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A PROBLEM BASED LEARNING APPROACH: THE BIOCHEMICAL ORIGIN OF LIFE ON EARTH

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Abstract

Students in an upper level biochemistry subject at Avondale College investigate the chemistry and biochemistry of the origin of life on earth using a problem based learning approach. Students work in groups analysing the various issues associated with this problem and develop skills in critical thinking, problem evaluation, assessment of theories in the light of evidence and oral and written communication. Their work is presented as an edited group report. Students apply the biochemistry learnt in earlier subjects and extend their knowledge where necessary while appreciating the many biochemical hurdles to producing the first reproductive primordial cell(s). Various biochemical aspects of this problem typically encountered by students are discussed. Students grow in confidence as they accept responsibility for their own learning. This educational approach allows time for extended discussion of science and faith issues related to the origin of life on earth. Students learn to appreciate the tensions at the science-faith interface and that these challenges are important opportunities for the development of intellectual and spiritual maturity.

Introduction

Finding a satisfactory answer to the question of the origin of life on earth in terms of contemporary biochemical understanding of the cell presents an enormous intellectual challenge in terms of both science and faith. The experiments of Miller and Urey at the University of Chicago in the early 1950s did much to advance scientific thinking about life's origins.[1,2] As a result of experimentation, their simple apparatus containing a gas mixture believed to mimic the theorised atmosphere of the early earth yielded very simple organic molecules. The scientific community, seizing upon the results of the experiment postulated that life must have originated from this primordial soup. In past years, criticism of the Miller and Urey experiment and associated theories attempting to explain the development of simple reproductive cellular life in terms of chemical evolution have led prominent scientists such as Fred Hoyle and Francis Crick to suggest alternative explanations of life's origins such as panspermia.[3,4] The acceptance of such highly speculative theories underscore the challenging nature of the question of the biochemical origins of life on earth. As observed by Michael Denton:

> Nothing illustrates more clearly just how intractable a problem the origin of life on earth has become than the fact that world authorities can seriously toy with the idea of panspermia.[5]

Investigations into the biochemical events that must necessarily take place in order to produce a metabolically active reproductive primordial cell serve as an excellent intellectual canvas for upper level biochemistry students. Asking questions about the development of cellular life integrates and challenges a student's understanding of biochemistry, metabolism and cell structure. Problem Based Learning (PBL) is a particularly useful educational methodology in this type of investigation and has been used with success in the Faculty of Science and Mathematics at Avondale College.[6] This paper will discuss student experiences with a PBL styled inquiry into the origin of life on earth that allows students to engage with biochemical facts and theories as well as providing opportunity to discuss issues of science and faith in a meaningful way.

Problem Based Learning (PBL)

Despite the successful use of PBL as an educational methodology in a variety of professional and educational programs including medicine, nursing and engineering it has not often been utilised in the biology component of non-professional degrees such as a BSc. PBL (and its various hybrid varieties) differ from typical lecture and note taking form of instruction. Instead of being presented with structured formal lectures and tutorials (where information is disseminated by the lecturer and the degree of retention by the student assessed), a change is made to a learning environment where students are exposed to a series of problems for which solutions are found. The lecturer becomes a facilitator, and the student becomes actively involved in the learning process working in small groups made up of their peers.

One of the significant educational characteristics of PBL is that the student assumes greater responsibility for their own learning. Instead of being passively involved as they would typically be in a lecture, students are encouraged to develop skills in critical thinking, problem evaluation, analysis of literature and assessment of established theories in the light of evidence. A student's oral and written skills are developed in a team setting as the problem is analysed and the group collaboratively searches for solutions. The process of problem solving becomes more important than the problem content, because the process can be applied to a variety of problems in a variety of disciplines. Student self-evaluation and reflection on the learning process are also important aspects of PBL. The above features are valued characteristics to be found in graduates from science programs and allow students to integrate specific discipline knowledge into the bigger picture.[7] The motivation for such a change in educational methodologies has been discussed elsewhere and includes the noted lack of enthusiasm of some students for lectures, poor performance of students in tests and examinations and the fact that many students do not retain knowledge or information for long periods of time.[8]

Students in an upper biochemistry subject (300 level or third year of degree) were divided into groups and supplied with detailed materials and instructions introducing them to PBL. In addition to a statement of the problem to be studied, students were supplied with a manual of selected related research papers along with a list of further references. The manual of printed research papers was supplied to guide students in their initial reading and give an overview of the area. Students were advised that these papers were by no means to be considered exhaustive and they were expected to extend their readings and investigations considerably.

The groups met twice a week for extended periods and minutes of meetings were kept. The aim of group meetings was to allow students to investigate assigned problems, make presentations to the group based on individual student reading and eventually formulate and write a seamless and well edited group report based on their investigations. Students were challenged by this learning process and took ownership of and responsibility for their learning. The lecturer was on hand as a resource and facilitator of the educational process. Students were assessed on the group report (50% of final grade), individual student portfolios (30% of final grade) and by peer and lecturer based assessment (20% of final grade). A student portfolio includes a student's research notes, presentations to the group, evidence of papers read and their individual contribution to the final group report. For peer assessment, students regularly assessed each other's contributions to the group problem solving activity using an anonymous survey instrument (see appendix). Students also filled out a self assessment for comparison purposes. The results of peer and lecturer assessment were returned to each student so they could gauge how they were performing within the group. The peer assessment was found to be a powerful motivational tool for students who may have been under performing.

Methodology of Problem Solution

Initially, students were often confused about their task and initial group discussions reflected a sense of trepidation on the part of some students. This is to be expected, both in terms of being exposed to a new educational methodology compounded with investigating biochemical problems of a complicated nature. Some guidance from the lecturer/facilitator was usually necessary in these early stages, but in general, students quickly adapted and the advantages of student ownership of the problem and responsibility for the learning experience readily became obvious.

Problem solving involved several predictable steps. Firstly students were encouraged to analyse the components of the problem in brain-storming sessions. Secondly, students clarified issues from these initial sessions and often needed to set limits on the area of inquiry to ensure the discussions did not follow interesting yet distracting tangents. Like any good research project, students quickly found that many questions can be generated from the original problem and many avenues of investigation become available. Often large sheets of paper or a white board were used to generate concept maps. This prompted students to come to terms with material not only from the discipline area of the problem, but also material studied in related disciplines. Thirdly, students assigned themselves specific aspects of the problem for investigation and the details of individual student tasks were recorded as minutes in the group log. Fourthly, individual students then undertook detailed literature investigation according to their assignments. Finally, students reported back to the group on these investigations using oral presentations informing the problem solving process for the entire group. The cycle repeated until students were in a position to write sections of the final group report.

The final group report is a substantial document. It is graded on content (reflecting adequate reading in the area), scientific accuracy, synthesis of scientific ideas and concepts (rather than a summary of the area), logic, argument, coherency (displaying a progression of ideas through the document), expression (written in a concise scientific manner), editing (the document should be the seamless product of an obvious editing process) and finally accuracy of referencing.

Problem Selection

The problems for this subject were very carefully selected. The fourteen week semester allows an in depth analysis of at least two biochemical problems. While there are a large number of biochemical problems that can be utilised in a subject such as this (other problems include such topics as the biochemistry of diabetes, systemic effects of smoking, and AIDS, etc), exposing students to the fundamental problem of the biochemical origin of life on earth allows a detailed study of this topic in a manner that could not be achieved in a lecture based course.

This problem is presented to students in the following manner:

> ***How did life arise on this planet? Investigate the biochemistry and molecular biology of the processes that would need to take place in order to establish reproductive life given the theorised state of the primeval earth. Would these prevailing conditions support the development of reproductive life?***

Subsequent investigations allow students to appreciate the scientific method and see how experiments can test hypotheses developed to explain historical phenomena. In depth consideration of this problem takes a multi-disciplinary approach and informs related science faith issues.

Any student intellectually engaged with this area will gain first hand appreciation for the complexity of life processes and will realise that the probability of these processes developing spontaneously through chance events is exceedingly small. The experience of students undertaking this endeavour will reflect the thought expressed by Professor Klaus Dose some twenty years ago:

> More than 30 years of experimentation on the origin of life in the fields of chemical and molecular evolution have led to a better perception of the immensity of the problem of the origin of life on earth rather than to its solution. At present all discussions on principal theories and experiments in the field either end in stalemate or in a confession of ignorance.[9]

However, not all scientists see this problem as insolvable and science undergraduates should be aware of all sides of the issue. As scientific techniques are refined and as scientific knowledge increases seemingly inexplicable phenomena are often explained. While admitting the problems associated with molecular progression from primordial soup to functional cell, Conway Morris is typical of many scientists when he states:

> It is not my intention to suggest that the origin of life is a scientifically intractable problem, but at this stage of the proceedings to register mild surprise at the relative lack of experimental success.[10]

Biochemical Aspects of the Problem of the Origin of Life on Earth

Students are usually surprised by the extent and depth of difficulties that are part of contemporary understandings of the development of the first reproductive primordial cell. Biology students are familiar with the account of chemical evolution leading to the speculated assembly of the first or primordial cell (or cells) found in the introductory chapters of most biology, biochemistry or physiology texts. This classic view describes the formation of organic molecules in an aqueous environment on the surface of the planet as a primordial soup and their spontaneous association as macromolecular components of a biochemically functional cell.

The development of the contemporary view has as its basis the experiments of Miller and Urey. These experiments utilised the work of earlier scientists such as Oparin and Haldane.[11] Oparin suggested that simple organic molecules could participate in reactions leading to the formation of molecules of increasing complexity. Haldane envisaged these types of reactions occurring in the primordial oceans (pre-biotic or primordial soup). Miller and Urey filled a flask with a variety of gasses such as water vapour, methane, ammonia and carbon dioxide. The flask was subjected to the electric discharges between two electrodes and the resulting condensing liquid was cooled and removed from the reaction vessel for analysis. The resulting mixture yielded a variety of simple organic molecules including a range of amino acids, carboxylic acids and nucleic acid bases. Students must recall much of the organic chemistry and simple biochemistry learnt at earlier stages of their degree studies. The following describes the issues and problems typically encountered by students undertaking a careful analysis of this view of the origin of life.

Students will note that under the conditions of the experiment, biologically significant macromolecules such as proteins, carbohydrates or polynucleotides (DNA and RNA) failed to form. The wider scientific community was satisfied that a basis for the production of these biological meaningful macromolecules had been demonstrated and that they could form by as yet unknown mechanisms from the simpler compounds produced. Thus the Miller and Urey experiment was used as a starting point to infer that simple organic molecules could assemble into macromolecules, which could then in turn self assemble into the primordial cell. This cell would then be the starting point for the evolutionary process of natural selection. Eventually the extraordinary diversity of life observed on this planet would be produced.

Students grappling with these issues come to realise that while the experiment was of value explaining the possible development of simple organic molecules, it did not provide any insight into how such molecules may develop into a functioning cell. Nothing short of a quantum leap would be necessary from such simple organic compounds to macromolecules, and a further quantum leap from macromolecules to a functioning cell. As yet there is little in the way of satisfactory suggestions for mechanisms accounting for how these extraordinary hurdles may be overcome.

With the rapid developments in biochemistry and molecular biology in recent decades there has been an exponential growth in the understanding of the complexity of cell structure and function. In the light of such knowledge, coupled with a revision of the theorised conditions of the early earth atmosphere, the explanatory power of the Miller and Urey experiment has subsequently come under scrutiny for its ability to furnish a satisfactory explanation for the development of life.[12,13,14,15,16] Students need to investigate the numerous problems that have now been raised with respect to this historic experiment.

It was assumed that the early atmosphere of the earth was reducing and the reaction flask in the experiment contained such a mixture. However, it is now suggested that oxygen was probably present and would result in oxidative destruction of reaction products as they were formed. In the apparatus, chemicals formed were removed from the reaction mixture for analysis and thus protected from destruction in the reaction flask. As mentioned, no information rich and thus biologically useful macromolecules (DNA, protein, lipids or polysaccharides) were produced as a result of the experiments. It is well established that the synthesis of macromolecules such as proteins is dependant upon chemical information in DNA in a complicated process which is itself dependant on enzymes coded for by DNA, such that the order of nitrogenous bases in DNA determine the order of amino acids in synthesized proteins. The order of amino acids in a protein molecule in turn determine its three dimensional shape and hence function. Thus if either DNA or protein *were* produced through such experiments, the order of either bases or amino acids would be purely random and yield DNA or protein molecules with no or at best very little biological function. Further, in biological systems protein molecules such as enzymes act in harmony with other enzyme molecules producing biochemically functional metabolic sequences. It is hard to envisage how such coordinated function may arise from such random chemical processes without a pre-existing DNA molecule containing meaningful information. Theories advanced to explain the origin of such information rich molecules and cellular metabolism (such as clay crystals and RNA worlds) are highly speculative.[17, 18]

The problem of chirality is a significant hurdle for the Miller and Urey experiment. Consequent upon the chemistry of the carbon atom, many organic molecules can exist as stereoisomers in either an L-form or its mirror image D-form (enantiomers). Biological systems utilise only L-form amino acids and only D-form sugars as components of larger macromolecules; yet L and D-forms of molecules are formed in roughly equal amounts known as racemic mixtures in chemical reactions outside of biological systems. This unique selection of specific forms of molecules for use in biological systems cannot be explained by such experiments. Finally, the experiments of Miller and Urey were carefully and purposefully planned, designed and constructed and it could be argued that the perceived randomness associated with the primitive earth was actually carefully ordered and controlled under the conditions of the experiment. Certainly this type of planning and experimental control may have contributed to the specific results obtained, particularly with respect to the removal of products from the reaction chamber of the experiment where they would be destroyed as they were made.

Consideration of the biochemical origins of life on earth allows students to consider some historical aspects of the development of scientific thought. While not directly related to the Miller and Urey experiment, Louis Pasteur addressed the concept of abiogenesis or spontaneous generation in1864. At this time, observations of mice, cockroaches, maggots and flies associated with rotting garbage and other materials gave rise to the theory that such matter formed living organisms in some mysterious way. In his landmark experiment involving his swan-necked flasks, Pasteur demonstrated that living organisms couldn't be derived from inanimate matter. A series of flasks filled with nutrient solutions were vigorously boiled (so as to sterilise the contents), and while some had their necks pulled into long contorted shapes, others were left so that microorganisms in the air could fall directly into the solutions. The latter flasks rapidly spoiled from falling air borne microorganisms, while those flasks with drawn necks remained sterile as microorganisms were denied direct access to the nutrient fluids by the drawn necks. Both types of flasks remained open to the atmosphere, and if the theory of spontaneous generation were true, both sets of flasks should have spoiled. While consideration of Pasteur's swan necked flasks does not directly inform Miller and Urey's' famous experiment it does allow students to observe that historically at least the concept of abiogenesis has been considered before.

Students need to consider the probabilities associated with the formation of biologically useful protein molecules from amino acid mixtures. As mentioned, to be useful in a biological system, a protein molecule must have a specified order of amino acids, the side chains of which determine the shape and hence function of the molecule. The order of amino acids is determined by the order of bases in DNA. The probabilities of generating either biologically active protein or polynucleotide molecules from precursor amino acids or nucleotides through random chemical process are astonishingly low to the point that one might conclude there is no chance of developing useful macromolecules by wholly naturalistic means as they are presently understood. Estimates of the probability of forming an average protein molecule using 20 amino acids vary between 1 chance in 10^{40} to 1 chance in 4.9×10^{191}. Given that there are about 2000 different types of protein molecule needed by a cell for normal metabolic purposes, the chances of assembling this many molecules simultaneously seem extremely remote. Similar estimations may be performed for nucleic acids, and the probability of the formation of a nucleic acid molecule coding for a protein with biological function, consisting of 100 amino acids is in the order of 1 chance in 10^{120}.[19, 20, 21]

Cellular Requirements for Life

Attempting to overcome the hurdles of describing how precursor organic molecules are formed and assembled into macromolecules may be conceptually less difficult than proposing how these various essential macromolecules once formed are organised into a reproductive cell. In their deliberations, students need to consider the basic biochemical requirements of any cell capable of division. In addition to having knowledge of basic cellular metabolic process, students must be thoroughly acquainted with the molecules that participate in the complex process of cell division.

So what are the basic requirements for life? An appreciation for the extraordinary complexity of the workings of the cell can be obtained by even a cursory glance at any biology or biochemistry text. The following are required by any cell in any biological system; but for life to flourish on this planet they must, most importantly, be possessed by the primordial cells resulting from a conjectured process of chemical evolution early in earth history. Firstly, such cells require a method for capturing energy (as in the case of photosynthetic organisms that make their own food) or a mechanism for utilising energy derived from pre-formed organic molecules (both methods involve very complex biochemistry even in the simplest of organisms). The energy is needed to drive other biochemical processes necessary for metabolic function.

Secondly, cells must possess at least an outer membrane to keep the outside environment from disturbing the staggering array of chemical reactions inside the cell required for life. Higher cells (the eukaryotes) also possess internal membrane structures for compartmentalisation of biochemical reactions (such structures include endoplasmic reticulum, chloroplasts and mitochondria). Thirdly, there must be a system by which genetic information can be stored. Organisms store such information as a chemical language, in the sequence of bases that make up DNA. Fourthly, this information must be accessed and used to direct the synthesis of enzymes and other proteins the cell requires to function. Finally, there is the all-important requirement for cellular division and self-replication. The stored genetic information must be replicated and passed onto daughter cells in order to produce descendant life forms.

Students rapidly appreciate that the biochemistry that forms the basis of these processes is of extraordinary complexity despite the apparent simplicity of the first theorised primordial organisms. It is easy to argue that no cell is 'simple' as there has to be a basic level of biochemistry for life process, and all living cells share this basic level. Students face an intellectual challenge as they apply the biochemistry they have learnt to the problem of the origin of life on earth. Confidence grows as they wrestle with a problem examined by so many scientists who are equally challenged to explain it. For any primordial cell to exist, all the biochemical systems must not only function correctly in their own right, but must also coordinate with the other systems. Thus, the primordial cell, like any other would depend on its energy-generating biochemistry in order to operate crucial metabolic processes and synthesise essential molecules. Information for molecular synthesis is stored in DNA. Energy generated by the cell is required for DNA synthesis and cellular replication. DNA synthesis depends upon enzymes whose blueprint is contained in DNA. None of these systems could function if it were not for the cell membrane separating the cell's biochemical reactions from the external environment. Further, enzymes encoded by information in DNA direct synthesis of the membrane itself. Some further aspects of the interdependency of cellular metabolic activity can be summarised in the following table:

The Interdependency of Essential Molecules or Biochemical Systems in a Self-replicating Cell.

	Minimal Requirements of any Self-Replicating Cell	***Ultimate Dependence On***
1	DNA	1,2,3,4,5,6,7,8,9
2	Messenger RNA (mRNA)	1,2,3,4,5,6,7,8,9
3	DNA and RNA polymerases	1,2,3,4,5,6,7,8,9
4	20 different amino acid activating enzymes	1,2,3,4,5,6,7,8,9
5	20 different transfer RNA (tRNA) molecules	1,2,3,4,5,6,7,8,9
6	Ribosomes (rRNA, ribosomal proteins, etc.)	1,2,3,4,5,6,7,8,9
7	Lipid membrane(s)	1,2,3,4,5,6,7,8,9
8	Carbohydrates or other appropriate energy sources	Other organisms
9	Metabolic enzymes for energy production	1,2,3,4,5,6,7,8,9

The obvious interdependency of operationally complex biochemical systems leads students to the realisation that with present scientific understanding it is extremely difficult to offer satisfactory explanations for not only the development of metabolic systems, but their coordination to produce reproductive cellular life. As Michael Denton comments:

> The problem of the origin of life is not unique – it only represents the most dramatic example of the universal principle that complex systems cannot be approached gradually through functional intermediates because of the necessity of perfect co-adaptation of their components as a pre-condition of function.[22]

Francis Crick, awarded a Nobel Prize for his work with James Watson on the structure of DNA expresses the same sentiments:

> An honest man, armed with all the knowledge available to us now, could only state that in some sense, the origin of life appears to be almost a miracle, so many are the conditions which would have to be satisfied to get it going.[23]

Student Attitudes and Enhancement of Learning Skills

Student attitudes to this learning methodology varied and showed both positive and negative aspects. Positive responses include an obvious enthusiastic excitement and expression of surprise at their freedom. They were challenged by the wealth of information available for study and methods of information retrieval. They were also challenged by the process of writing and editing a significant piece of work. Some were appreciative of the fact that they were being treated like a colleague in place of a student-lecturer relationship. There was often an awareness of the fact that the responsibility of learning was theirs and this led to an obvious self-development in this regard. Some were cheered by the fact that they could tell the facilitator to take a 'back seat' in their learning process as they were clearly driving. They enjoyed the experience of brain storming a complicated topic rather than being lectured to, and learning appeared to occur faster than in normal classes. In fact there was a growing perception that less reliance on the lecturer/teacher is acceptable if not desirable. Some students also developed the recognition that PBL is one of the best ways to extract, manage and apply information.

There were however some negative experiences, for example, some students where unsure of their boundaries in the learning process and expressed concern. In the early part of the course, some students were lost, confused and unsure of what to do. There was concern over group assessment and group conflict. Some students found it too easy to procrastinate and some expressed the view that PBL was just as hard as traditional face to face learning. Others felt the topic coverage in the course was reduced. Some were uneasy about the reduced input from the lecturer in comparison with lecture style deliveries.

Others expressed frustration for other subjects they were undertaking at the same time which followed a more traditional educational methodology. They felt that they had an increased desire to ask questions, but felt irritated at not having enough time in lectures. They also wanted to know how a given lecture topic area fits into the wider context (which is not always explained in a traditional lecture situation). Some had the wish to investigate a topic at greater depth, but were annoyed at not being able to do so.

From an educator's point of view there were obvious developments in PBL related learning skills; such as critical thinking, information retrieval and synthesis, communication skills, conflict resolution, report writing and editing. It was pleasing to observe an increased self confidence in some students and the successful synthesis of self acquired knowledge. Some students demonstrated an appreciation for the cross disciplinary nature of scientific investigation (for example, chemistry students with specialised knowledge were able to apply it in a different context such as biology to help solve a problem). Some students had the confidence to approach lecturers in other disciplines for advice and consultation. Others showed appreciation for the limits of scientific investigation. Some students displayed improved learning in other subjects and were keen to tackle other projects and research based subjects. Others recognised the fact that skills acquired in PBL were directly applicable to the work place or graduate degrees.

Faith and Learning

Consideration of the biochemical origins of life on earth highlights to students one of the most interesting and difficult problems faced by modern biochemistry. Indeed, aside from this specific problem, there is much yet for scientists to learn about how chemicals and biochemicals interact in functional biochemical systems. But what impact may these investigations have on faith and learning?

Considering our present understanding of the difficulties associated with the development of life on earth, most Christians tend to suggest the impossibility of a primordial cell ever having arisen by natural chemical processes. It may be tempting to posit some sort of god of the gaps type argument to cover these difficulties. However such positions may be less than tenable if advances in scientific knowledge offer explanations for some of these mysterious areas that we have ascribed to God's activity. Typical of many sincere evangelical Christians who work as scientists, Francis Collins (head of the Human Genome Project), in his book, *The Language of God* advises:

> Faith that places God in the gaps of current understanding about the natural world may be headed for crisis if advances in science subsequently fill those gaps. Faced with incomplete understanding of the natural world, believers should be cautious about invoking the divine in areas of current mystery, lest they build an unnecessary theological argument that is doomed to later destruction. There are good reasons to believe in God, including the existence of mathematical principles and order in creation. They are positive reasons, based on knowledge, rather than default assumptions based on (a temporary) lack of knowledge.[24]

For example, it is interesting to note the developments in the area of the anthropic principle where the universe appears to be fine tuned for the production of carbon based intelligent life.[25] Paul Davies refers to this as the "Goldilocks enigma", where the porridge eaten by Goldilocks was neither too hot nor too cold, but just right.[26] Michael Denton, in his most recent book, *Nature's Destiny: How the Laws of Biology reveal Purpose in the Universe,* examines a host of factors ranging from the anthropic principle to the fact that man is uniquely adapted for the use of fire (an essential ingredient for the development of technology).[27] Denton concludes that the entire universe, from molecules to galaxies is uniquely tuned and perhaps programmed for one purpose, the development of carbon based life with mankind as its eventual climax. The fine tuning of physical and chemical laws seems to predispose the chemical matter of the universe to allow certain biochemical and biological outcomes over others. In a similar fashion, it is argued by some that evolutionary mechanisms are convergent in a manner so that intelligent carbon based life is an inevitable result.[28] The implication for the contemporary scientific view of the origin of life on earth is that there may be an inherent tendency for simple chemicals to associate and combine to form molecular structures that move down convergent pathways resulting in the emergence of simple life forms. At this stage the precise mechanisms associated with such convergence are not known but may be elucidated in the future. Care should be exercised as what appears to be currently implausible may actually turn out to be plausible as scientific knowledge expands.

To teach science in an Adventist institution can be a challenging experience for both educator and student, particularly when matters related to the interface of science and faith are discussed. An investigation into the development of life using a PBL rather than a lecture approach allows sufficient time for extended discussions of science-faith issues that may arise and be of concern to students. Adventist tertiary students need an educational environment that provides opportunities for the thoughtful consideration of scientific theories and issues that may challenge basic Christian faith. Students need to feel that they can openly discuss issues of concern to them and should be encouraged to realise that the development of an individual's faith is an on going process. Challenges to faith are an important opportunity for growth and the development of intellectual and spiritual maturity.

It is probably true to say that science students are faced with more faith challenging situations than students in other discipline areas. It is important for those engaged in the process of integrating faith and learning (both student and educator) to realise that neither the disciplines of science or religion alone have complete answers to all questions asked by tertiary students in this area. The science student should be encouraged to take both science and religion seriously and approach both these areas with intellectual honesty. Such an approach is foundational to the development of mature faith. Holmes suggests:

> Christian commitment does not limit intellectual opportunity and endeavour, but rather it fires and inspires purposeful learning. Christian education should not blindfold the student's eyes to all the world has to offer, but it should open them to truth wherever it may be found, truth that is ultimately unified in and derived from God.[29]

With respect to discipline areas studied there are often shades of grey and conflicting data. Students have different abilities to process various levels of information and knowledge. Faith and belief among students will also vary considerably. The concerns that can arise from this milieu need to be addressed in a caring Christian tertiary environment. The pursuit of truth whether theological or scientific is an opportunity to worship God with the intellect with which he has endowed us.[30] For those engaging in this pursuit Gaebelein offers this advice:

> We do indeed give the primacy to that spiritual truth revealed in the Bible and incarnate Christ. That does not mean, however, that those aspects of truth discoverable by man in the realm of mathematics, chemistry or geography, are any whit less God's truth as it is in Christ. The difference is clearly a question of subject matter.[31]

Einstein once said that "the only incomprehensible thing about the universe is that it is comprehensible." This comprehensibility we observe may be one of the results of being created in the image of God, intelligence recognising the work of intelligence. Sire reflects on the meaning of *Logos* in John 1:1-4.[32] While the term *Logos* literally means 'word', in Greek thought it also meant thought, reason or rationality – the rationality behind the universe. That rationality behind the universe became flesh (John1:14), Jesus Christ becoming an integral part of His creation allowing "...a continuity between the Meaning of God in Jesus and the meaning of the world truly understood by people."[33]

This has particular appeal to the scientist and science student alike, the challenge of a world created by the *Logos* being understood by those created in the image of God, the ultimate rationality behind the universe. The challenge of Christian educators, particularly those in the scientific disciplines, is to point students to the reality of the rationality of the understandable universe and the *Logos* of whom the scriptures testify.

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Appendix

BI360.2 INVESTIGATIVE BIOCHEMISTRY

ASSESSMENT SHEET

Self/Peer/Lecturer Assessment for: (Name of student will be printed here)

Please fill in the following assessment sheet using the key below:

- 1 never
- 2 rarely
- 3 sometimes
- 4 most of the time
- 5 always fulfils criteria completely

For the person under consideration circle the number that is most appropriate:

	Never				**Always**
A. Participation in group meetings/discussion.	**1**	**2**	**3**	**4**	**5**
B. Degree of preparation for group meetings/discussions.	**1**	**2**	**3**	**4**	**5**
C. Fulfils responsibilities allocated at group meetings.	**1**	**2**	**3**	**4**	**5**
D. Communicates well with the group.	**1**	**2**	**3**	**4**	**5**
E. Makes a positive contribution to group dynamics.	**1**	**2**	**3**	**4**	**5**

Note:

A. Participation in group meetings/discussion:

1. The student does not participate in and very rarely contributes to group discussions. If any contributions are made, they do not reflect a familiarity with the issues at hand and are not thoughtful nor constructive.

3. The student will sometimes participate in and contribute to group discussions. The contributions sometimes reflect a familiarity with the issues at hand and are sometimes thoughtful and constructive.

5. The student will always participate in and contribute to group discussions. The contributions always reflect a familiarity with the issues at hand and are always thoughtful and constructive.

B. Degree of preparation for group meetings/discussions:

1. The student does not prepare for the group discussion, failing to read around the area for discussion in addition to their allotted task. They do not keep abreast of where the group is in terms of discussion and direction.

3. The student sometimes prepares for the group discussion by reading around the area for discussion in addition to their allotted task. They sometimes keep abreast of where the group is in terms of discussion and direction.

5. The student always prepares for the group discussion by reading around the area for discussion in addition to their allotted task. They always keep abreast of where the group is in terms of discussion and direction.

C. Fulfils responsibilities allocated at group meetings:

1. The student does not show any responsibly in fulfilling tasks assigned at group meetings and does not report on this activity at the next group meeting, or date assigned by the group.

3. The student sometimes shows responsibly in fulfilling tasks assigned at group meetings and reporting on this activity at the next group meeting, or date assigned by the group.

5. The student always shows responsibly in fulfilling tasks assigned at group meetings and reporting on this activity at the next group meeting, or date assigned by the group.

D. Communicates well with the group:

1. The student does not communicate their thoughts and ideas in a clear, concise scientific manner. (Communication can also take the form of diagrams, small presentations, handouts, use of the white board, OHP or other aids).

3. The student sometimes communicates their thoughts and ideas in a clear, concise scientific manner. (Communication can also take the form of diagrams, small presentations, handouts, use of the white board, OHP or other aids).

5. The student always communicates their thoughts and ideas in a clear, concise scientific manner. (Communication can also take the form of diagrams, small presentations, handouts, use of the white board, OHP or other aids).

E. Makes a positive contribution to the group dynamics:

1. The student does not contribute to the harmony of the group. They do not encourage an atmosphere of intelligent discussion where all points of view are heard. They may be argumentative or can overly sidetrack the group by injecting issues not directly relevant to the task in hand.

3. The student sometimes contributes to the harmony of the group. They sometimes encourage an atmosphere of intelligent discussion where all points of view are heard. They do not dominate the discussions, nor are they argumentative. They do not overly sidetrack the group by injecting issues not directly relevant to the task in hand.

5. The student always contributes to the harmony of the group. They always encourage an atmosphere of intelligent discussion where all points of view are heard. They do not dominate the discussions, nor are they argumentative. They never sidetrack the group by injecting issues not directly relevant to the task in hand.