a micro scale. something times 10 to the power minus 6."*

When asked to elaborate on the meaning,

*"Because that's micro what...In the extended unit. "*

*Q: What is a microorganism ?*

*"Microorganism uh. ....something...that's alive la, then...very small. So until 10 to the power of minus 6.*

*Q: What happens when it become to 10 to the power minus 5?*

*"10 to the...?"*

To S3 microbe is a small living that goes in the range of  $10^{-6}$  m. He is probably referring to the measurement of micron which is at the range of  $10^{-6}$  m but he is not certain on its meaning behind it or comprehends the minuteness of the scale. To S3, anything that measures  $10^{-6}$  m is a microbe.

His idea on microbes was also related to former learning in primary school where his earliest introduction to microbe was the plankton.

*Q: Why... do you say in the sea?*

*"...what I heard ...because in primary school that's something called plankton ...they say is a...microorganism ..so I think most of them is from the sea"*

##### Term 'Colony'

S3 describes what he has done in his secondary school days and has seen a colony. He knows about the accumulation of microbial cells due to reproduction

but probably did not realise that that these accumulation of new cells which are identical genetically, actually derived or originated from a single cell. His idea on colony is a grouping of microbes without any regard on its origin.

*" 'colony' ....if I'm not wrong right, .....group of bacteria together then it forms a colony. Because I used to do experiment in my secondary school ...enhancement programme.. ...you put in the bacteria inside a agar...thing, you know, you inject it. Then after a while, you take it out then you see the bacteria multiplying..... So and then that...that whole bunch right, considered as 1 colony."*

### Antibiotics

Student S3 thinks antibiotic is a type of drug used to combat viruses. He probably based incorrect knowledge of antibiotic on his experience on the medication given to him when he has a bacterial infection since medication is not given for viral infection.

*"it means ...it's...it's something like virus . ...then you're actually filling in the virus so that the virus inside...so that the antibiotic can actually ...fight against the virus that is already inside your body."*

*Q: The antibiotics fight against the virus.?*

*"Maybe you have the virus inside your body, then you need antibiotics to actually ...fight against the.....virus that is already inside your body"*

*Q: What's the nature of the antibiotics? What is it ?*

*"...from what I know it's a drug la...it's a drug. Then I eat some them before. Think one of them is the...yah...the white one.. it's sealed in a ...don't know la, forget already ...I usually eat it when .....have fever. Then they will give you antibiotics."*

When he was asked about the function of microbes, he used his class experience to derive them. The example he gave was about the degradation of urea an organic matter into soluble ions by the organism. It is likely that he was referring to brief introduction on microbiology given to his class a week ago about the use of microbes to break down urea, a source of fertilizer, into soluble ions in the discipline of agriculture.

*Q: Alright uh...do you know of any function of microbes?*

*"...it's to convert organic matter into soluble ions so that the soluble ions...yah it's to...it's to convert organic matter into ions la, like the urea example that you give me..."*

**Ideas about:** Microbial growth

**Pre interview Q2:**

S3 claims that he will not see anything but thinks that something small is probably present in the clear water collected from the stream. He refers these things as microbes and realise the need to use a microscope to view these small things to see if they are present.

He also did not realise and had no idea that the odour probably arise due to some microbial activity or processes which would have given him a hint that some organisms are present. These odour will become more pronounce after 3 days due to biological processes like anaerobic respiration and fermentation fuel by the population growth of microbes. Some signs of turbidity indicating microbial is expected after 3 days.

S3 expects that microbes probably is present but has no idea on the tremendous ability of the organism to multiply and divide rapidly in such a 'short period' of 3 days.

*Q: Now you are given a test-tube with clear water taken from a stream nearby. What will you see?*

*"See...if it's clear...uh...clear means nothing. It's a colourless solution. ...colourless solution, then maybe there's some odour... .."*

*Q: Some odour?*

*"Yah."*

*Q: Ok, would you expect, would you expect anything inside there? Would you expect to see anything inside?*

*"...I don't think...I don't think can see anything inside. I know it's clear.. but if you want to look under microscope, then maybe some microorganisms"*

*Q: Would you expect some microorganisms to grow inside there?*

*"I expect "*

*Q: But you can't see them?*

*"Yah, but cannot see them."*

*Q: Ok, now what happens if the same tube of water uh, I leave it there and then show it to you 3 days later?*

*"Is the test-tube enclosed or..."*

*Q: ...it's closed.*

*"It's closed uh. What most likely in the cap there's some strange odour la. After 3 days...because usually... ..There's a certain smell uh...there's a certain strange odour at the cap there. "*

*Q: What, will you see anything inside?*

*"no .. cannot see .., got one strange odour "*

*Q: So but do you still think there's living things inside, after 3 days?*

*"Living things inside there uh...I think there is..."*

*Q: Will you see anything inside?*

*"Don't think so.."*

*Q: So, but you don't know where the odour comes from?*

*I don't know where the odour comes from.*

**Ideas about:** What a microbe is (classification).

### **Pre interview Q3:**

When asked how he would consider a thing as a microbe, S3 again referred to the earlier answer of classifying any living things as long as it measure at  $10^{-6}$ . He probably did not think that microbes can be larger than a micron like the yeast cell.

*Q: How would you consider a particular thing uh, as a microorganism?*

*"Microbe...how I define just now any creature then..... times 10 to the power minus 6 "*

He was able to initially able to distinguish between a microbe and a non microbial grouping for the ant because under normal circumstances, ants can be observed visually. However, he soon changed his mind and revert his decision when he was told that the ant size was  $10^{-6}$ . S3 clearly shows that he based his decision to classify things as microbe according to it physical dimension, thus needing a microscope. Argument based on independent single cell organisms was not used. Has no idea that a microbe is made up of a single cell.

*Q: Ok, fine. ....so if you got a...say a very tiny...say a tiny ant, would you consider that a microbe?*

*": ...no."*

*Q: But if you have an ant, an ant to the power minus 6, would you consider as a microbe?*

*"Yes. "...*

*Q: Why?*



*S3: because it's small and can't see them without a microscope*

S3 also used the ideas on living and physical dimension to classify the pollen as a microbe. He seems to regard highly on the idea of being alive first before applying the idea of the physical size. So 2 ideas are present for the case of pollen.

*Q: Ok, what about a...a pollen? If I can get a pollen 10 to the power minus 6, would you consider that as a microbe?*

*"But is it alive or not? Alive yes, it's a microbe...not alive, then no"*

*Q: ...must think of alive then can be consider a microorganisms?*

*"...organisms are alive .... plants animals...they are organisms, so they are supposed to be living things."*

*Q: Alright, but plants and animals are not microbes.*

*S3: Oh..yes...(silence)*

*Q: So if I...I got a pollen, say, a...a...plant pollen...and It's 10 to the power minus 6. Would you consider that as a microorganism?*

*"Yes ...Cause I know that the pollen, you know...uh...can actually... can actually divide. Then the pollen can actually, be used for you know... fertilization. Yes, the pollen can be a microorganism. "*

It also demonstrated that S3 was using his limited knowledge on pollen incorrectly classify pollen. Pollen will only undergo cell divide but only after fertilisation and he did not realise that microbes are capable of reproducing on its own via cell division on its own without the involvement of another cell. His familiarity on microbial organisms is limited at this stage.

*Q: .....any examples of microbes that you can name, would you know?*

*"I don't know any. ...you never teach... ..."*

**Ideas about:** Occurrence of microbes

#### **Pre interview Q4:**

S3 referred microbes as 'germs' when the issue of hand washing came up in this instance. Earlier in the interview there was no mention of germs in the discussion. Was there a reason for the negative 'tag' to this term?

*Q: We are advised before we have our lunch or dinner, we have to wash our hands. ...why do we have to do that?*

*"...it's to ...wash away the germs right..".*

Q: *From where?*

*"...that sticks onto your body. It can be many form.... Maybe the...sweat palms, you know then there're germs on it. Then we do some work, there're germs on it."*

He seems to infer that the germs present in the hands and body originated and came from the air around him. He also probably thought that the sweaty condition on part his body like hands makes it more vulnerable to come in contact with the germs that were already present and flying about in the air around him. Thus, the reason to wash them before eating. But S3 did not specifically say that it causes diseases but seem to point towards that.

Q: *So where do...these germs come from?*

*"...from the air. ..."*

Q: *Explain, please.*

*"As we eat, our hands come into contact with the air...Palms...palms actually stick onto it. All germs come into contact."*

Q: *Where, where do they come from? Stick on the hands, before they stick on the hands, where do they come from?*

*"...somewhere ... Maybe the germs are flying into the air. Then you have sticky palms then the thing sticks onto it."*

At the end of the interview on occurrence of microbes, S3 probably thinks that the 'germs' are likely to be pathogenic and can make him sick. This can be indicated by his confidence that hand washing with soap will have a antiseptic affect on his hands thus freeing him of the 'germs'. But S3's view on the pathogenicity of microbes could not be confirmed since some of his ideas were contradictory. This was seen in with regard to his views on occurrence of microbe inside the body.

Q: *...is it advisable to use soap when washing hands?*

*"Yes."*

Q: *Why?*

*"It's to kill away the germs..."*

Q: *So when you...when you use soap to wash uh...your hands, it kills away the germs.?*

*"Yah".*

Q: *Would it kill uh...all the germs? Or a little bit of it.*

*"Yah, 99%. .Ya so most of it, but not all ...".*

Q: Ok. Alright, now erm...so what will happen to you when all these microbes are...found in your body?

"No idea. ...they will just multiply!."

Q: Will you be sick because of that?

"I don't think so la..."

Further questioning revealed that S3's ideas on the occurrence of microbes also include land and sea. When queried on his ideas about microbes in humans, he appeared to associate microbes with dead tissues found at the soles of feet although its purpose of its presence was not discussed.

His limiting idea on the microbe where its purpose and function is concerned was shown in his failure to relate the presence of microbe in large intestine. It is believed that this failure was largely due to poor terminology used during the interview. This was shown when his responses about the microbial presence in large intestine being linked to the bile storage in the intestine was meant to indicate that organic matter (bile) in the intestine was broken down into ions. 'Sounding' more like the reference was being made on digestion, the question was then repeated back to him for confirmation. At some point during the interview, the student seemed confused and had to be guided back into the discussion.

Q: ..... Just now you were saying that microbes can be found the air uh, so where else can it be found?

"Land, air and sea ..."

Q: My question was, so do you think that there's any microbes in you?

"...I think...there is"

Q: uh. where did it come from? Which...which part?

"Dead tissues?"

Q: Where? Can you identify some areas where you think there's dead tissue?

"...soles of the feet.

.... You know when you walk, you walk until tired then you see the sole a bit...you know the skin is going to peel out, yah so those are the dead...tissues .."

Q: (guiding S3.....) What about...inside you, would there...be any?

....which part of the body do you think is (microbe) inside you?

"...large intestine."

Q: Why do you think large intestine?

"...because...that is where all the bile is stored...I believe there is microbes inside the bile."

Q: ...where are... ..what...what do these microbes do in the intestine?  
" Maybe convert the bile into ions."

Q: Any...anything else you want to add?  
" Fertilizer? No idea. "

Q: To convert means?  
" Convert means...make the...organic matter...into...ions..yes. So that it can...ya, make into ions."

Q: Ok, so what happen to these ions then?

" These ions...these ions remains... ..depends la because if you add water right, these ions are mobile right, ya. "

Q: This is for what purpose.  
"For fertilizer purposes."

Q: You mean as a source of fertilizer for example...plants?  
" Yes."

Q: I'm referring more to what is inside humans you know.  
" Humans only?"

Q: Yes,. Inside humans only.  
(Silence)....." No function."

Q: ..so I just to want to find out ...if I read it correctly, you were saying that microbes in the small intestine is to break down the stuff uh, break down things ...  
"Ya".

Q: Break down things means what?.  
"You know ..the large food is broken down to smaller pieces.. I Think digestion means breaking down the food.... will be better description. "

The student though knew about the presence of microbe in the intestine, he did hinted that the microbe probably originated from the air outside the body when he explained briefly about routes taken by the intestinal microbes when entering the body.

Q: How do these... microbes stay in your intestine managed to get into your body? How do they do that?  
" From your nostrils, from your mouth, the ears... Any...any channel also."

**Ideas about:** Living characteristics

**Pre interview Q5:**

**Virus**

Student began recalling the image of a bacteriophage which has the legged features for a viral when he was asked what the virus looks like. He also describes the way the virus inject or transfer the genetic material to host cells. This shows he has come across some information about the shape of a popular shape of viral particle often shown in books and know a little about the infection mechanism.. His impression or idea about the size of viral could amount to it being smaller than that of his earlier dimension for a microbe. This shows he knew that viral is smaller than bacteria.

*Q: Can you explain what a virus looks like?*

*"Virus... from what I know right, it's a 3-legged...it's a 3-legged creature la, ok. Then what this virus do is, they land on your skin, ok, then they like mosquito la, they inject something then put something inside, then they...run away"*

*Q: Ok, how big do you think this virus is?*

*"I guess, 10 to the power of minus 9. "*

*Q: Is bacteria larger or virus?*

*"Think bacteria are larger."*

S3 considered virus as a living thing and did not explain why he thinks it is a living thing. He also could not explain why he thought the virus is 'special' that it is neither an animal nor a plant cell.

*Q: Ok. Are these virus living organisms?*

*"They are alive uh? They are living. "*

*Q: Ok, they are living. Uh...so if they are living, are they uh...plants or animals?*

*"Neither. Special category. I know they are not animals or plants.....so special category."*

He expressed about uncertainty about the intake of oxygen but he associate breathing with oxygen intake. S3 is also uncertain about viral nutritional requirements and how it derives its nutrients. The student's idea on reproduction for virus appears to be incorrect when he described the process of binary fission with a single cell dividing into 2 and sharing the same chromosome number. This process occurs in most bacteria. So far S3's ideas about the living characteristics and knowledge about the virus are insufficient besides it being found in the air and its vague mental image and what it does. His idea about reproduction is based on his thinking that size has a direct influence on reproduction. The

smaller the organism, the faster the progenies are produced. Size dominate his understanding on reproduction.

*Q: Alright, uh, do they breathe or not?*

*" They...er...they breathe la, but I don't know whether they take in oxygen or not, because some virus can survive without oxygen."*

*Q: ..... How do they feed? How do they uh...consume their food?*

*"Solar energy. ...don't know , if the virus is photosynthetic then ....it is able to make it's own food ...if not then most likely the virus uh, would eat something that is smaller than itself..."*

*Q: And how would they move about?*

*"Move about? by air ...Float in the air .."*

*Q: ....and how do they reproduce?*

*" Binary fission. "*

*Q: I mean can you explain...how...how this binary fission works?*

*"...for maybe the single cell will be split into 2 and then after it split into 2 right, it still share the same number of chromosome ."*

*Q: Any idea how fast it reproduce?*

*"...hmm...faster than the production of bacteria but slower than the speed of light. Because what I think is, things that are smaller reproduce faster, ya reproduce faster."*

## **Bacteria**

S3 mistook bacteria for the other microbes when he describes the shapes of various microbial organisms. For bacteria, its shape is mainly rod shape. He seems to portray some confusion between microbes and bacteria by associating similar shapes which exist between bacteria and other microbial organisms.

*S3: What's a bacteria, look like to you?*

*"Bacteria...A dot. A very small one. Can look through a microscope."*

*Q: Alright, what's the shape of the dot?*

*"It can be...spiral, it can be...elongated, it can be...spherical. "*

His idea of living was based on the fact that the bacteria reproduce and in this case, he did manage to describe the process to show his understanding.

*Q: Ok. Are...are bacteria living things?*

*" Yes"*

Q: *Why do you say they are living things?*

*" They are able to reproduce.....Binary fission...divide in 2 and then again divide into 2."*

S3 ideas about breathing is the same as how a human breath which is through the nose. He realised the difficulty in explaining when he could not use the 'nose scenario' to explain how the bacteria 'breath'. His alternative biological process of using osmosis has no impact about the intake of oxygen into the bacteria. This indicates the student's poor understanding on concept of respiration which concerns the intake of oxygen and removal of carbon dioxide at the cellular level. He could only comprehend the 'surface level' of respiration process (to him its breathing) with regard to oxygen being drawn at the nose.

Q: *Ok, anything else?*

*"..they...they breathe."*

Q: *How do they breathe?*

*"... they don't have nostrils .... ...I don't know how the air goes in .., may be it's true...osmosis. ...but they need air . "*

The student also possesses poor knowledge about the very nature of bacteria being a prokaryote in which the nucleus is not present. In this instance, S3 claimed that bacteria has nucleus. Perhaps this misconception is due to vagueness or unfamiliar on the definition and clarification of such terminology commonly used in microbiology.

It was however surprising he regarded the bacteria as a single cell organism with flagella. S3 could not recognize the significance for the bacteria to be motile and unlikely that he knew the function of the flagella which is necessary for the bacteria to move in the moist environment found in the body.

Q: *Ok. These bacteria, are they plants or animals?*

*"Ya...they. usually eukaryotic. Ya. Most of...most of them are single cell, yah, then some actually have flagella."*

Q: *Are they eukaryotic or prokaryotic?*

*" Eukaryotic. Of course there are exceptions ....."*

Q: *How would they move?*

*"...by the air. .... In the body...crawl on the walls. On the intestine or what..."*

Q: *... How would they crawl?*

*"I would think like the earthworm like that...or caterpillar..."*

Q: *They have legs or not?*

*" No legs ..."*

Q: Tail?

*"Some have, not all. ..."*

Q: What's the tail for?

*"It will be for moving about."*

On the bacterium's nutritional requirements, S3 had the idea that the bacteria gets its food by engulfing or 'grabbing' other smaller organisms such as the virus. Involvement of other biological processes such as aerobic or anaerobic respiration, oxidation, membrane transport which were needed to facilitate movement of mineral nutrients were not mentioned. So his conception of a microbe obtaining nutrients by means of a physical mechanism to surround its 'food' contributed toward the poor understanding of the living characteristic of bacteria.

Similar to his earlier response on the function of microbes where he recall information from the introductory lecture held a week ago at the start of semester, S3 again mentioned of the photosynthetic function of cyanobacteria. Its inclusion could hamper the validity of the data and thus will not be regarded as part of the students' explanation.

Q: .... How they can feed?

*"Bacteria...hmm...they feed on virus. ... They feed...Either they feed on something smaller on them or either they...they have like you know cyanobacteria you know, yes they got the green pigment so they can photosynthesize. ..."*

Q: How?

*"Just grab the food..I guess? ...."*

- End -