THE EFFECT OF A MULTI-USER VIRTUAL ENVIRONMENT ON STUDENT CAUSAL REASONING ABILITY, ECOLOGICAL WORLDVIEW, AND CONCEPTUAL CHANGE IN THE STUDY OF ECOSYSTEMS

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Abstract

Students tend to perform poorly in reasoning tasks pertaining to causation in ecology. The target group is a Form 3 class of all male students in School B, a school in East Trinidad. The teacher-as-researcher has decided to enroll in action research to investigate the use of a multi-user virtual environment, called EcoMUVE, on improving student causal reasoning ability and determining how ecological worldview and conceptual change are also affected by it. Results showed that EcoMUVE may be a good teaching tool for improving causal reasoning ability. Recommendations were made about EcoMUVE and related variables after reflection on this action.

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Introduction

The student learning experience may arguably be dependent upon, amongst other things, inherent student learning ability, facilitated by the teaching strategy—the vehicle to segue students from the unlearned to the learned. In an all-male, form three integrated science class at School B—a secondary school in east Trinidad—the state of affairs is one of students having difficulties when answering classroom assessment items related to reasoning about environmental issues in a unit of work related to *man's effect on the environment* (Ministry of Education, 2008, pp. 77-78). This was deemed to be an issue of *causal reasoning ability*: students' ability to reason about complex causal relationships; regarded as the degree of recognition of complex causality in ecosystems (Huber & Snider, 2005; Grotzer, et al., 2011). As this unit of work may be regarded as a capstone unit for imbuing knowledge about ecological relationships and consideration for the environment, it begs to wonder how the apparent lack of causal reasoning ability interplays with their views about the environment—an issue of *ecological worldview*: fundamental views about nature and humans' relationship to it (Dunlap, Van Liere, Mertig, & Jones, 2000, p. 427) . The students' low performance in these classroom assessment items may well indicate a lapse in learning about ecological science concepts as students seem to hang on to the informal previous knowledge they bring to the classroom rather than transition into incorporating or accepting the formal knowledge taught in the unit—an issue of *conceptual change*: learning which involves the construction and acceptance of new ideas, or the restructuring of existing ideas" (Bell, 2005, p. 22).

The root problem lies in what seems to be a lack of student causal reasoning ability which permeates and persists regardless of the traditional teaching strategy used (use of posters, presentations, and dramatizations). This is very worrying because there seems to be a lack of understanding about ecological science concepts which has manifested in poor academic performance and this becomes problematic as it may result in dire implications with respect to how students treat with the environment now and in the future—an issue of their environmental stewardship.

An appropriate, alternative teaching strategy, derived from the literature, was sought to be utilized and its effectiveness assessed with an intention of targeting and enhancing student causal reasoning ability, and observing how causal reasoning ability interplays with ecological worldview and conceptual change, which were considered to be related areas of concern by the researcher and subsequently hypothesized to be theoretically linked after reviewing existing literature, thus, worthy of investigation. The alternative teaching strategy is in the form of EcoMUVE which is a multi-user virtual environment used for the study of ecosystems developed by Harvard University (Harvard University, 2012). This research therefore served to report on findings based on a theoretical framework linking the research issues (stemming from an observed lack of student causal reasoning ability due to a suspected ineffective teaching strategy)—findings which would either corroborate or contradict the purported relationships amongst them as described by the theoretical framework and which would add new understandings to the body of literature in educational research as it pertains to helping to determine the effectiveness, thus, usefulness of this alternative teaching strategy in teaching student causal reasoning ability and how this may affect student ecological worldview, and conceptual change in the study of ecosystems. This would also serve to inform teaching practice in the School B context. The rest of this chapter will outline the intellectual ancestry of the problem and conceptualize the research issue and focus.

Background to the Problem

This section delineates the problem from a global, regional, and local perspective as well as observations made in the science classroom. It also illustrates the derivation of the target issues from the context of the problem; causal reasoning ability, ecological worldview, conceptual change, and an effective teaching strategy.

Global background. *Worldview* may be described as culturally organized macro-thought...cognitive assumptions that determine the outlook of reality (Kearney, 1984, p. 1). Kearny also describes the dynamics of causal relationships as *causality* which interact closely with factors of perception called Space and Time universals (Kearney, 1984, p. 106). An individual (student) would have an outlook on reality which is determined in part by their outlook on space and their outlook on time in relation to that particular context (the environment). This directly relates to factors decribed in the global literature as *effects over distance* and *changes over time*, which are components of what is known as *complex causality* in the study of ecosystems—outlined by a Harvard University study into an ecosystems multi-user virtual environment software called EcoMUVE (Dede & Grotzer, 2012, pp. 13-14). A student's worldview about the environment may thus be determined in part by their preconceived perceptions of causality related to the environment. This forms their *ecological worldview* or their belief system as it relates to the environment. An ecological worldview may also be described as "the recognition that every environmental change in a system generates a series of interrelated consequences" (Lin & Oxford, 2012, p. 66). Thus, changes in the environment may be purportedly understood by students so far as their preconceived notions of what constitutes cause and effect. This forms a "unifying paradigm" to which the students abide by as it relates to their relationship with the environment (Lin & Oxford, 2012, p. 66). Ecological worldview represents a perception of reality about the environment that a student has and forms the *a priori* template of thought that a student brings to the classroom.

In the classroom, *an effective teaching strategy* attempts to transition students from this a priori knowledge to the formal science knowledge. Dede and Grotzer, in 2012, argued that "students who understand how to reflect upon their causal default assumptions and how to think about causal patterns learn science concepts better than those who do not" (p. 2). Determining the effectiveness of an alternative teaching strategy (where previously used strategies were suspected to have an unsatisfactory effect) to help students enhance their causal reasoning ability and discovering how their causal reasoning ability affects their ecological world view and understanding of the desired ecological science concepts forms the premise of this thesis. The desired strategy therefore involves *teaching for conceptual change*. Teaching for conceptual change involves moving students from naïve conceptualizations toward more accurate and expert understandings of science concepts (Shope III, 2006, p. 10).

Delineating the problem from the global literature, the emergent target terms of *causal reasoning ability*, *ecological worldview*, *conceptual change*, and *effective teaching strategy* were identified as being part of the main research issue. These dynamics also come into play in a regional educational context.

Regional background. Regionally, there are similar concerns pertaining to causal reasoning ability. For example, on a Caribbean Secondary Education Certificate (CSEC) Human and Social Biology (HSB) past paper question, students were given a scenario where the hotels that were built near the ocean had faulty sewage treatment plants—students were asked to explain the effects of dumping of sewage into the ocean on oxygen content and the food chain (CXC, 2008, p. 14). The report for this exam suggested students performed poorly and that they "*did not apply the knowledge of the concept* to explain how the oxygen content, the water and the food chain were affected" (Caribbean Examinations Council, 2008, p. 9). A lack of application of knowledge may indicate a lack of executing and implementing knowledge—skills associated with the "Applying" level of the cognitive process dimension, according to the revised Bloom's Taxonomy (Krathwohl, 2002, p. 215). This may have implications on how students apply their knowledge to environmental issues in authentic situations.

The report also goes on to suggest that students had a "*misconception* of the sewage preventing oxygen from diffusing into the water" (Caribbean Examinations Council, 2008, p. 9). The desired response would be that the sewage consists of microorganisms such as bacteria which utilized oxygen, causing an oxygen deficiency in the water. Misconceptions indicate holding fast to stubborn viewpoints informed by traditional knowledge, rather than the conventional science and may propagate if conceptual change failed to occur. This forms a sense of resilience in the minds of the students with respect to how they already interpret ecological relationships.

A suggestion was made in the report to take students "on a field trip to sewage plant... concretizes the concept" (Caribbean Examinations Council, 2008, p. 9). This is an example of an instance where a teaching strategy had been suggested in response to the problem of student learning causal reasoning in ecological science: a feat that this research seeks to address by assessing the effectiveness of an alternative teaching strategy. Challenges with misconceptions and reasoning also arise in the local context.

Local background. Local literature suggests that student resilience in learning science concepts do occur. Rampersad and Solomon argue that students' prior knowledge is resilient (as cited in Herbert, 2004, p.140). Students hang on strongly to what knowledge they bring to the classroom. Unless this is transitioned into the conventional science being taught, meaningful learning may be a difficult feat to achieve. When trying to learn new content science content, the differences between "the intellectual patterns in traditional knowledge and conventional science will affect students' understanding of the nature of science" (George & Glasgow, 1999, p. 22). These differences seem not to be abridged by the traditional teaching methods employed. In order to delink complex causal relationships in the environment, the student as a young scientist has to have an appreciation for multiple causes as evidence for supporting claims and explaining phenomena. Local literature suggests that immediacy and directness in cause/effect systems omits variables critical to interrelatedness in conventional science (George & Glasgow, 1999, p. 13). An ecosystem is a cause/effect system which consists of many prolonged and indirect causes which must be appreciated in order to understand ecological relationships. The ecological concepts should be pitched at a certain level of authenticity in order for students to appreciate real variables and how they operate and interrelate with the environment; example abiotic and biotic factors, and spatial and temporal changes. This again suggests utilization of a teaching method that would introduce these concepts to facilitate student learning.

Observations in the classroom. Presently I teach integrated science to an all-male, form three class at School B—a secondary school in east Trinidad. The science standard topic considered is *Man's Effect on the Environment* (Ministry of Education, 2008, pp. 77-78). In the section of the science syllabus, the main concept is to have students understand that "human activities are altering the environment in dramatic and far-reaching ways" (Ministry of Education, 2008, p. 77). Traditionally, direct teaching, has been the dominant teaching strategy, which includes student note-taking exercises, and homework tasks which would require the use of the internet for research. Strategies in the curriculum document for lower secondary school science for this particular unit have been implemented, which include the use of: posters, presentations and dramatization (Ministry of Education, 2008, pp. 77-78). In addition, over the years other strategies suggested by the science curriculum have also been utilized: videos via YouTube, debates, field trips (Ministry of Education, 2008, p. 88). The curriculum requires that students develop an understanding for the scope of causes and consequences of alterations to the environment (Ministry of Education, 2008, p. 77). This suggests that students develop proper causal reasoning ability as it relates to environmental issues. The requirement to learn about this content is a requirement for conceptual change. The nature of the content suggests that students have a sense of environmental awareness which speaks to their ecological worldview. The use of the suggested teaching strategies assigned to this unit of work seem not to be effective in having students understand multiple causes and effects which occur in ecosystems. This is not to say that the suggested and traditional strategies are obsolete, but that they have been found wanting. The researcher is a certified teacher of good standings and above par commendation, therefore teaching style does not come into question. All things being equal, the exploration of using an alternative teaching strategy to assess its effectiveness becomes prudent in this matter.

Consider the following sample classroom assessment item: *a landowner washes his garments every day with a strong laundry detergent in an upstream pond—describe the short term effects and the long term effects of the landowner's activity*. A sample food web of the feeding relationships in the pond habitat is shown in Figure 1.

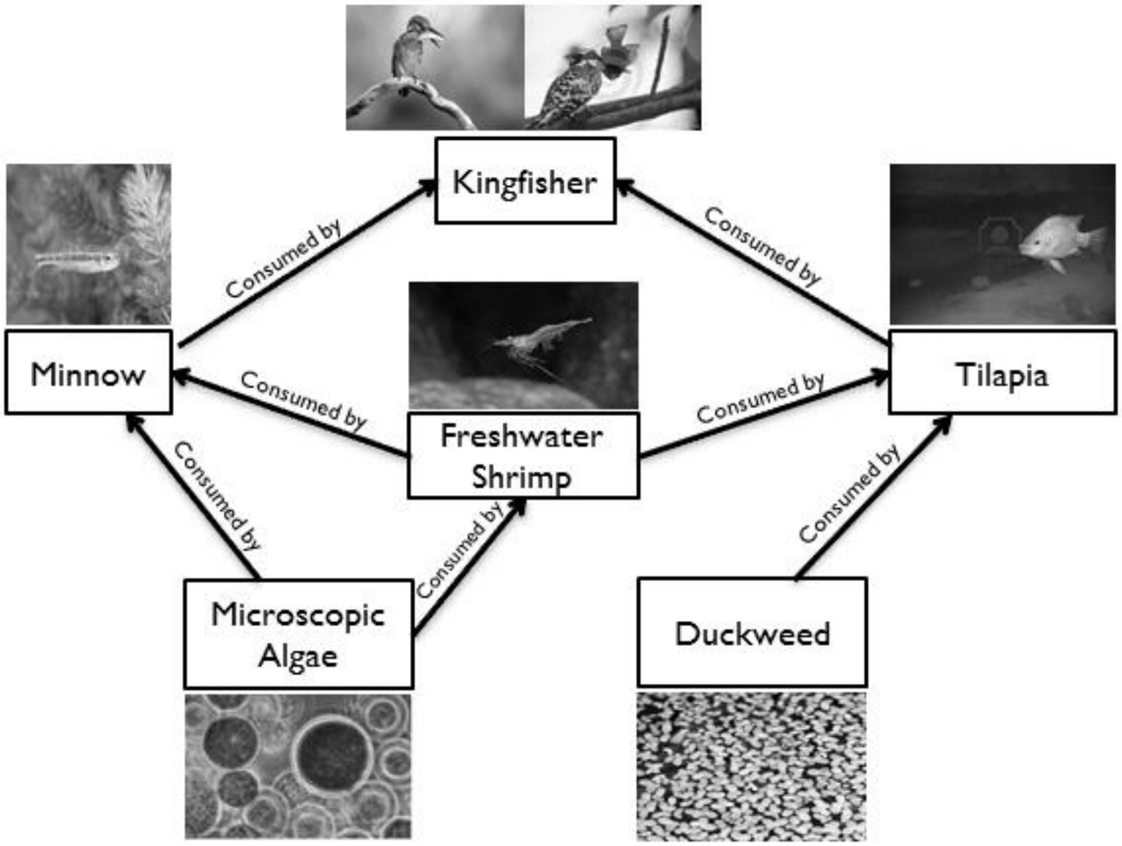


Figure 1. A pond food web sample. This represents some of the feeding relationships in the pond habitat described in the sample classroom assessment item.

Common student responses—see Figure 2—included students stating that:

- *The fishes in the pond will become poisoned by the chemicals*: this seems to be a simplistic (obvious or popular) viewpoint, drawn from their traditional knowledge. A desired response would have been that the phosphates present in the detergent would be absorbed by the microscopic algae and cause an algal bloom at the surface of the pond (eutrophication). This would be a representation of non-obvious causes acting at a distance being involved in a process which changes over time. These incorporate elements of complex causality.
- *The organism that consumes a poisoned organism will die and so on. Eventually all the organisms in the pond will die*: This seems to illustrate reasoning along a

direct, linear path where causes and effects are domino but short term and occur in a localized system. A desired response would have included an explanation that algal growth caused deficiency in O_2 (oxygen) gas, thus organisms suffocated; sunlight for other aquatic plants was blocked by algal bloom, downstream habitats affected. This represents processes from non-obvious causes which occurred over time—a characteristic of complex causality.

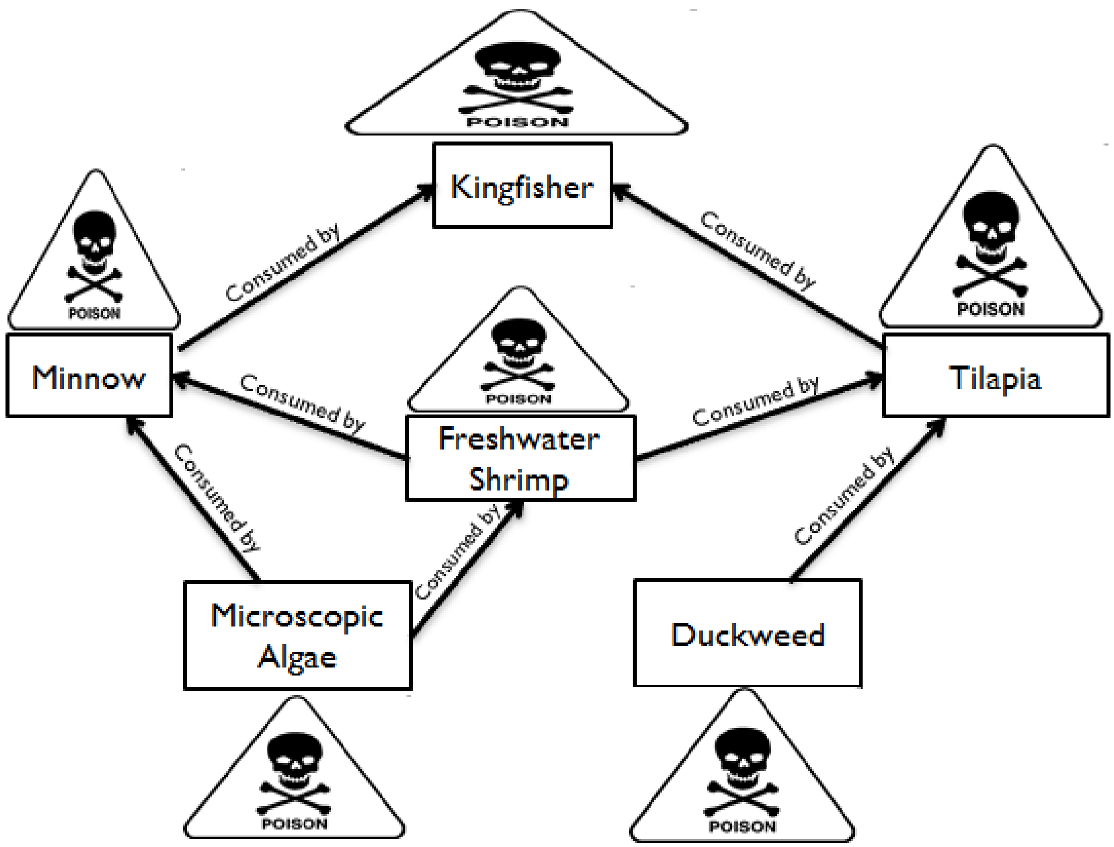


Figure 2. Common responses of students to questions about alterations to the environment. Students displayed simplistic viewpoints with limited reasoning.

I taught ecology to form three students for the past nine years, during which time I have observed that on classroom assessments, students seem to be constantly challenged by items which require them to reason as it relates to causes and effects of alterations to the natural environment. Some student responses seemed to be simplistic and remote from a deep sense of reasoning and environmental awareness before and after the teaching intervention. The students seem to hang on to the narrow, misconceived viewpoints about ecological concepts that they bring to the science classroom—a sort of resilience to new science content. This may suggest that, as it relates to ecology, the current teaching strategies may be ineffective in enhancing student causal reasoning ability, which may affect ecological worldview and conceptual change.

Problem statement

The problem being researched stems from the state of affairs of unsatisfactory *causal reasoning ability* (ability to reason about complex causal relationships) in the study of ecosystems by form three students at School B—a secondary school in east Trinidad. This state of affairs forms a dichotomy of concerns: the state of student *ecological worldview* (how they view their role as humans in respect of the environment) and student *conceptual change* (ability to transition from naïve, preconceived science concepts to formal science concepts). The state of affairs reflects poor on academic performance in ecological science at this level and becomes problematic since there seems to be a likelihood of it being reflected as irresponsible decision-making, with respect to environmental issues, on the part of the students now and as they may be as adults—a possible eventual lapse in environmental stewardship. The state of affairs has persisted using the current teaching strategies (presentation, posters, and dramatization) as suggested by the curriculum document for this unit of work on man’s effect on the environment (Ministry of Education, 2008, pp. 77-78). Herein lies the problem: lack of student causal reasoning ability, regardless of implementing traditional teaching strategies.

Purpose statement

This research sought to discover the effectiveness of using an alternative teaching strategy in a unit of work pertaining to man's effect on the environment (Ministry of Education, 2008, pp. 77-78). This teaching strategy is in the form of a marriage between two generally suggested strategies by the lower secondary school science curriculum document: *simulation* and *computer-based learning* (Ministry of Education, 2008, p. 88). The alternative teaching strategy under examination was an immersive *computer simulation* known as EcoMUVE, which is a multi-user virtual environment, produced by Harvard University for the purpose of students learning about complex causality in ecosystems (Harvard University, 2012). In this research, EcoMUVE's effectiveness was examined in a unit of lessons pertaining to man's effect on the environment.

The purpose of this quantitative, quasi-experimental, one group pretest/posttest design, action research study is to discover if a multi-user virtual environment (MUVE) intervention can be used to enhance causal reasoning ability in tandem with ecological worldview, and conceptual change—before and after the intervention—of form three integrated science students at School B—a secondary school in east Trinidad. The unit of work is *man's effect on the environment* (Ministry of Education, 2008, pp. 77-78). Generally, the independent variable will be considered as the intervention called EcoMUVE, and will generally be defined as a pedagogical intervention consisting of an immersive virtual environment that contains a representation of a pond habitat to be administered along with a suggested unit of lessons in the teaching of complex causality (Dede & Grotzer, 2012). The first dependent variable will be considered as *causal reasoning ability* which will be generally defined as students' ability to reason about complex causal relationships; regarded as the degree of recognition of complex causality in ecosystems (Huber

& Snider, 2005; Grotzer, et al., 2011). The second dependent variable will be considered as *ecological worldview* and will generally be defined as fundamental views about nature and human's relationship to it (Dunlap, Van Liere, Mertig, & Jones, 2000, p. 427). The third dependent variable will be considered as *conceptual change* and will generally be defined as learning which involves the construction and acceptance of new ideas, or the restructuring of existing ideas" (Bell, 2005, p. 22).

Research questions

1. How does EcoMUVE affect students' causal reasoning ability?
2. How does EcoMUVE affect students' ecological worldview?
3. How does EcoMUVE affect students' conceptual change?
4. What is the relatedness amongst students' causal reasoning ability, ecological worldview, and conceptual change?

Operationalization of the research questions. The research questions would be operationalized as described in Table 1 (causal reasoning ability), Table 2 (ecological worldview) and Table 3 (conceptual change).

Table 1.
Causal Reasoning agents: definitions and variables.

CAUSAL FEATURE RELATED TO COMPLEX CAUSALITY		DEFINITIONS	VARIABLES	
			PRETEST	POSTTEST
Effects over distance	***Spatially Distant***	*Occurred beyond the banks of the pond.*	EOD1	EOD2
	Action at a Distance	*Beyond what could be seen when standing at the pond.*		
Changes over time	***Processes or Steady State***	*Dynamics that are going on over time*.	COT1	COT2
Non-obvious Causes		*Cannot be seen with the naked eye.*	NOC1	NOC2
CAUSAL REASONING ABILITY		*Ability to reason about complex causal relationships. Regarded as the degree of recognition of complex causality*.	**CAUSAL1** **= EOD1 + COT1 + NOC1**	**CAUSAL2** **= EOD2 + COT2 + NOC2**

Note. Adapted from Grotzer, T., Tutwiler, S., Dede, C., Kamarainen, A., Metcalf, S., & Jeong, D. (2011). Helping students learn more expert framing of complex causal dynamics in ecosystems using EcoMUVE. *National Association of Research in Science Teaching (NARST)*, Orlando, FL.

Table 2.
Ecological Worldview facets, definitions, and variables.

ECOLOGICAL WORLDVIEW FACETS	**DEFINITIONS**	**VARIABLES**	
		PRETEST	**POSTTEST**
Reality of Limits to Growth (items 1, 6, & 11)	*Awareness of limits to growth of human societies in relation to environmental space and resources* (p. 433).	RLG1	RLG2
Antianthropocentrism (items 2, 7, & 12)	*Against the belief that nature exists primarily for human use and has no inherent value of its own* (p.431).	AAC1	AAC2
The Fragility of Nature's Balance (items 3, 8, & 13)	*Nature is balanced, highly interdependent and complex, and therefore susceptible to human interference* (p. 429).	FNB1	FNB2
Rejection of Exemptionalism (items 4, 9, & 14)	*Rejection of the idea that humans, unlike other species, are exempt from the constraints of nature* (p. 432).	ROE1	ROE2
Possibility of an Ecocrisis (items 5, 10, & 15)	*Awareness of potentially catastrophic environmental changes besetting humankind brought about by human-induced global environmental change in general* (p.432).	POE1	POE2
ECOLOGICAL WORLDVIEW	*Fundamental views about nature and human's relationship to it* (p. 427).	**EWORLDVIEW1** = RLG1 + AAC1 + FNB1 + ROE1 + POE1	**EWORLDVIEW2** = RLG2 + AAC2 + FNB2 + ROE2 + POE2

Note. Adapted from Dunlap, R., Van Liere, K., Mertig, A., & Jones, R. E. (2000). Measuring endorsement of the New Ecological Paradigm: A revised NEP scale. Journal of Social Issues, 56, 425-442.

Table 3.
Conceptual change score, definition, and variables.

CONCEPTUAL CHANGE SCORE	**DEFINITION**	**VARIABLES**	
		PRETEST	**POSTTEST**
Conceptual Knowledge [student score on conceptual knowledge items]	▪ *Conceptual knowledge* may be defined as the "interrelationships among the basic elements within a larger structure that enable them to function together" (Krathwohl, 2002, p. 214). ▪ *Conceptual change* may be defined as "the construction and acceptance of new ideas, or the restructuring of existing ideas" (Bell, 2005, p. 22)	**CONCEPTUAL1**	**CONCEPTUAL2**

Note. Instrument derived from The EcoMUVE Project Team. (2012). EcoMUVE Post-Survey. Retrieved from EcoMUVE: advancing ecosystems science via situated collaborative learning in multi-user virtual environments: http://ecomuve.gse.harvard.edu/documentation/EcoMUVE_PondPostsurvey_Jan2011.pdf

Research Hypotheses

1. **Effect of EcoMUVE on Causal Reasoning Ability.**

- H_0: CAUSAL1 is not significantly different from CAUSAL2

  H_1: CAUSAL1 is significantly different from CAUSAL2

2. **Effect of EcoMUVE on Ecological Worldview.**

- H_0: EWORLDVIEW1 is not significantly different from EWORLDVIEW2

  H_1: EWORLDVIEW1 is significantly different from EWORLDVIEW2

3. **Effect of EcoMUVE on Conceptual Change.**

- H_0: CONCEPTUAL1 is not significantly different from CONCEPTUAL2

  H_1: CONCEPTUAL1 is significantly different from CONCEPTUAL2

4. **Interrelatedness amongst Causal Reasoning Ability, Ecological Worldview, and Conceptual Change.**

- H_0: $\tau = 0$; $\rho = 0$
- H_1: $\tau \neq 0$; $\rho \neq 0$
- Where τ = Kendall's tau-b correlation coefficient, and ρ = Spearman's rho correlation coefficient.

Expected Outcomes

Effective schooling entails the development of students who are productive, caring, critical thinkers (R. Hackett, personal communication, 2012). What we put in, what we produce is what will come right back to us (J. Alexander, personal communication, 2012). Ecological worldview may affect personal decision-making and social responsibility as it relates to addressing serious environmental concerns. The study was approached in such a way that should there be a resulting enhancement of student causal reasoning ability, then this may bode well for the possibility of students applying causal reasoning skills learned in the teaching strategy to other content areas and life skills.

Granted that this is a single strategy and an eclectic approach is usually recommended for effective teaching, this study allows us to exclusively look at the effects of this strategy on developing causal reasoning, and the manner in which it may indirectly affect ecological worldview, and conceptual change—both of which are theoretically linked to causal reasoning ability. A transformational perspective of the study was the teaching of causal reasoning ability towards conceptual change. A discovery perspective (adding to body of literature) of the study entailed reporting on effects of causal reasoning on ecological worldview, and conceptual change and using these findings to further assess the effectiveness of the teaching intervention.

The study was important in attempting to teach inductive reasoning which is an important facet of the nature of science; learning to make more observations and learning about tentativeness in science hence more informed decision-making, critique, and open-mindedness. Male students are interest in immersive video games. This is evident from observations made by the researcher in school.

The study's goals are aligned in part with the Ministry of Education's Strategic Plan 2011-2015 goals in terms of environmental awareness: "*environmentally aware*, protective of the physical environment and demonstrates an understanding of sustainable development" (Ministry of Education, 2012, p. 47). This may inform teaching practice for science teachers in the school in context and internal school policy and best practice in science and possibly across disciplines.

Literature Review

Critical Analysis of the Literature

The genesis of this research lies with the observations of what is likely to be a lack of students' ability to reason when it comes to deciphering cause and effect relationships in the study of ecosystems. It aimed at investigating the effectiveness of a multi-user virtual environment on student causal reasoning ability and sought to determine the relationship amongst student causal reasoning ability, their ecological worldview (due to related concerns about their environmental stewardship) and their conceptual change (due to a need to find out if, this intervention would result their learning of the ecological science concepts which, after all, is a necessary expected outcome requirement by the curriculum in the usage of any teaching strategy for this unit).

Insights from the literature were garnered to inform the research process in the context of the research problem. Several theories in the literature from several authors in similar fields were thoroughly and critically examined to frame the research in such a way that the research questions can be adequately investigated and credible meaning can be derived henceforth.

Empiricism, logical positivism and the matter of causation. The research problem is primarily based on an issue of *causal reasoning* also referred to in the vast literature as *causality* or *causation*. There is no better place to begin discussing causal reasoning, than with the philosophical works of David Hume. Hume suggests that the nexus between the *identity* of objects and their *contiguity of space and time* is as a result of causation or a relationship between *cause* and *effect*: two objects, one which precedes the other and produces an action which results in the other (Hume, 1739, pp. SBN 73-74). According to Hume, cause and effect are "relations, of which we receive information from experience and not from any abstract reasoning or reflection" (Hume, 1739, p. SBN 69). This sets the tone for two important trails of thought.

The first trail of thought is that causation, according to Hume, is based primarily on experience which is synonymous with *prior knowledge*. This relates to the traditional knowledge that students bring to the science classroom—in this context, knowledge about how things relate in space and time with respect to the environment as the students knew it. This must be taken into consideration when helping students learn formal science concepts or conventional knowledge about the environment in the unit on ecosystems. One may postulate then that a new experience for students may give rise to new understandings about causation. The question of a teaching strategy comes into play. A teaching strategy to facilitate this learning must then be philosophically grounded or strongly associated with specific objectives of the unit to be taught and the likelihood of students' reception of its method—the teaching strategy used in this research was EcoMUVE, a multi-user virtual environment created by a team at Harvard University (Harvard University, 2012).

The second trail of thought is that causation is based on observable evidence, not abstract reasoning. This point of view, if abided by as a wholesale, hardline approach to all scientific inquiry, belongs to the views expressed in the empiricist paradigm of science. Hume was regarded as largely an empiricist. Hume regards *probable reasoning* as that which involves some semblance of evidence (something seen or remembered) for making *inferences* in cause and effect relationships (Hume, 1739, p. SBN 89). This part of his classification of reasoning represents a classical empiricist view about making generalizations based only on observations by the senses. It is important to note at this juncture that empirical evidence is an important tenant of the nature of science (Abd-El-Khalick, Waters, & Le, 2007, pp. 838-839). Empirical data, however, may not necessarily be only a measure of the obvious that our natural senses can realize but it also involves many unseen variables that must be measured through various other means (instruments, calculations, theories, and so on). When studying ecosystems for example, data regarding pH levels, dissolved gases/chemicals, temperature, wind speed, amount of sunlight, chlorophyll content, population sizes and a whole slew of other types of environmental data are not immediately (naturally) observable but measured in many different ways and used to determine relationships and provide possible explanations to various ecological activities. The teaching intervention (EcoMUVE) in this research project also takes into account a need for measuring non-obvious empirical data, changes over time and effects over distance.

However, Hume also offers a subtle nuance to his empiricist views as he acknowledges abstraction as *demonstrative reasoning* which does not influence actions but only *directs judgment* concerning causes and effects (Hume, 1739, p. SBN 414). This view segued into another paradigm of science known as logical positivism—where laws of nature or generalizations are based on empirically observable statements which can be logically deduced (Monk & Dillon, 2010, p. 26). The matter of ideas in causation was inferential in nature and this was an explicit characteristic of logical positivists known as induction or *inductive reasoning.* It may be important to also note at this juncture that the nature of science may also be inferential (Abd-El-Khalick, Waters, & Le, 2007, pp. 838-839).

A brief critique of empiricism, logical positivism, and falsification. One common flaw in empiricism and logical positivism is that there simply cannot be enough evidence to determine scientific truth. Besides this, naive empiricism runs the risk of a tendency towards the non-acceptance of new knowledge and naive logical positivism runs the risk of the spuriousness of knowledge if improper claims are deduced from ambiguous presuppositions. Karl Popper introduced the concept of falsification which involves informed conjectures or hypotheses that are tested and either confirmed or refuted then peer reviewed and tested again (Popper, 2002). Whichever the result, the nature of science acknowledges that scientific findings are tentative (Abd-El-Khalick, Waters, & Le, 2007, pp. 838-839). Falsification involves deductive reasoning and was eventually coined as the hypothetico-deductive method of scientific inquiry, and it is the prevailing method by which scientific investigations are described to be carried out—the scientific method.

This “scientific method” is brandished in the first chapter of the current Form 1 science text (Tho, Goh, & Ho, 1997). A critique of even this is that scientific discovery has no one method. According to the old adage, when Sir Isaac Newton conceptualized the universal law of gravitation, he observed an apple falling from a tree and took it from there. When Galileo Galilei developed the pendulum theory, he was observing swinging chandeliers in the Pisa Cathedral! These works changed the world in great ways and were discovered in no pre-determined manner. According to Thomas Kuhn, the changing scientific paradigms are known as paradigm shifts or changing scientific worldviews where one paradigm transitions (during a period called a “crisis”) then dethrones the other in what is termed as a scientific revolution which involves not only changes in science philosophy but in the context of social, economic, political, religious and other “human” factors (Kuhn, 1962). It should be important to note at this juncture that human factors influence scientific belief and the actions of individuals.

The relevance of causation, ecological worldview and learning ecological science. In this post-modern era, science seems to be all-encompassing of the many perfections and imperfections that begot it, in the quest for truth and meaning. The study of ecological science is no different and embraces salient characteristics extracted from the discourse thus far: science is empirical, inferential, tentative, and is affected by human nature. These characteristics make up the nature of science which is defined by McComas, in 1998, as:

> A hybrid arena which blends aspects of various social studies of science including the history, sociology, and philosophy of science combined with research from the cognitive sciences such as psychology into a rich description of what science is, how it works, how scientists operate as a social group and how society itself both directs and reacts to scientific endeavors. (p. 4)

Ecosystems comprise of a myriad of cause and effect relationships and the environment affects humans as humans affect it in many different ways. Empirical data is needed to be measured in order to study biotic and abiotic factors, how they relate to each other, and the systems that govern them that are not immediately observable with the naked eye, that: for example the biological processes of photosynthesis, respiration, decomposition and the effects of pollutants—over distance and time. Understanding this would allow students to appreciate the behavior of associated variables in the environment, make inferences, and help them make hypotheses to be tested in determining possible causes of or explaining how internal/external factors affect the system.

From this students would be expected to envelop a sense of responsibility or take a position on their environmental stewardship. In addition, causal reasoning ability is synonymous with induction or with their inductive inference which is a part of critical thinking (Fischer & Scriven, 1997, p. 123). Critical thinking may be defined as "reasonable and reflective thinking focused on deciding what to *believe or do*" (The Critical Thinking Company, 2004). This further substantiates the power and significance of causal reasoning ability because it may affect one's beliefs and one's actions and in the context of the research problem it is also important to acknowledge that, according to the literature, how strongly students believe may affect how strongly they understand, which may in turn affect the manner in which they interact with the environment. This is an example how, in theory, inquiry aspects of ecological science crosses over with social aspects of ecological science and this becomes important to investigate.

From the literature review thus far, it is clear that if there is a problem with student causal reasoning ability, then there should also be a check on their ecological worldview and how well they accept formal ecological concepts (conceptual change) because these aspects of their thinking, perspectives, learning are all related. These relationships were juxtaposed to each other according to how they presented themselves from critically analyzing the literature and represented in a theoretical framework.

Theoretical Framework

Figure 3 illustrates the research problem in the context of a theoretical framework.

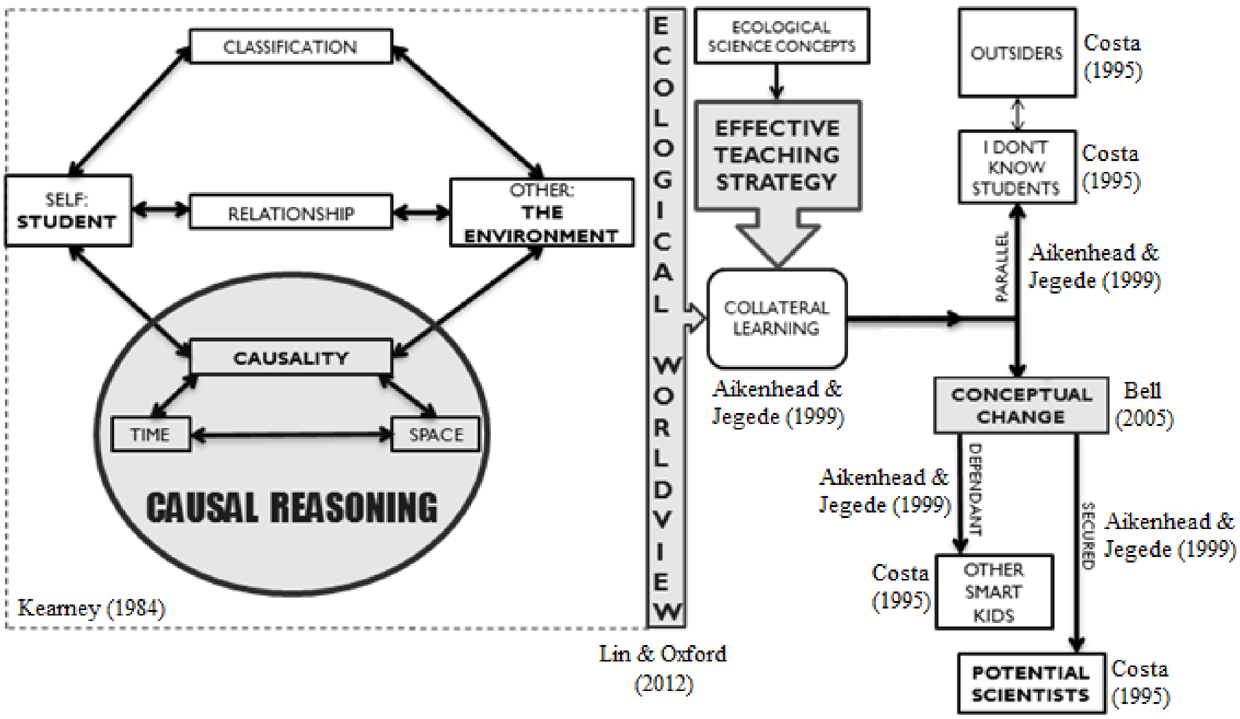


Figure 3. Theoretical framework of the state of affairs. Adapted from: Kearney, M. (1984). Worldview. Novato, CA: Chandler & Sharp Publishers, Inc. p.106; Lin, J., & Oxford, R. (2012). Transformative eco-education for human and planetary survival. Charlotte, NC: Information Age Publishing; Aikenhead, G. & Jegede, O. (1999). Cross –cultural Science Education: A Cognitive Explanation of a Cultural Phenomenon. Journal of research in science teaching. p. 279; Costa, V. B. (1995). When science is "another world": Relationships between worlds of family, friends, school, and science. Science Education 79 (3), 313-333.

Kearny describes *causality* as one of seven *universals* or facets of perception which make up an individual's *worldview*. The theoretical framework illustrates how a student's worldview would be informed by Kearny's *logico-structural model of worldview* (Kearney, 1984, p. 106). In the context of this research, a student's worldview on the environment (their *ecological worldview*) would be determined by the interactions amongst seven determinants (or facets of worldview) called universals: The Self (individual: student) which has a particular relationship with The Other (in this case the environment) which will be governed by rules pertaining to their classification of things about the environment that will all be operationalized by a set of rules pertaining to causality (their perspectives on environmental causal relationships) which would be informed by perspectives about time and space—causality, time and space considered as being part of their *causal reasoning*. All the universals combined would form the student's worldview about the environment or their *ecological worldview*. In order to bring across the conventional science (which consists of ecological science concepts), an *effective teaching strategy* is necessary to facilitate learning of students who come to the classroom with their ecological worldview. It was considered that an alternative teaching strategy, targeting students' causal reasoning ability may assist in improving the status quo—hence the basis for this research.

An effective teaching strategy may also facilitate collateral learning, a term expatiated by Aikenhead and Jegede, which could lead to parallel collateral learning (conflict between traditional knowledge and conventional science), dependent collateral learning (assimilating conventional science with traditional knowledge), and secured collateral learning (accepting conventional science seamlessly)—secured collateral learning being the desired form of learning to be achieved (Aikenhead & Jegede, 1999, pp. 279-280). A student who is capable of making the smooth cognitive transition from their traditional knowledge (embedded in their ecological worldview) to the conventional science knowledge (ecological science concepts) is said to have achieved *conceptual change*. Conceptual change will determine if students understand the conventional science concepts and possibly inform a new ecological worldview. The degree of conceptual change can lead students to exist on a particular spectrum of understanding of ecological science which could deem them to be Outsiders (no understanding), I Don't Know Students (little understanding), Other Smart Kids (some understanding), or Potential Scientists (sophisticated understanding) (Costa, 1995).

The definitions of key terms thus far are as follows:

- "*Causal reasoning* is that form of reasoning in which an individual demonstrates that an event that happens first [the cause] has the means, powers, and facilities, and/or desire to produce the second event [the effect]" (Huber & Snider, 2005, p. 136).
- *Complex causality* may be considered as an indicator of the ability for students to identify complex causal relationships which consists of (causal agents) non-obvious causes, changes over time, and effects over distance (Grotzer, et al., Helping students learn more expert framing of complex causal dynamics in ecosystems using EcoMUVE, 2011, p. 11).
- An *ecological worldview* is "the recognition that every environmental change in a system generates a series of interrelated consequences" (Lin & Oxford, 2012, p. 66).
- *Conceptual change* may be defined as "the construction and acceptance of new ideas, or the restructuring of existing ideas" (Bell, 2005, p. 22)

The teaching intervention. *Teaching for conceptual change* involves moving students from naïve conceptualizations toward more accurate and expert understandings of science concepts (Shope III, 2006, p. 10). Aikenhead describes this as *cultural border crossing* which is a "transition between a student's life-world and school science" (Aikenhead & Jegede, 1999, p. 269). Mayer, in 2002, describes *understanding* as building connections between the new knowledge to be gained and prior knowledge (p. 228). Teaching for conceptual change can be linked to Aikenhead's description of cultural border crossing. Once cultural border crossing/understanding is achieved successfully, then it can be said that meaningful learning has occurred and this successful transition from the unlearned to the learned is synonymous with *conceptual change*. Therefore, the effective teaching strategy used encompassed teaching for conceptual change.

A multi-user virtual environment. Choosing the teaching intervention was primarily based on brainstorming the issue and searching for an alternative teaching strategy that would be appropriate for tackling the research problem. The alternative strategies of a simulation and computer-based learning were suggested in the science curriculum (Ministry of Education, 2008, p. 88). These suggestions were not made specifically for this unit, so the researcher sought to try them as a solution to the problem. The teacher as researched noticed that students seemed quite comfortable and confident in the use of their laptops in school when playing games. This brought to mind the works of Aikenhead and Jegede, in 1999, who explained that *discomfort* can cause border crossings to be less smooth and needed to be managed, *lowered self-esteem* can cause border crossings to be easily hazardous, giving way to students reacting to protect their egos, and *psychological pain* can cause avoidance and make border-crossing seem impossible (p. 272). This forms the basis of student resilience to learning new content relating to causal relationships in the environment which in theory may perhaps be reduced with the use of this type of intervention.

The researcher thought that the use of a simulation via computer-based learning would help with the ease of learning. In the literature, serious virtual reality games facilitate *distributed cognition* which may be defined as “the scientific study of cognition as it is distributed across internal human minds, internal cognitive artifacts, groups of people, and space and time (Dieterle & Clarke, 2005, p. 10). Distributed cognition consists of *physical distribution of cognition* (for example, limits of space are removed by having virtual items that can be used for example a virtual microscope and a virtual notepad for record-keeping), *social distribution of cognition* (for example, when enhanced collaborative learning is achieved with students working together in groups as expert rather than an individual as expert the jigsaw approach), and *symbolic distributed cognition* (for example, when the students become familiar with scientific jargon and symbols in fieldwork, linking concepts and propositions using concept maps which provide a logical bridges between concepts) (Dieterle & Clarke, 2005, pp. 4-5). These are some benefits of using virtual environments to enhance student learning via conceptual change.

In reality, it would be highly unethical to simulate an environmental disaster then study it. With EcoMUVE one can do this and go back and forth in time to look at changes. This is an advantage of the software over the traditional methods.

Methodology

Type of Study

After much reflection on the methodology used for this research, it was concluded that this type of study fell within the realm of what can be deemed as an *action research*.

Justification for the action research classification. There are many versions of action research. This research study represents but one of them. Hopkins describes action research to be "the combination of action and research which renders that action a form of disciplined inquiry in which a personal attempt is made to understand, improve and inform practice" (as cited in Cohen, Manion, & Morrison, 2007, p. 297). This study had a two-prong, reciprocal approach. The first was to seek to improve student causal reasoning ability via improving teaching practice, in relation to the second, which was to further understand the theoretically related aspects of the students' learning—contributing to the body of knowledge about the practice—which may in turn serve to substantiate the teaching practice itself and inform the use of this practice in the given context. This matched with what was considered to be action research, where practice is juxtaposed to knowledge production: "The fundamental aim of action research is to improve practice rather than to produce knowledge. The production and utilization of knowledge is subordinate to, and conditioned by, this fundamental aim" (Elliott, 1991, p. 49). Elliot goes on to show that action research in education can be inclusive of theory when he states that action research "resists the temptation to simplify cases by theoretical abstraction but will use and even generate theory to illuminate practically significant aspects of the case" (Elliott, 1991, p. 52). These were the principles which were undertaken by the researcher: to improve practice and take a peek at how it can further be improved by observing it in action and further understanding the theory of related aspects of learning and how they interplay...reflecting as the intervention proceeds but most significantly so on the entire process (at the end of it) in order to know how acting upon the findings of the implementation of the pre-determined teaching strategy (EcoMUVE) should again proceed.

This type of action research concentrated on a combination of two main aspects of the reflective process: *knowing-in-action* and *reflection-on-action*. Knowing-in-action may be defined as “strategies, understandings of phenomena, and ways of framing a task or problem appropriate to the situation” (Schon, 1987, p. 28). Reflection-on-action may be described as “the rungs of a ladder” (Schon, 1987, p. 114). In this context, the rung of the reflective process (reflection-on-action) occurred at the end of the intervention—reflecting about the intervention. Reflection-in-action occurred during the intervention (tutor comments in lesson plans) which served to supplement reflection-on-action but this was of a subordinate nature to reflection-on-action, which took precedence because it took into account reflecting on the entire teaching intervention as a whole rather than its individual parts. This was owing to the predetermined nature of the intervention (EcoMUVE), which has its own curriculum which was adopted by the researcher. This is not to say that variations in the intervention were disallowed if the situation called for it but that the suggested intervention was generally kept constant, veering towards reflecting upon the entire intervention.

The knowing-in-action research has to do with a tacit knowledge of the EcoMUVE intervention while it was being implemented—a predetermined teaching strategy based on the tacit knowledge the teacher-as-researcher has about students and what needs to be improved with them (causal reasoning ability). The reflection-on-action was the overriding type of reflective process—that is reflecting about the intervention after it was complete.

The model of action research fitted a seven-step model from the literature (Cohen, Manion, & Morrison, 2007, pp. 306-307). This model was adopted as follows:

1. *Decide on one common problem* – In this case it was students not performing well on assessment items pertaining to reasoning in the unit of work on ecosystems.
2. *Identify causes of the problem* – In this case it was a suspected lack of student causal reasoning ability.
3. *Brainstorm a range of practical solutions to address the problem* – In this case, looking at the suggested methods by the curriculum which included the use of fieldtrips, YouTube, debates, simulation, computer-based learning, (Ministry of Education, 2008, p. 88). Eventually the researcher came across EcoMUVE (Harvard University, 2012). This discovery was made while the researcher was in the process of creating a virtual environment as a practical solution using Thinking Worlds (Thinking Worlds, 2011).
4. *From the range of practical solutions, choose one and plan how to put the solution into practice* – EcoMUVE was eventually chosen because it matched the aims of the national lower secondary school science curriculum and has a keen focus on causality. Time also did not permit the development of a virtual environment for trial.
5. *Determine the 'success criteria' for the solution* – Defining variables. Use of instruments to measure causal reasoning ability before and after the intervention. Observation of students' responses. Using quantitative statistical measures to observe and learn about how student causal reasoning ability interacted with theoretically related aspects of learning. Being reflective about the lessons carried out. And using reflections to inform the assessment of the intervention.
6. *Put the plan into action* – Carry out the unit of work using EcoMUVE.

7. *Evaluate outcome using success criteria in Step 5*.
8. *Review and plan what needs to be done in light of the evaluation* – Data analysis and findings, discussions and recommendations.

Type of Design

The type of research design was the quasi-experimental, one group, pretest-posttest design.

Justification for the research design. The design is quasi-experimental because there is no random sample and there are confounding factors. The one group, pretest-posttest design has the following flaws of internal invalidity: weaknesses in history, maturation, testing, instrumentation, interaction of selection and maturation, and possible concerns with regression (Campbell & Stanley, 1963, p. 8). Maturation was considered as controlled since the study was complete in two weeks. History was considered somewhat controlled since the pretest was done within the intervention timeframe but before the core treatment (that is at the end of the third lesson)—therefore pre-knowledge and tools in the virtual environment were in plain sight of the students. Of course it would be disingenuous to expect that all students would perform competently in the pretest because of an absence of the actual lesson. This expectation was not the case. This control sought to level the playing field so that a proper extent of change in variables can be measured when comparing variables before and after the intervention (focuses on trends pertaining to shifts in variables, not magnitude of variable themselves). With respect to instrumentation, the test items (causal features worksheet) were developed over ten years of research from credible sources. The pretest being the same as the posttest would introduce the possibility of testing effects. The researcher noted that the use of equivalency testing for pretest-posttest assessment would reduce the threat of testing effects. Checks for violations of assumptions to normality were made and data was analyzed via triangulation in calculations.

When analyzing the data, it was important to acknowledge that in a quasi-experimental pretest-posttest research design such as this, findings may be susceptible to Type I errors (falsely rejecting the null hypothesis). This error may be due to effects such as previous knowledge of or familiarity with the treatment, student motivation, anxiety...a long list of confounding factors. Besides the researcher attempting to control some effects that may force Type I errors, in the calculation, a robust statistical method was used to treat with the data. This was in the form of structural equation modeling.

Structural equation modeling. The robustness and flexibility of *regression analysis using unobserved variables* and the clarity of presentation using structural equation modeling to produce path analysis in the IBM SPSS AMOS v.20 statistical program presented an appropriate opportunity to investigate the relatedness of causal reasoning ability, ecological worldview, and conceptual change variables. A path analysis model was created to analyze this relatedness where student causal reasoning ability was theoretically linked to student ecological worldview, and where both variables were theoretically linked to student conceptual change—based on the theoretical framework as described in Figure 3 of the literature review.

Unique, unobserved variables with regression weights of 1 were used to represent errors not found on the path diagram (taking errors which may contribute to Type I errors into account). The acknowledgement and inclusion of these unobservable errors into the path diagram equation in computing the relatedness statistics was a critical component which, together with consideration for the research assumptions, may serve to substantiate findings with a reasonable level of plausibility that the EcoMUVE intervention could have a tendency to be more attributable to variances observed in posttest scores where learning may have thought to have occurred. This is as far as learning from the findings would go. These findings are not representative of generalizable claims but of tendencies and trends.

Profile of participants

Students. The student sample size was n = 15. This consisted of all male form three students from School B. School B is a secondary school in St. George West District. In the transition from form two to three, class membership was determined by a random number selection system by School B's administration. The ability of the group therefore should be mixed. The selection was however a convenient sample as the teacher-as-researcher merely chose all the boys in the class. Initially, the sample size was n = 30, however students who were present for both pretest and posttest, and who were present for all or most of the lessons during the intervention period were treated as the effective sample which turned out to be n = 15.

Epoché. The teacher is the researcher and participated in the study as the teacher facilitating the unit of work on ecosystems using EcoMUVE. The teacher as researcher (and participant) had a desire to improve student causal reasoning ability. The teacher also has a desire to improve teaching practice. The teacher has an interest in the effect use of information communication technologies (ICT's) in science classroom. The researcher has a vested interest in deriving the truth or the closest semblance to it in educational research. The researcher believes in impartiality. It is the researcher's view that whatever has to be properly done in order to maintain integrity and validity of data, should be done properly. The researcher is always consciously willing to disallow biases if ever faced with the predicament of any personal conflict of interest with the study and the self.

The researcher declares that there is value to be had from the perceptions of students. After all, education is a human thing so although there is quantitative rigor to be had in a better research design, consideration is asked for the views of the student participants to be taken as valuable, considering the manner of data collection and the assumptions made.

Data Collection

The main methods of data collection in this study were:

1. Compare causal reasoning ability scores—assessed using a causal features assessment worksheet—before (pretest) and after (posttest) the EcoMUVE intervention (Grotzer, et al., Helping students learn more expert framing of complex causal dynamics in ecosystems using EcoMUVE, 2011, pp. 14-15).
2. Compare ecological worldview scores—measured using the Revised New Ecological Paradigm Scale—before (pretest) and after (posttest) the EcoMUVE intervention (Dunlap, Van Liere, Mertig, & Jones, 2000, p. 433).
3. Compare student conceptual change scores—measured by using the EcoMUVE Post-Survey, coined by the researcher as the *ecological concepts survey*; treated as a unit test—before (pretest) and after (posttest) the EcoMUVE intervention (The EcoMUVE Project Team, 2012).
4. To determine and assess the relationship amongst causal reasoning ability, ecological worldview, and student conceptual change—quantitative non-parametric correlational tests (Kendall tau-b and Spearman's rho).
5. Ancillary data collection (to contribute to overall accuracy): A qualitative member check (optional, two-item, open-ended, free-response, anonymous questionnaire activity) to get

the student's view on how EcoMUVE impacted on their learning. See Appendix E for details.

Data collection instruments

1. Causal reasoning ability. Table 4 illustrates the instrument used to measure causal reasoning ability—a causal features assessment worksheet (Grotzer, et al., Helping students learn more expert framing of complex causal dynamics in ecosystems using EcoMUVE, 2011, pp. 14-15). Table 5 illustrates the rubric for the causal features assessment worksheet.

Table 4.

Causal features assessment worksheet used to determine causal reasoning ability

Part 1

Name____ Date _________

There are a lot of dead fish at Scheele Pond! What do you think may have caused the fish to die? List as many ideas as you can think of.

1. ____
2. ____
3. ____
4. ____
5. ____

(Use the back of the paper if you would like more space.)

What information would you like to find out to help figure out what killed the fish? List as many ideas as you can think of.

1. ____
2. ____
3. ____
4. ____
5. ____

(Use the back of the paper if you would like more space.)

Part 2

Answer the following questions about <u>the dead fish at Scheele Pond</u>.

The mayor told the local news what he considered to be the most important things to do to find out the cause of the fish kill. For each one, circle whether you agree or disagree that it is one of the most important things to do and tell why you agree or disagree.

1. "We need to focus on the area right around the pond. One of the most important things to do is to find out about the things that have happened within a few feet of the pond's edges."

Circle one: I agree I disagree
Why do you agree or disagree?
____
____

1. “We need to focus on the last couple of days. One of the most important things to do is to see what has been going on in the two to three days before the fish died.”

Circle one: I agree I disagree
Why do you agree or disagree?
____
____

2. “We need to focus on the things that we can see. If we just look, the problem will be obvious.”

Circle one: I agree I disagree
Why do you agree or disagree?
____
____

Note. Adapted from Grotzer, T., Tutwiler, S., Dede, C., Kamarainen, A., Metcalf, S., & Jeong, D. (2011). Helping students learn more expert framing of complex causal dynamics in ecosystems using EcoMUVE. *National Association of Research in Science Teaching (NARST)*, Orlando, FL., pp. 14-15.

Table 5.
Causal features assessment worksheet rubric

<table>
<tr><th colspan="2" rowspan="2">CAUSAL FEATURE RELATED TO COMPLEX CAUSALITY</th><th rowspan="2">DEFINITIONS</th><th colspan="2">VARIABLES</th><th colspan="2">SCORING</th></tr>
<tr><th>PRETEST</th><th>POSTTEST</th><th>PART 1</th><th>PART 1</th></tr>
<tr><td rowspan="2">Effects over distance</td><td>Spatially Distant</td><td>Occurred beyond the banks of the pond.</td><td rowspan="2">EOD1</td><td rowspan="2">EOD2</td><td rowspan="3">10 MARKS
Rationale: 1 mark for each adequate instance of a causal feature related to complex causality; maximum of 5</td><td rowspan="3">6 MARKS
Rationale: 1 mark for choosing “disagree” and 1 mark for a consistent, adequate explanation of a</td></tr>
<tr><td>Action at a Distance</td><td>Beyond what could be seen when standing at the pond.</td></tr>
<tr><td>Changes over</td><td>Processes or Steady</td><td>Dynamics that are going on over time.</td><td>COT1</td><td>COT2</td></tr>
</table>

time *State*				marks for items 1 and 2 respectively.	causal feature related to complex causality.
Non-obvious Causes	*Cannot be seen with the naked eye.*	NOC1	NOC2		
CAUSAL REASONING ABILITY	*Ability to reason about complex causal relationships. Regarded as the degree of recognition of complex causality.*	CAUSAL1 **= EOD1 + COT1 + NOC1**	CAUSAL2 **= EOD2 + COT2 + NOC2**	**16**	

Note. Adapted from Grotzer, T., Tutwiler, S., Dede, C., Kamarainen, A., Metcalf, S., & Jeong, D. (2011). Helping students learn more expert framing of complex causal dynamics in ecosystems using EcoMUVE. *National Association of Research in Science Teaching (NARST)*, Orlando, FL.

2. Ecological worldview. Table 6 illustrates the instrument used to measure *ecological worldview*—the *Revised New Ecological Paradigm Scale* (Dunlap, Van Liere, Mertig, & Jones, 2000). This instrument is a 15-item likert scale instrument with a reliability of .83 which is good (implies low likelihood of errors due to regression). Table 7 illustrates the rubric for this ecological worldview instrument.

Table 6.
Revised new ecological paradigm scale used to measure ecological worldview

Ecological Worldview

NAME: ____ DATE: ___________

On a scale from 1 (strongly disagree) to 5 (strongly agree), please indicate how much you agree or disagree with the following statements:

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

1. We are approaching the limit of the number of people the earth can support.
2. Humans have the right to modify the natural environment to suit their needs.

3. When humans interfere with nature it often produces disastrous consequences.
4. Human ingenuity will insure that we do NOT make the earth unlivable.
5. Humans are severely abusing the environment.
6. The earth has plenty of natural resources if we just learn how to develop them.
7. Plants and animals have as much right as humans to exist.
8. The balance of nature is strong enough to cope with the impacts of modern industrial nations.
9. Despite our special abilities humans are still subject to the laws of nature.
10. The so–called ''ecological crisis'' facing humankind has been greatly exaggerated.
11. The earth is like a spaceship with very limited room and resources.
12. Humans were meant to rule over the rest of nature.
13. The balance of nature is very delicate and easily upset.
14. Humans will eventually learn enough about how nature works to be able to control it.
15. If things continue on their present course, we will soon experience a major ecological catastrophe.

Note. Adapted from Dunlap, R.; Van Liere, K.; Mertig, A.; Jones, R.E. (2000). Measuring Endorsement of the New Ecological Paradigm: a revised NEP scale. *Journal of Social Issues*. pp. 425-442.

Table 7.
Revised new ecological paradigm scale rubric

ITEM	**SCORE**				
	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
1. We are approaching the limit of the number of people the earth can support.	1	2	3	4	5
2. Humans have the right to modify the natural environment to suit their needs.	5	4	3	2	1
3. When humans interfere with nature it often produces disastrous consequences.	1	2	3	4	5
4. Human ingenuity will insure that we do NOT make the earth unlivable.	5	4	3	2	1
5. Humans are severely abusing the environment.	1	2	3	4	5
6. The earth has plenty of natural resources if we just learn how to develop them.	5	4	3	2	1
7. Plants and animals have as much right as humans to exist.	1	2	3	4	5
8. The balance of nature is strong enough to cope with the impacts of modern industrial nations.	5	4	3	2	1

9. Despite our special abilities humans are still subject to the laws of nature.	1	2	3	4	5
10. The so–called ‘‘ecological crisis’’ facing humankind has been greatly exaggerated.	5	4	3	2	1
11. The earth is like a spaceship with very limited room and resources.	1	2	3	4	5
12. Humans were meant to rule over the rest of nature.	5	4	3	2	1
13. The balance of nature is very delicate and easily upset.	1	2	3	4	5
14. Humans will eventually learn enough about how nature works to be able to control it.	5	4	3	2	1
15. If things continue on their present course, we will soon experience a major ecological catastrophe.	1	2	3	4	5

Note. The even-numbered items are reverse-scored. Maximum score for each of the five ecological worldview facets is 15. Overall, the minimum score is 15 and the maximum score is 75.

3. Conceptual change. Table 8 illustrates the instrument used to measure conceptual change which indicates students' understanding of scientific concepts taught in the EcoMUVE. It is called termed here as the Ecological Concepts Survey. It is derived from the EcoMUVE Post-Survey (The EcoMUVE Project Team, 2012).

Table 9 illustrates the rubric for this instrument. The cognitive process dimensions and the knowledge dimensions for each question were determined by considering the cognitive action verbs and the knowledge category descriptions of the revised Bloom's taxonomy (Krathwohl, 2002, pp. 214-215).

Table 8.
Ecological concepts survey used to measure student conceptual change.

Ecological Concepts survey
NAME: ____ DATE: ____________
For the following questions, read the question and answer to the best of your ability. For SOME multiple choice questions, you may be able to circle more than one answer. Read the question carefully to know what to do.
1.) Resources are living and non-living things that organisms use from the environment. List the resources that are

used by minnows (a small fish).

2.) There are gases (like oxygen and carbon dioxide) dissolved in the water of lakes, streams and ponds. Describe at least three ways that these gases get into the water.

3.) Which of the following statements about respiration is true?
a. Only plants do respiration.
b. Only animals do respiration.
c. Both plants and animals do respiration.
d. No plants or animals do respiration

4.) All matter is made up of
a. cells
b. atoms
c. molecules
d. compounds

5.) Which of the following answers shows a consumer and producer in a food chain?

a. A cat eats a mouse.
b. A rabbit eats a carrot.
c. A spider eats a fly.
d. A snake eats a frog.

6.) Why might a pond have a high chlorophyll measurement?

a. there is more algae in the water
b. there is more pollution in the water
c. there are more fish in the water
d. there are more bacteria in the water

7.) When water is cloudy and hard to see through, it has a higher level of:

a. chlorophyll

b. nitrates
c. pH
d. turbidity

8.) Which is the best pH range for water organisms to be healthy?

a. 1-2
b. 2-4
c. 4-6
d. 6-8

9.) What factors in the environment might cause the number of individuals in a population to change over time? List as many as you can think of:
____

10.) The energy that is stored in food originally comes from

a. air
b. soil
c. sunlight
d. plants

11.) How do decomposers obtain their food?

a. hunting and killing other organisms for food
b. changing carbon dioxide and water into food
c. absorbing food from dead organisms
d. producing food from oxygen and sunlight

12.) When organisms use oxygen to break apart glucose and starch for energy it is called:

a. Photosynthesis
b. Respiration
c. Oxygenation
d. Reproduction

The drawing below represents part of a food web in a pond. Use this drawing to answer questions 13 and 14.

13.) If all of the small fish in the pond died suddenly from a disease that killed only the small fish, what would happen in the next month to the algae in the pond?

a. There would be more algae in the pond.
b. There would be fewer algae in the pond.
c. There would be the same number of algae in the pond.

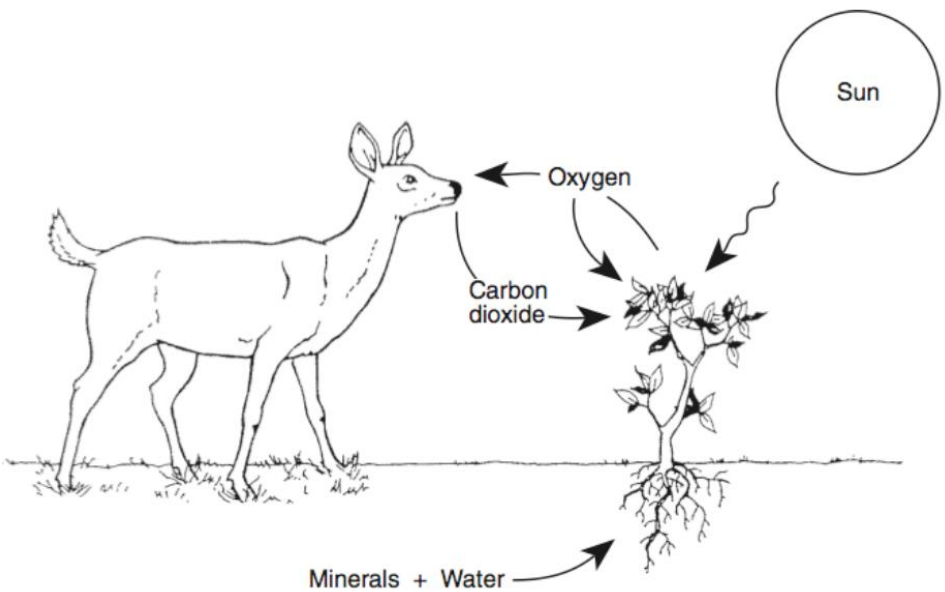
14.) If all of the small fish in the pond died suddenly from a disease that killed only the small fish, what would happen in the next month to the large fish in the pond?

a. There would be more large fish in the pond.
b. There would be fewer large fish in the pond.
c. There would be the same number of large fish in the pond.

15.) What is most likely to happen next if you add nitrates and phosphates to water for plants?

a. the plants die
b. the plants get smaller
c. the plants get bigger
d. there is no effect on the plants

The diagram below shows some relationships within a natural community.



16.) Which statement best explains the relationships shown?

a. Water changes over time to a nonrenewable resource.
b. Living things exchange materials with their environment.
c. Minerals recycle the dead materials in the environment.
d. Living things produce other living things.

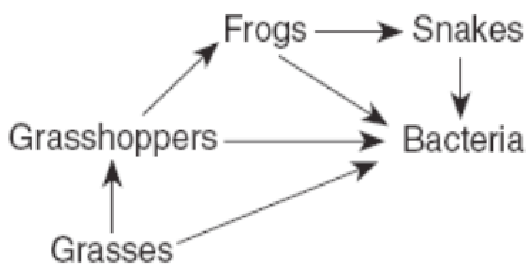
17.) Which of the following statements about atoms in ecosystems are true?
Circle **the best answers.** (You can circle one or more answers.)

a. The same atoms can be rearranged to make different things.
b. Organisms get energy by destroying atoms.

c. Some atoms are alive.
d. Plants use the energy from the sun to create new atoms.

18.) During photosynthesis, plants use sunlight to _____________?
Circle **the best answers.** (You can circle one or more answers.)

a. Make glucose, a kind of sugar.
b. Take carbon out of the soil.
c. Break down food into energy.
d. Make oxygen.



19.). Use the food web above to answer the following question: Are the grasses important to the other things? If so, circle all the things below that the grasses are important to.

Grasshoppers
Bacteria
Frogs
Snakes

Explain the reasons why the grasses are important to the things you circled.
____
____
____

20.) Five students talked about what happens to a dead underwater plant in a pond many years after it dies. Which do you agree with **most**?

a. “Nothing happens to it because the plant is dead.”
b. “The plant becomes pond mud.”
c. “The plant disappears.”
d. “The plant turns soggy and mushy.”
e. “Small pieces of the plant get buried under the pond mud.”

21.) Think about your answer for question #20 above. Why does it happen?
Circle **the best answers.** (You can circle one or more answers.)

a. The plant breaks apart on its own.
b. It gets eaten by underwater bugs and insects.
c. It might get mushy but nothing happens, the plant is just there.
d. The plant is eaten by tiny bacteria that are too small to see.
e. Rotting makes the pieces of the plant disappear.

Note. Adapted from The EcoMUVE Project Team (2012). EcoMUVE Post-Survey. Retrieved from http://ecomuve.gse.harvard.edu/documentation/EcoMUVE_PondPostsurvey_Jan2011.pdf

Table 9.
Ecological concepts survey rubric

ITEM	EXPECTED RESPONSE	SCORE		ECOLOGICAL CONCEPT	COGNITIVE DOMAIN CATEGORY	KNOWLEDGE DIMENSION CATEGORY
1.	Water	1	Maximum: 4 marks	• Interaction between biotic/abiotic • Photosynthesis/respiration	**REMEMBERING** - Item Excerpt: "List the resources that are used by minnows" - Action Verb: *Recognizing*	**CONCEPTUAL KNOWLEDGE** - Rationale: Knowledge of principles and generalizations.
	Sunlight	1				
	Oxygen	1				
	Food	1 mark for "Food" Or 1 mark for correct food source stated.				
2.	Gases dissolve in water from air/wind at water surface.	2		Photosynthesis/respiration	**UNDERSTANDING** - Item Excerpt: "Describe at least three ways that these gases get into the water" - Action Verb: *Explaining*	**CONCEPTUAL KNOWLEDGE** - Rationale: Knowledge of theories, models and structures.
	Photosynthesis by aquatic plants (introducing oxygen).	2				
	Respiration by aquatic organisms (introducing carbon dioxide).	2				
3.	C	1		Respiration	**REMEMBERING**	**FACTUAL**

				- Item Excerpt: "Which of the following statements about respiration is true?" - Action Verb: *Recognizing*	**KNOWLEDGE** - Rationale: Knowledge of terminology.
4.	B	1	Structure and properties of matter	**REMEMBERING** - Item Excerpt: "All matter is made up of..." - Action Verb: *Recalling*	**FACTUAL KNOWLEDGE** - Rationale: Knowledge of terminology.
5.	B	1	Biotic factors	**UNDERSTANDING** - Item Excerpt: "Which of the following answers shows a consumer and producer in a food chain?" - Action Verb: *Classifying*	**CONCEPTUAL KNOWLEDGE** - Rationale: Knowledge of classifications and categories.
6.	A	1	Photosynthesis	**UNDERSTANDING** - Item Excerpt: "Why might a pond have a high chlorophyll measurement?" - Action Verbs: *Interpretation, Inferring, Explaining*	**CONCEPTUAL KNOWLEDGE** - Rationale: Knowledge of principles and generalizations.
7.	D	1	Abiotic factors	**REMEMBERING** - Item Excerpt: "When water is	**FACTUAL KNOWLEDGE** - Rationale:

				cloudy and hard to see through, it has a higher level of:" **-** Action Verb: *Recalling*	Knowledge of specific details and elements.
8.	D	1	Abiotic factors	**REMEMBERING** **-** Item Excerpt: "Which is the best pH range for water organisms to be healthy?" **-** Action Verb: *Recalling*	**FACTUAL KNOWLEDGE** - Rationale: Knowledge of specific details and elements.
9.	• Abiotic factors (example dissolved oxygen, nitrates and phosphates, chlorophyll a, pH, turbidity). • Biotic factors (example food availability, competition, predation)	4 (1 mark each)	Interaction between biotic/abiotic	**ANALYZING** **-** Item Excerpt: "What factors in the environment might cause the number of individuals in a population to change over time? List as many as you can think of:" **-** Action Verb: *Attributing*	**CONCEPTUAL KNOWLEDGE** - Rationale: Knowledge of principles and generalizations.
10.	C	1	Interaction between biotic/abiotic	**REMEMBERING** **-** Item Excerpt: "The energy that is stored in food originally comes from" **-** Action Verb: *Recalling*	**FACTUAL KNOWLEDGE** - Rationale: Knowledge of specific details and elements.
11.	C	1	Decomposition	**REMEMBERING** **-** Item Excerpt: "*How*	**FACTUAL KNOWLEDGE**

				do decomposers obtain their food?" - Action Verb: *Recalling*	- Rationale: Knowledge of specific details and elements.
12.	B	1	Respiration	**REMEMBERING** - Item Excerpt: "When organisms use oxygen to break apart glucose and starch for energy it is called" - Action Verb: *Recalling*	**FACTUAL KNOWLEDGE** - Rationale: Knowledge of terminology.
13.	A	1	Food chain	**APPLYING** - Item Excerpt: "Use this drawing to answer questions 13 and 14" [Drawing of a food chain: ALGAE → SMALL FISH → LARGE FISH] - Action Verb: *Implementing*	**PROCEDURAL KNOWLEDGE** - Rationale: Knowledge of subject-specific techniques and methods.
14.	B	1		**ANALYZING** - Item Excerpt: "If all the fish in the pond died suddenly...what would happen in the next month to...?" - Action Verb: *Attributing*	**CONCEPTUAL KNOWLEDGE** - Rationale: Knowledge of principles and generalizations.
15.	C	1	Eutrophication	**UNDERSTANDING** - Item Excerpt: "What is most likely to happen next if you add nitrates and	**CONCEPTUAL KNOWLEDGE** - Rationale: Knowledge of theories, models

				phosphates to water for plants?” **-** <u>Action Verb</u>: *Explaining*	and structures.
16.	B	1	Interaction between biotic/abiotic	**UNDERSTANDING** **-** <u>Item Excerpt</u>: “The diagram below shows some relationships within a natural community”, “Which statement best explains the relationships shown?” **-** <u>Action Verb</u>: *Interpreting*	**CONCEPTUAL KNOWLEDGE** - <u>Rationale</u>: Knowledge of principles and generalizations.
17.	A	1	Structure and properties of matter	**REMEMBERING** **-** <u>Item Excerpt</u>: “Which of the following statements about atoms in ecosystems are true?” **-** <u>Action Verb</u>: *Recognizing*	**FACTUAL KNOWLEDGE** - <u>Rationale</u>: Knowledge of terminology.
18.	A	1	Photosynthesis	**REMEMBERING** **-** <u>Item Excerpt</u>: “During photosynthesis, plants use sunlight to” **-** <u>Action Verb</u>: *Recalling*	**FACTUAL KNOWLEDGE** - <u>Rationale</u>: Knowledge of terminology.
	D	1			
19.	Grasshoppers	1	Food web and photosynthesis	**ANALYZING** **-** <u>Item Excerpt</u>: “Use the food web above	**PROCEDURAL KNOWLEDGE** - <u>Rationale</u>: Knowledge of
	Bacteria	1			

				to answer the following question: Are grasses important to the other things?" **-** Action Verb: *Attributing*	subject-specific techniques and methods.
	Frogs	1		**EVALUATING** **-** Action Verb: *Checking*	**CONCEPTUAL KNOWLEDGE** - Rationale: Knowledge of principles and generalizations.
	Snakes	1			
	Grasses absorb CO2/provide O2.	1	Food web and photosynthesis	**UNDERSTANDING** **-** Item Excerpt: "Explain the reasons why the grasses are important" **-** Action Verb: *Explaining*	**CONCEPTUAL KNOWLEDGE** - Rationale: Knowledge of principles and generalizations.
	Grasses are a major source of food for grasshoppers/bacteria	1			
	Grass availability indirectly affects the health/presence of other organisms along the food chain.	1			
20.	B	1	Decomposition	**EVALUATING** **-** Item Excerpt: "Five students talked about what happens to a dead underwater plant in a pond many years after it dies. Which do you agree with the most?" **-** Action Verb:	**CONCEPTUAL KNOWLEDGE** - Rationale: Knowledge of principles and generalizations.

				Critiquing	
				CREATING - Action Verb: *Generating*	**METACOGNITIVE KNOWLEDGE** - Rationale: Knowledge of strategic knowledge.
21.	D	1	Decomposition	**UNDERSTANDING** - Item Excerpt: "Think about your answer for question #20 above. Why does it happen?" - Action Verb: *Explaining*	**CONCEPTUAL KNOWLEDGE** - Rationale: Knowledge of principles and generalizations.
	E	1			
OVERALL TOTAL		**40**			
TOTAL MARKS FOR CONCEPTUAL KNOWLEDGE		**30**			

Note. Any other reasonable answer was also considered. Cognitive and Knowledge dimensions adapted from Krathwohl D.R. (2002). A Revision of Bloom's Taxonomy: an overview. *Theory into practice*, 214-215.

Instructional planning

Table 10 shows the instructional planning chart for the study, outlining the EcoMUVE strategy. It shows a summary plan of how the intervention proceeded. The justifications and derivations of particular instructional objectives are important. The EcoMUVE intervention was properly analyzed to determine its suitability for use in this context. This came from thoroughly analyzing the curriculum documents involved from EcoMUVE and the national SEMP science curriculum and forming the unit plan. A table of specifications was made which was comparable to the specifications for the unit test. For the unit plan and lesson plans, see Appendix A. The lessons were carried out based on lesson plans provided in the EcoMUVE Pond Teacher Guide (Dede & Grotzer, 2012, pp. 22-66). To view sample lesson plans and associated artifacts, see Appendix B.

Table 10.
Instructional planning chart for the unit of work using the EcoMUVE educational game

LESSON	INSTRUCTIONAL OBJECTIVE	COGNITIVE DIMENSION CLASSIFICATION	KNOWLEDGE DIMENSION CLASSIFICATION	ECOMUVE TEACHING STRATEGY	EVALUATION TECHNIQUES
1. Making discoveries in the ecosystem.	1.1 Identify organisms in a pond habitat.	Remembering	Factual Knowledge	**Learning Cycle:** ▪ **Analyze:** students describe what an ecosystem is. ▪ **Expand:** students learn how to operate EcoMUVE program. ▪ **Explore:** students see how much different organisms they can find. ▪ **Review/Extend/Apply:** students name one organism they found and share their discoveries with class.	▪ Questioning ▪ Discussion ▪ Recording concerns

2. Food webs and energy transfer.	2.1 Arrange organisms in a food web which represents the transfer of energy. 2.2 Learn the roles of producers, consumers and decomposers in an ecosystem and categorize organisms accordingly.	Analyzing	Conceptual Knowledge	**Learning Cycle:** ▪ **Analyze:** students given definition of producer, consumer, and decomposer and asked to group organisms correctly. ▪ **Expand:** students learn how to use online food web tool and learn about feeding relationships using pond field guide; students given food web activity sheets. ▪ **Explore:** students construct food webs using online food web tool. ▪ **Review/Extend/Apply:** students review and discuss implications of removing an organism from the food web and learn about food and energy transfer.	▪ Review food web activity worksheet and trophic level worksheet.
3. Biotic and abiotic factors	3.1 Notice, measure and document changes in biotic factors over time. 3.2 Notice, measure and document changes in abiotic factors over time.	Applying	Procedural Knowledge	**Learning Cycle:** ▪ **Analyze:** students list biotic and abiotic factors from what they have observed and discuss its relevance; students learn about scientists who study ecosystems (ecologists, water chemists, biologists) and their measurement tools; students fill in the water measurement learning quest. ▪ **Expand:** students learn how to use the measurement tools in EcoMUVE. ▪ **Explore:** students use calendar tool to go to July 28th and note their observations ▪ **Review/Extend/Apply:** students share	Review of: ▪ Pond Learning Quest Online Activity http://ecomuve.gse.harvard.edu / Pond_LQ.html ▪ Worksheet

				their observations about July 28th and discuss what they would like to find out on the next pond visit.	
▪ **CAUSAL REASONING ABILITY PRETEST** ▪ **CONCEPTUAL CHANGE PRETEST** ▪ **ECOLOGICAL WORLDVIEW PRETEST**					
4. Science team roles	4.1 Investigate causes behind an environmental issue. 4.2 Hypothesize why an observed environmental issue occurred.	Analyzing Creating	Conceptual Knowledge	**Learning Cycle with Jigsaw approach—** students separated into specialist science teams: microscopic specialists, private investigator, water chemist, and naturalist**:** ▪ **Analyze:** teams brainstorm 4 ideas (hypotheses) about why the fish may have died. ▪ **Expand:** teams briefed about their roles and organize who will be doing what in the group. ▪ **Explore:** teammates in their respective roles use EcoMUVE to explore and record evidence of why the fish may have died. ▪ **Review/Extend/Apply:** teams discuss findings.	Review of: ▪ Group role sheets: an extended formative assessment) ▪ Individual specialist role sheets.
5. Ecosystem processes at the atomic level	5.1 Understand that atoms are neither created nor destroyed (the principle of conservation of matter). 5.2 Understand that, through ecological processes, molecules can be broken apart and atoms rearranged to form different molecules.	Understanding	Conceptual Knowledge	**Learning Cycle:** ▪ **Analyze:** students learn what an atom is and how to use the atom tracker tool in EcoMUVE. ▪ **Expand:** students use the atom tracker tool to track carbon, phosphorous, and oxygen; record their findings on the atom tracker worksheets and work on the atom tracker reflection	Review of: ▪ Atom tracker sheet

	5.3 Understand that atoms by themselves are abiotic, but through the processes of photosynthesis and respiration, atoms become a part of living things (there is a strong relationship between abiotic and biotic parts of an ecosystem).			sheet. ▪ **Explore:** whole class discussion on trends in atoms tracked; students' understanding probed about the role of atoms in ecosystems. ▪ **Review/Extend/Apply:** students suggest how the atoms played a role in the Scheele ecosystem.	
6. Ecological processes	6.1 Connect knowledge of atoms to ecological processes like photosynthesis, respiration, and decomposition.	Apply	Conceptual Knowledge	**Learning Cycle with Jigsaw Approach—** students separated into their scientific teams**:** ▪ **Analyze:** teams use one computer to collate data collected, look at trends over time and decide on what other evidence may be needed to furnish the hypothesis they brainstormed in Lesson 1. ▪ **Expand:** whole-class discussion on trends of atoms which occur over time and how atoms are rearranged to form new molecules in ecological processes; students allowed to move to computers. ▪ **Explore:** students collect data in EcoMUVE based on new team discussions about the link between atoms and ecological processes; students share teammate data files and explore findings.	▪ Guided discussions to bring about linkage between atoms and ecological processes within EcoMUVE. ▪ Observations and guidance with collating and interpreting data.

7. What are causal relationships?	3.1 Understand how to represent complex causal relationships using a concept map.	Creating	Procedural Knowledge	**Learning Cycle:** ▪ **Analyze:** students understand that relationships in ecosystems are complex; complete the cats parachuting form Borneo exercise—create concept maps (causal maps). ▪ **Explore:** students create concept map of what they think is happening with the fish kill in the Scheele pond. ▪ **Review/Extend/Apply:** students turn in their causal maps and share discoveries.	Review of causal maps and clearing up of misconceptions or gaps in understanding.
8. Evidence to support causal relationships	8.1 Interpret graphs of variables changing over time in an ecosystem.	Applying	Procedural Knowledge	**Learning Cycle:** ▪ **Analyze:** brief review of complexity in causal relationships; students ponder on what warrants what the linkages in their maps created to be causal relationships. ▪ **Expand:** students guided to understanding that data collected can be used to support how things are related using examples from their findings and from the pond curriculum guideline; students make inferences about the relationship between other variables based on patterns observed. ▪ **Explore:** students return to computers and examine their	Reviews of proposed evidence to support relationships students have created (class discussion).
	8.2 Recognize the importance of using data and evidence to support a scientific claim.	Understanding	Conceptual Knowledge		

				graphs; students try to support their concept maps with reason and data. ▪ **Review/Extend/Apply:** review of relationship that students identified.	
9. Building cases	9.1 Work in groups to represent a final hypothesis for the team and create a group concept map.	Analyzing	Conceptual Knowledge	**Learning Cycle with Jigsaw Approach:** ▪ **Analyze:** students review draft concept maps. ▪ **Expand:** each student in their specialist role present their idea with an argument and evidence about what may have caused the fish kill (using presentation materials provided); each group has 5 minutes to present their ideas ▪ **Explore:** students work in teams to begin creating a final group concept map inclusive of argument and evidence. ▪ **Review/Extend/Apply:** question and answer session about the presentation of the group concept map for the following day.	Respond to any concerns students may have about the activity via attending to groups individually and whole-class discussion.
		Creating	Procedural Knowledge		
10. Sharing conclusions	10.1 To communicate a hypothesis and offer evidence to support their claim.	Evaluating	Procedural Knowledge	**Learning Cycle with Peer Review:** ▪ **Expand:** students briefed with rules of engagement for the presentation: audience (students) expected to evaluate each other based on the support of the argument, and evidence for the causal relationships presented.	Whole-class discussion

				▪ **Explore:** each group present (5 minutes per group) their final supported hypotheses. ▪ **Review/Extend/Apply:** discussion on presentations: which data was important, hardest to find/put together, and what is the likelihood of these causal relationships being present in other ecosystems.	
11. Debriefing the experience	11.1 Understand how complex causality occurs in areas beyond ecosystem science.	Applying	Metacognitive Knowledge	**Learning Cycle with Authenticity:** ▪ **Analyze:** briefly review all that was done thus far. ▪ **Expand:** explain to students the causal relationships in the Scheele pond and clear up misconceptions from the final presentations. ▪ **Explore:** students offer suggestions as to where the phenomenon can occur real life, how it can be avoided and why it isn't likely for oxygen to be depleted on land. ▪ **Review/Extend/Apply:** students reflect on how the experience affects what they think about causal relationships in the real world: how could the concept be applied into previous science topics covered and the upcoming unit (Conservation).	Review of student reflections: ▪ Discussions ▪ Written reflections
▪ **CAUSAL REASONING ABILITY POSTTEST** ▪ **CONCEPTUAL CHANGE POSTTEST** ▪ **ECOLOGICAL WORLDVIEW POSTTEST**					

Narration of experience

The timeline of events are narrated using excerpts from tutor comments for each lesson. They are as follows:

1. March 5TH, 2013:
    - *Lesson 1*: “They made a lot of discoveries using the tools in the game and were at awe at the amount of information they got on each organism. They were sometimes found with eyes glued to the screen with enthusiasm.”
    - *Lesson 2*: “There was no internet connection. Few students had their laptops so they had to work in big groups. There was an issue with one laptop with restrictions. The IT technician was called to see about it but he was busy. The students had to watch on from a distance. This part of the lesson should be familiar to them as we did the topic of food webs last term. The students were very interested in getting information that described how the organisms interacted with each other. Some students were giving trouble. They saw the new format as an opportunity to “ole talk”.
2. March 8TH , 2013:
    - *Lesson 3*: “Students seem to be getting the hang of using the measurement tools in the game. They seem to be picking up fast. Some students were petrified at the fish kill in the game on July 28th. Immediately some expressed that the fish died because pollution. Some were bewildered as to how the fish died. A few students from the last class who were not involved became a bit more interested as students were looking at all the dead fish. I administered the pretests to the boys. They were eager to do the first one (causal features assessment). The ecological

worldview pretest was well accepted as well. It seemed to have them thinking. The conceptual change pretest however had some students visibly turned off because of it looked bulky. A student express "Whey sir, so much pages? We have to do it now?" Students had no internet connection in the classroom to the pond activity was given for homework."

3. MARCH 11TH , 2013:

- *Lesson 4*: "The students became excited about assuming the role of a scientist doing an investigation. They seem to take pride in their avatar and showed confidence in themselves. There were a few students who continue to try to defy the activity. I can see the pouting. I can feel the resistance. I made arrangements (with permission from my HOD [head of department]) with another teacher to take her classes so I can get extra with the students. Some students were visibly upset about this. I thought immediately about the "discomfort" hindrance to collateral learning as described by Aikenhead and Jegede in 1999. I knew that this would not be good for their learning causal relationships or anything coming from me for that matter. So I tried to get speak to them in a pacifying manner and got them involved in the activities. I walked around and helped students with little issues of navigating the software but everything seemed like it was on automatic. I didn't have to do much. It was like the students were so absorbed in gathering data in their roles that sometimes I felt as though they didn't think I was there! I realized that this activity was a good one as students seem own the data. They spoke with authority on what they found and what they thought could have been the cause of the fish kill. The groups make hypotheses but they suggested that they would like more time to finalize their investigations. I did not pressure them but asked that they share their thoughts about why they thought the fishes died. Healthy contributions were given. Some students were very observant and had identified the fertilizer issue from the farm. They said the farmer was dumping fertilizer that poisoned the fish. Some students offered the hypothesis that the water had less oxygen (because they noticed the drop in oxygen just before the July 28th fish kill) but they could not say why. I explained to them that a hypothesis is a theory, explanation or an educated guess that must be tested or confirmed. It's just a way of investigating things in science. We move on to the next lesson this afternoon."

- *Lessons 5&6*: "I noticed that there was one student in particular who was amazingly, rather exceptionally spot on with what the desired explanation was for the fish kill. However in his pretest, he did not articulate it in writing as well as he came and articulated it to me verbally. Had I not interacted with him by way of discussion, his scores would have told a different story to me. I see him taking charge of his group and leading the way with discussions about how the atoms go from one form to the next in its cycle. I am wondering if his was a case of anxiety or did it represent something else...makes me wonder if there are many more like him who silently become enlightened by the software lesson format and can articulate the content in discussion but not written expression. Is this thing a matter of writing expression or causal reasoning? My goodness...I will continue to observe and reflect. At least there is a constant buzz of interest and productive activity form most of the boys. For one thing though, this EcoMUVE seems to really have an “immersive” effect.”

4. MARCH 12TH , 2013:

- *Lessons 7 &8*: “I decided to condensed lessons 7 and 8 because they are very similar in nature and the activities overlap. The students thought the cats parachuting from Borneo story was mind-blowing and I think this was a turning point in them thinking outside of the box and appreciating aspects of causation. The students’ use of the virtual field book was extensive but we had no immediate access to a printer. It is a big school... approximately 1200 students and approximately 112 teachers. There is limited space for classes. I was not able to secure the ideal ICT environment because the computer labs were in use for various reasons. The class of Form 3 is at the top floor of a block in School B. If we leave the class to find a place to print the graphs, we will lose class time. I offered the guys the option of drawing the graphs. They concurred. I was impressed at their meticulousness and want to find out what was going on. They did a lot of comparing and contrasting of data. From this they wanted some more time to conceptualize the final hypothesis. I did not pressure them to complete the task today. I congratulated them and told them to present it tomorrow. Preparations for sporting activities were afoot in the school. I am recognizing that students are absent from class to be involved in co-curricular activities because sports day was next week (the 21st). Sometimes I feel as though I am trying to win them over the sometimes lapse in focus. I can see that I am having a problem with student attrition from class in this unit. May be a threat to the research.”

5. MARCH 13TH , 2013:

- *Lessons 9 & 10*: The student presented their concept maps. They were really good and I told them to use it in their explanations. I was very impressed by how much knowledge they retained and how fluent and articulate they are with respect to this topic. I hadn't known them to be this articulate in other topics before. On student had a good hypothesis that the duckweed ultimately was a factor that caused the fish to die because the phosphates caused the duckweed population to overgrow, blocking the surface of the water. He said that this blocked absorption of oxygen in the water at the surface and that the duckweed absorbed a large volume of oxygen at night...interesting. Another student who seemed like he was neither here nor there while using the software, came forward and was simply the best. He came close to speaking about almost all of the causal patterns that lead to the fish kill. He spoke about the fish coming to the surface to get oxygen because it was decreasing days before and because they were at the surface the herons swooped down and eat em'. The guys and I have a good rapport. I asked the students if I could record the presentation or at least take pictures, they politely declined my request. I respected their preference. Students recounted many aspects of the game and spoke about the farmer's fertilizer entering the farm through surface run off. I told students that I would debrief them tomorrow with the official explanation but assured them that there is no one explanation, all of them had good ideas and that is a part of how the nature of science works.

6. MARCH 15TH, 2013:

- *Lesson 11*: On the board, I drew the official concept map that I got from page 12 of the EcoMUVE pond teacher guide. I explained it. A discussion followed and any misconceptions were cleared up. This was the final lesson. Alas...I felt proud of the boys and they were still talking and debating among themselves what caused the fish to die and explaining to their peers, etc. I like how they seem to "own" the data and I can feel it in the air... a buzz of confidence and a vote of thanks for the unique format of lessons. Let's see how they fear on a written exam. I informed them that on Tuesday we will do a final assessment session. Twas a good experience. I am concerned about the absenteeism and about how some students saw the spate of unorthodox lessons as an excuse to do whatever they want (blag and go to see about activities related to Sports Day). Does this mean that the teaching strategy is for the chosen few? Or rather will it have interest for some and not others? I get the sense that they see anything outside of chalk and talk ...unless it is something not serious... as optional. We shall see what the research has to say."

Schematic overview of the study

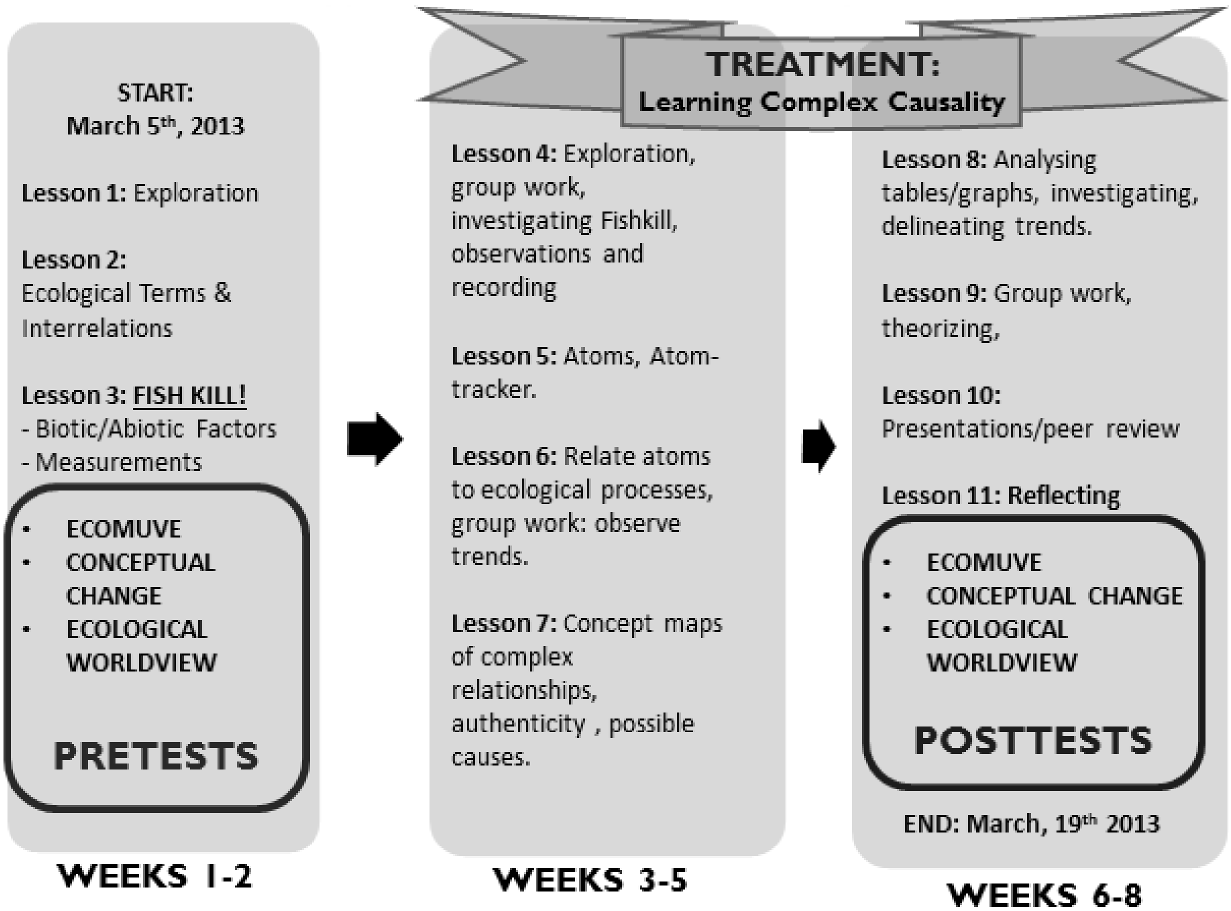


Figure 4. Intended schematic overview of the study.

Limitations

Student indiscipline—from past experiences this has been a serious threat to the quality of participation. No control group—it would be unethical for me to teach one class the traditional way and the other using the new intervention. This may also lead to jealousy amongst students and concern amongst parents. School interruptions—example: unplanned events, spontaneous time-table changes, lack of water, electricity, and availability of rooms.

Delimitations

School B – a secondary school in Trinidad. Participation is delimited to one researcher (the author) who is the integrated science teacher, n=30 form three students (all male), parents of these students, class form teacher, School B management team & the information technology technician. I will provide stand-alone EcoMUVE software for all student-participants. The findings will be relevant to School B only.

Data Analysis and Presentation of Findings

Purpose of the study

The purpose of this quantitative, quasi-experimental, one group pretest/posttest design, action research study is to discover if a multi-user virtual environment (MUVE) intervention can be used to enhance causal reasoning ability in tandem with ecological worldview, and conceptual change—before and after the intervention—of form three integrated science students at School B—a secondary school in east Trinidad. The unit of work is *man's effect on the environment* (Ministry of Education, 2008, pp. 77-78).

Description of variables

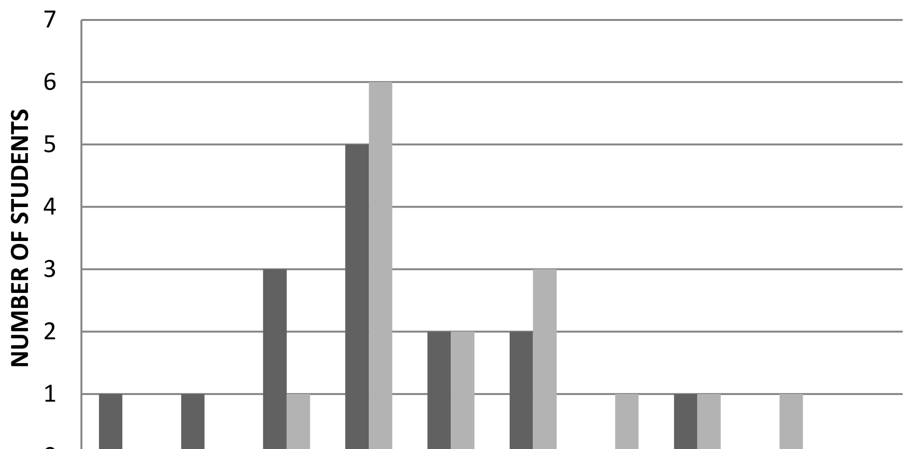
The following is a list of the main variables used in the data analysis:

- CAUSAL1 represents the variable for causal reasoning ability pretest scores.
- CAUSAL2 represents the variable for causal reasoning ability posttest scores.
- EWORLDVIEW1 represents the variable for ecological worldview pretest scores.
- EWORLDVIEW2 represents the variable for ecological worldview posttest scores.
- CONCEPTUAL1 represents the variable for conceptual change pretest scores.
- CONCEPTUAL2 represents the variable for conceptual change posttest scores.

Data Analysis

1. How does EcoMUVE affect students' causal reasoning ability?

1. (a) Observations of causal reasoning ability posttest-pretest frequency distributions. Figure 5 below represents the frequency distribution of student causal reasoning ability posttest and pretest scores. The trend shows a positive shift in student causal reasoning ability scores with more students scoring higher after the EcoMUVE intervention. See Appendix C for raw data and frequency distribution statistics pertaining to causal reasoning ability.



	0 - 10	11 - 20	21 - 30	31 - 40	41 - 50	51 - 60	61 - 70	71 - 80	81 - 90	91 - 100
NO. OF STUDENTS (PRETEST)	1	1	3	5	2	2	0	1	0	0
NO. OF STUDENTS (POSTTEST)	0	0	1	6	2	3	1	1	1	0

CAUSAL REASONING ABILITY SCORES (%)

Figure 5. Causal reasoning ability posttest-pretest frequency distribution bar graphs.

This primary observation seems to indicate that the EcoMUVE intervention may have contributed to an improvement in student causal reasoning ability. Further analysis via comparison of means significance tests were conducted to determine the nature of the trends observed.

1. (b) Causal reasoning ability posttest-pretest paired samples t-test. A paired-samples t-test (a parametric test) was conducted to evaluate the impact of the EcoMUVE teaching intervention on students' causal reasoning ability scores, measured using the *causal features assessment worksheet* instrument before (pretest) and after (posttest) the intervention (Grotzer, et al., Helping students learn more expert framing of complex causal dynamics in ecosystems using EcoMUVE, 2011, pp. 14-15). Table 11 below shows a summary of the relevant findings.

Table 11.
Paired samples t-test results between causal reasoning ability posttest-pretest scores

DATASET (N = 15)	MEAN (M)	STANDARD DEVIATION (SD)	t	DEGREES OF FREEDOM	p-VALUE	Eta Squared
CAUSAL2	48.33	17.43	2.382	14	.032	0.29
CAUSAL1	35.83	18.67				

From Table 11, it was observed that there was a statistically significant increase by 12.5 percentage points in the mean student causal reasoning ability scores between the Posttest [M=48.33, SD=17.43] and Pretest [M=35.83, SD=18.67] scores, where $t(14)=2.382$, p (.03) < α (.05). The null hypothesis [H_0: CAUSAL1 is not significantly different from CAUSAL2] was rejected.

The alternative hypothesis was therefore accepted:

- H_1: CAUSAL1 is significantly different from CAUSAL2

The eta squared effect size statistic ($\eta^2=.29$) indicated a medium effect according to Cohen's eta squared index for tests of significance—where .10 = small, .30 = medium, and .50 = large *(Cohen J. , 1992, p. 5)*. This implies that the EcoMUVE teaching intervention may have contributed to explaining 29% of the variance in the causal reasoning ability posttest scores. Considering the assumptions and justifications for this study, it may be concluded that the EcoMUVE teaching intervention resulted in a significant increase (with a medium effect) in student causal reasoning ability. See Appendix D for details on paired samples t-test statistics pertaining to causal reasoning ability.

1. (c) Causal reasoning ability posttest-pretest related samples Wilcoxon Sign Rank Test. Since the sample size $n < 30$ ($n=15$) violated the assumptions for use of parametric tests, a related samples Wilcoxon Signed Rank Test (a non-parametric test) was conducted to triangulate the results of the impact of the EcoMUVE teaching intervention on students' causal reasoning ability in 1 (b) above. See Appendix C for the assumptions met for use of parametric tests.

Figure 6 below shows the SPSS v.20 output summary of the relevant findings:

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of differences between CAUSAL1 and CAUSAL2 equals 0.	Related-Samples Wilcoxon Signed Rank Test	.042	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Figure 6. Results of the Wilcoxon Sign Rank Test for causal reasoning ability posttest-pretest scores

The results shown in Figure 6 indicates a significant increase in the mean causal reasoning ability scores where p (.04) < α (.05). The null hypothesis [H_0: CAUSAL1 is not significantly different from CAUSAL2] was rejected.

The alternative hypothesis was accepted:

- H_1: CAUSAL1 is significantly different from CAUSAL2

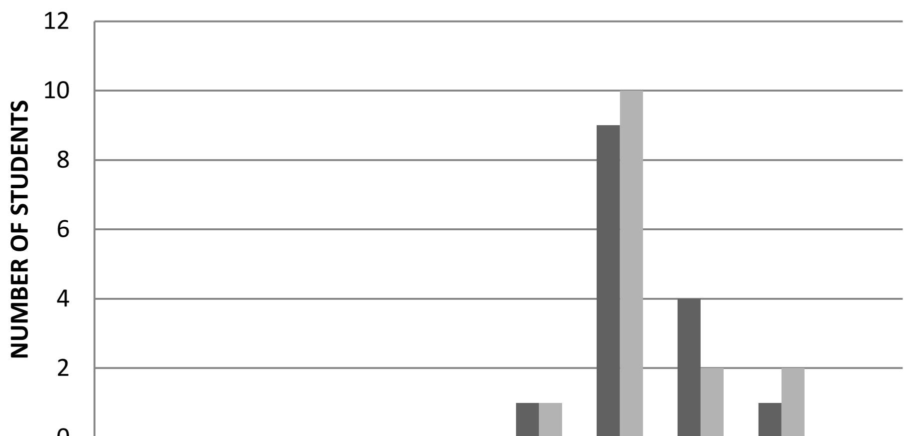
The results from the parametric paired sample t-test were corroborated via triangulation with the results from the Wilcoxon Sign Rank Test. Based on the results of this research, it may be concluded that the EcoMUVE teaching intervention contributed to a significant increase (with a medium effect) in the mean causal reasoning ability scores, deeming the EcoMUVE teaching intervention an effective tool for improving student causal reasoning ability in the study of ecosystems.

1. (d) Causal concepts posttest-pretest ancillary findings. Ancillary analysis using a paired samples t-test on posttest-pretest causal concepts (effects over distance, non-obvious causes, and changes over time) indicated that there was no significant difference in *effects over distance* and *non-obvious causes* scores, however, there was a significant increase in the *changes over time* scores where $p\ (.01) < \alpha\ (.05)$.

It may be concluded that the EcoMUVE teaching intervention contributed to a significant increase—with medium effect—in overall student causal reasoning ability; specifically improving the *changes over time* causal concept. See Appendix D for further details on causal concepts ancillary findings.

2. How does EcoMUVE affect students' ecological worldview?

2 (a) Observations of ecological worldview posttest-pretest frequency distributions. Figure 7 below represents the frequency distribution of student ecological worldview posttest and pretest scores. The graph shows that students scored high but with little change in the distribution of ecological worldview scores after the EcoMUVE intervention. See Appendix C for raw data and frequency distribution statistics pertaining to ecological worldview.



	0 - 10	11 - 20	21 - 30	31 - 40	41 - 50	51 - 60	61 - 70	71 - 80	81 - 90	91 - 100
NO. OF STUDENTS (PRETEST)	0	0	0	0	0	1	9	4	1	0
NO. OF STUDENTS (POSTTEST)	0	0	0	0	0	1	10	2	2	0

Figure 7. Causal reasoning ability posttest-pretest frequency distribution bar graphs.

This primary observation seems to indicate that the EcoMUVE intervention did not have a significant effect on student ecological worldview. Further analysis via comparison of means significance tests were conducted to determine the nature of the trend observed.

2. (b) Ecological worldview posttest-pretest paired samples t-test. A paired-samples t-test was conducted to evaluate the impact of the EcoMUVE teaching intervention on students' ecological worldview, measured using the Revised New Ecological Paradigm Scale—before and after the intervention (Dunlap, Van Liere, Mertig, & Jones, 2000, p. 433). Table 12 below shows a summary of the relevant findings.

Table 12.
Paired samples t-test results between ecological worldview posttest-pretest scores

DATASET (N = 15)	MEAN (M)	STANDARD DEVIATION (SD)	t	DEGREES OF FREEDOM	p-VALUE	Eta Squared
EWORLDVIEW2	67.64	8.36	-.42	14	.68	.01
EWORLDVIEW1	68.18	6.15				

From Table 12, it was observed that there was a small decrease of .53 percentage points in the mean ecological worldview scores which represented no significant difference between the Posttest [M=67.64, SD=8.36] and Pretest [M=68.18, SD=6.15] scores, where $t(14)=-.42$, $p(.68) > \alpha(.05)$. The alternative hypothesis, [H_1: EWORLDVIEW1 is significantly different from EWORLDVIEW2] was rejected.

The null hypothesis was therefore accepted:

- H_0: EWORLDVIEW1 is not significantly different from EWORLDVIEW2

The eta squared statistic ($\eta^2=.01$) indicated a very small effect according to Cohen's eta squared index for tests of significance—where .10 = small, .30 = medium, and .50 = large *(Cohen J. , 1992, p. 5)*. This implies that the EcoMUVE teaching intervention may have contributed to explaining 1% of the variance in the ecological worldview posttest scores. Considering assumptions and justifications for this study, it may be concluded that the EcoMUVE teaching intervention resulted in a non-significant decrease (with a very small effect) in ecological worldview scores. See Appendix D for details on paired samples t-test statistics pertaining to ecological world view.

2. (c) Ecological worldview posttest-pretest related samples Wilcoxon Sign Rank Test. Since the sample size n < 30 (n=15) violates the assumptions for use of a parametric test, a related samples Wilcoxon Signed Rank Test was conducted to triangulate the results of the impact of the EcoMUVE teaching intervention on students' ecological worldview in 2 (b) above. See Appendix C for the assumptions met for use of parametric tests. Figure 8 below shows the SPSS v.20 output summary of the relevant findings.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of differences between EWORLDVIEW2 and EWORLDVIEW1 equals 0.	Related-Samples Wilcoxon Signed Rank Test	.850	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Figure 8. Results of Wilcoxon's Sign Rank Test for ecological worldview posttest-pretest scores.

The results shown in Figure 8 indicates a non-significant decrease in the mean ecological worldview scores where p (.85) > α (.05). The alternative hypothesis, H_1, was rejected.

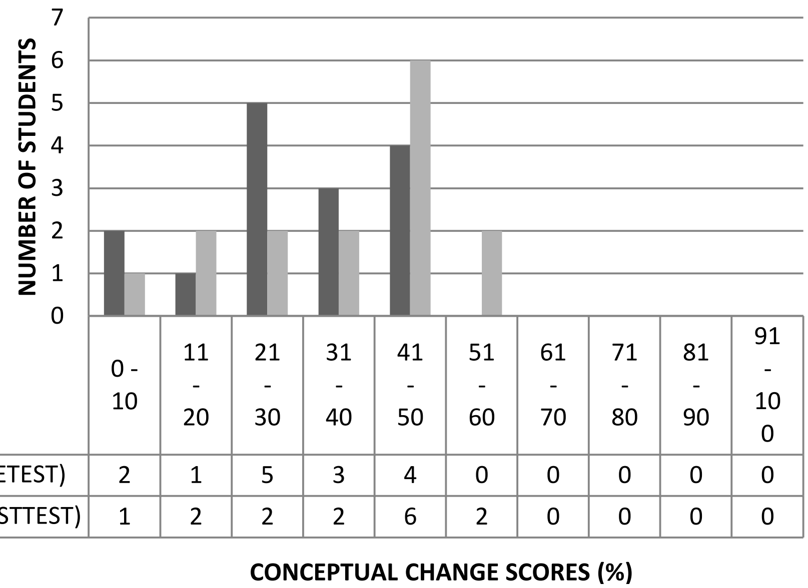
The null hypothesis was therefore accepted:

- H_0: EWORLDVIEW1 is not significantly different from EWORLDVIEW2

The results from the parametric paired sample t-test were corroborated via triangulation with the results from the Wilcoxon Sign Rank Test. Based on the results of this research, it may be concluded that the EcoMUVE teaching intervention contributed to a non-significant decrease (with a very small effect) in the mean ecological worldview scores, deeming the EcoMUVE teaching intervention, in its present form, an ineffective tool for improving student ecological worldview in the study of ecosystems.

3. How does EcoMUVE affect students' conceptual change?

3. (a) Observations of conceptual change posttest-pretest frequency distributions. Figure 9 below represents the frequency distribution of student conceptual change posttest and pretest scores. The trend shows a large increase in student conceptual change scores with some students scoring higher after the EcoMUVE intervention. See Appendix C for raw data and for frequency distribution statistics pertaining to conceptual change.



	0 - 10	11 - 20	21 - 30	31 - 40	41 - 50	51 - 60	61 - 70	71 - 80	81 - 90	91 - 100
NO. OF STUDENTS (PRETEST)	2	1	5	3	4	0	0	0	0	0
NO. OF STUDENTS (POSTTEST)	1	2	2	2	6	2	0	0	0	0

Figure 9. Conceptual change posttest-pretest frequency distribution bar graphs.

This primary observation seems to indicate that the EcoMUVE intervention may have somewhat contributed to an improvement in student conceptual change. Further analysis via comparison of means significance tests were conducted to determine the nature of the trends observed.

3. (b) Conceptual change posttest-pretest paired samples t-test. A paired-samples t-test was conducted to evaluate the impact of the EcoMUVE teaching intervention on students' conceptual change scores, measured using *ecological concepts survey* (also called the EcoMUVE Post-Survey) instrument before and after the intervention (The EcoMUVE Project Team, 2012).

Conceptual change was conceptualized by the researcher as a measure of the *conceptual knowledge* dimension, thus an item analysis was done on the instrument (which was also treated as unit test) and only items which measured students' conceptual knowledge dimension—determined using the new Bloom's taxonomy guidelines—were scored (Krathwohl, 2002, p. 214). Table 13 below shows a summary of the relevant findings.

Table 13.
Paired samples t-test results between conceptual change posttest-pretest scores

DATASET (N = 15)	MEAN (M)	STANDARD DEVIATION (SD)	t	DEGREES OF FREEDOM	p-VALUE	Eta Squared
CONCEPTUAL2	47.79	15.67	3.383	14	.004	0.45
CONCPETUAL1	30.89	13.07				

From Table 13, it was observed that there was a statistically significant increase by 16.9 percentage points in the mean student conceptual change scores between the Posttest [M=47.79, SD=15.67] and Pretest [M=30.89, SD=13.07] scores, where $t(14)=3.383$, $p\ (.00) < \alpha\ (.05)$. The null hypothesis [H_0: CONCEPTUAL1 is not significantly different from CONCEPTUAL2] was rejected.

The alternative hypothesis was therefore accepted:

- H_1: CONCEPTUAL1 is significantly different from CONCPETUAL2

The eta squared effect size statistic ($\eta^2=.45$) indicated a large effect according to Cohen's eta squared index for tests of significance—where .10 = small, .30 = medium, and .50 = large *(Cohen J. , 1992, p. 5)*. This implies that the EcoMUVE teaching intervention may have contributed to explaining 45% of the variance in the conceptual change posttest scores. Considering the assumptions and justifications for this study, it may be concluded that the EcoMUVE teaching intervention resulted in a significant increase (with a large effect) in student conceptual change. See Appendix D for details on paired samples t-test statistics pertaining to conceptual change.

3. (c) Conceptual change posttest-pretest related samples Wilcoxon Sign Rank Test. Since the sample size $n < 30$ ($n=15$) violated the assumptions for use of parametric tests, a related samples Wilcoxon Signed Rank Test was conducted to triangulate the results of the impact of the EcoMUVE teaching intervention on students' conceptual change in 3 (b) above. See Appendix C for the assumptions met for use of parametric tests.

Figure 10 below shows the SPSS v.20 output summary of the relevant findings.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of differences between CONCEPTUAL2 and CONCEPTUAL1 equals 0.	Related-Samples Wilcoxon Signed Rank Test	.007	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Figure 10. Results of the Wilcoxon Sign Rank Test for conceptual change posttest-pretest scores

The results shown in Figure 10 indicates a significant increase in the mean conceptual change scores where p (.01) < α (.05). The null hypothesis [H_0: CONCPETUAL1 is not significantly different from CONCEPTUAL2] was rejected.

The alternative hypothesis was accepted:

- H_1: CONCEPTUAL1 is significantly different from CONCEPTUAL2

The results from the parametric paired samples t-test were corroborated via triangulation with the results from the Wilcoxon Sign Rank Test. Based on the results of this research, it may be concluded that the EcoMUVE teaching intervention contributed to a significant increase (with a large effect) in the mean conceptual change scores, deeming the EcoMUVE teaching intervention an effective tool for improving student conceptual change in the study of ecosystems.

3. (d) Findings from structural equation modeling. A structural model in the form of a path analysis diagram was constructed using in IBM SPSS AMOS version 20. The structural model was designed based on the theoretical framework as described in Figure 3 of the Literature Review. The theoretical framework links causal reasoning ability to ecological worldview and purports that both variables may have influence over conceptual change. Figure 11 shows the path analysis diagram created for this analysis. See Appendix D for a detailed summary of the model statistics.

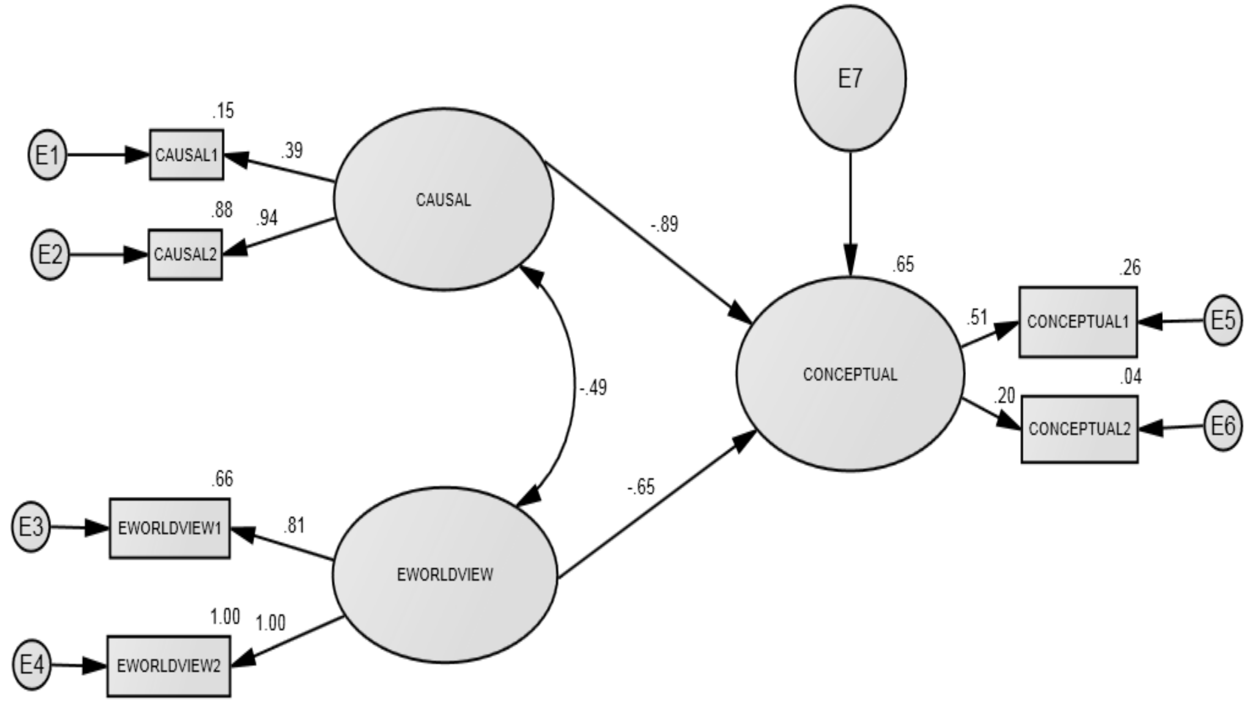


Figure 11. Structural model (regression with unobserved variables) for theoretical framework linking causal reasoning ability, ecological worldview, and conceptual change. E1, E2, E3, E4, E5, E6, and E7 are unobserved errors with regression weight 1 respectively. Baseline Comparisons of Model Fit: NFI Delta1=.833, RFI rho1=.581, IFI Delta2=1.064, TLI rho2=1.272, and CFI=1 indicate a fairly good model fit.

- From Figure 11, it can be determined that 88% of the variance in CAUSAL2 (causal reasoning ability posttest scores) can be explained by its predictor which may be considered to be student causal reasoning ability; 12% due to unobserved factors (E2). The 73 percentage point increase in variance explained by causal reasoning ability from pretest (15%) to posttest (88%) occurred parallel to the significant increase in causal reasoning ability posttest scores which may be due to the 29% impact of the EcoMUVE intervention, based on the analysis of research question 1. This tells the story of EcoMUVE having a significant effect on enhancing student causal reasoning ability.
- From Figure 11, it can be determined that 100% of the variance in EWORLDVIEW2 (ecological worldview posttest scores) can be explained by its predictor which may be

considered to be student ecological worldview. The 34 percentage point increase in variance explained by ecological worldview from pretest (66%) to posttest (100%) occurred parallel to the non-significant decrease in ecological worldview posttest scores which may be due to the 1% impact of the EcoMUVE intervention, based on the analysis of research question 2.

- From Figure 11, it can be determined that 4% of the large, significant increase in conceptual change posttest scores can be explained by its predictor which may be considered to be student conceptual change; 96% due to unobserved factors (E6). The 22 percentage point drop in variance could probably be due to the 45% impact of the EcoMUVE intervention, based on the analysis of research question 3.

4. What is the relatedness among students' causal reasoning ability, ecological worldview, and conceptual change? It may be necessary at this point to note that from the structural model in Figure 11, controls for unobserved errors were applied to pretests, posttests, and to the student conceptual change latent/measurement model. Findings across pretest and posttest were deemed reportable due to the catering for errors (E1-E7), however findings for the relationship amongst causal reasoning ability, ecological worldview, and conceptual change were suspected to be spurious due to the absence of unobserved errors as the program did not allow calculation of estimates when unique variables were added to the aforementioned measurement models. Moreover, there were violations to sample size and homogeneity as described in Appendix C. As a result, non-parametric correlation methods were used to discover the relatedness amongst CAUSAL2, EWORLDVIEW2, and CONCEPTUAL2.

The Kendall's tau-b and Spearman's rho (non-parametric) tests were administered and findings considered. The Pearson's product-moment correlation (parametric) test was also administered, for observational purposes only. The results were not considered owing to the test's known vulnerability to violations of homogeneity and normality—see Appendix C. To review scatterplots of the datasets, see Appendix D. Table 14 below shows a summary of the relevant correlational findings.

Table 14.
Summary of correlations for CAUSAL2, EWORLDVIEW2, and CONCEPTUAL2

VARIABLES	**PEARSON**	**KENDALL**	**SPEARMAN**	**CORRELATION**		
(N = 15)	**r**	**τ**	**ρ**	**STRENGTH**	**SIGN**	**p-VALUE**
CAUSAL2 vs. EWORLDVIEW2	**-0.47*** p (=,080) > 0.05	**-.537** p (=.009) < 0.05	**-0.649** p (=0.01) < 0.05	**STRONG**	**NEGATIVE**	**SIGNIFICANT**
CAUSAL2 vs. CONCEPTUAL2	**-0.48*** p (=0.866) > 0.05	**0.00** p (=1.000) > 0.05	**+0.001** p (=0.997) > 0.05	**NONE**	**NEUTRAL**	**NOT SIGNIFICANT**
EWORLDVIEW2 vs. CONCEPTUAL2	**-0.14*** p (=0.633) > 0.05	**+0.052** p (=0.800) > 0.05	**+0.085** p (=0.764) > 0.05	**SMALL**	**POSITIVE**	**NOT SIGNIFICANT**

Note. * = coefficients ignored. Preference was given to the non-parametric test results (Kendall's tau-b and Spearman's rho) owing to the violations of homogeneity and normality (n < 30; where n=15) across datasets which are violations against the use of the parametric test (Pearson's product-moment correlation).

The results from Table 14 pave the way to paint the picture of the relationship amongst the variables after being treated with the EcoMUVE intervention. After considering all assumptions and taking appropriate actions to ensure the reliability of the data, it can be inferred that there is a strong, significant negative correlation between student causal reasoning ability and ecological worldview scores (τ=-.54; ρ=-.65) while there is a small, insignificant positive correlation between ecological worldview and conceptual change scores (τ=+.05; ρ=+.09). The following flow chart in Figure 12 below shows a summary of the correlational relatedness of the said variables.

Figure 12. Path diagram showing correlational relationships amongst CAUSAL2, EWORLDVIEW2, and CONCEPTUAL2 variables.

It can be concluded that:

- For CAUSAL2 vs. EWORLDVIEW2 and EWORLDVIEW2 vs. CONCEPTUAL2, the null hypothesis [H_0: $\tau = 0$; $\rho = 0$] is rejected and the alternative hypothesis [H_1: $\tau \neq 0$; $\rho \neq 0$] is supported.

- For CAUSAL2 vs. CONCEPTUAL2, the null hypothesis [H_0: $\tau = 0$; $\rho = 0$] is accepted because $\tau = 0$; $\rho = 0$. The alternative hypothesis [H_1: $\tau \neq 0$; $\rho \neq 0$] is rejected.

The correlations across the variables tend to fit the theoretical framework (see Figure 3) in terms of the strength of association between causality and ecological worldview, and the hairline association between ecological worldview and conceptual change. The data hints at the finding that the students' ecological worldview may have a part to play in their overall learning of ecological concepts in the study of ecosystems. The direction of correlation will be expatiated in the following chapter along with discussions and recommendations for this and other findings.

Summary of findings

Table 15 shows a summary of findings based on the research questions.

Table 15.
Summary of findings

RESEARCH QUESTION	RELEVANT FINDINGS
1. How does EcoMUVE affect students' causal reasoning ability?	▪ EcoMUVE may have had a medium effect (29% of the variance explained) on a significant increase in student causal reasoning ability scores. [Paired t-test: p (.03) < α (.05); Wilcoxon Sign Rank test: p (.04) < α (.05); Effect size: η^2=.29)]. ▪ EcoMUVE seems to have a significant effect on enhancing student causal reasoning ability. [From structural equation model: Figure 11] ▪ EcoMUVE seems to have invoked heightened perception of student ecological worldview but ecological worldview remained significantly unchanged after the intervention. [From structural equation model] ▪ EcoMUVE had a large effect on student performance in the conceptual change instrument but only a small part of this feat can be attributed to student conceptual knowledge. [From structural equation model] ▪ Ancillary findings: there was a significant increase in the *changes over time* causal concept only.

2. How does EcoMUVE affect students' ecological worldview?	▪ EcoMUVE may have had a very small effect (1% of the variance explained) on a non-significant decrease in student ecological worldview scores. [Paired t-test: p (.68) > α (.05); Wilcoxon Sign Rank test: p (.85) > α (.05); Effect size: η^2=.01)].
3. How does EcoMUVE affect students' conceptual change?	▪ EcoMUVE may have had a large effect (45% of the variance explained) on a significant increase in student conceptual change scores. [Paired t-test: p (.00) < α (.05); Wilcoxon Sign Rank test: p (.01) < α (.05); Effect size: η^2=.45)].
4. What is the relatedness among students' causal reasoning ability, ecological worldview, and conceptual change?	▪ Causal reasoning ability scores show a significantly strong negative correlation with ecological worldview scores [τ=-.54; ρ=-.65]. ▪ Ecological worldview scores show a non-significant, small, positive correlation with conceptual change scores [τ=+.05; ρ=+.09]. ▪ Causal reasoning ability scores show no correlation with conceptual change scores. [τ=0.00; ρ=0.00].

Note. For ancillary findings, see Appendix D and Appendix E

Ancillary findings from qualitative member check. Students expressed that the EcoMUVE strategy indeed contributed to their learning as opposed to if another method would have been used. However they admit that other reasons may have resulted in the increase in scores and other teaching methods could supplement the EcoMUVE strategy to reinforce learning, example: a field trip. See Appendix E for details. Discussions in relation to the literature and recommendations on all relevant findings would be covered in the next chapter.

Discussion and Recommendations

Discussion

Note that all claims in this section is applicable to the context of School B and not applicable in a generalized sense unless further research is done to corroborate it.

Effect of EcoMUVE on student causal reasoning ability. The results showed a possible medium effect on a significant increase in student causal reasoning ability scores after the intervention as compared to before. This indicated that the EcoMUVE teaching strategy was found to be a good teaching strategy for improving student causal reasoning ability. This corroborates the findings of a Harvard University study where aspects of causal reasoning showed a significant increase at the post assessment. Figure 13 below shows this.

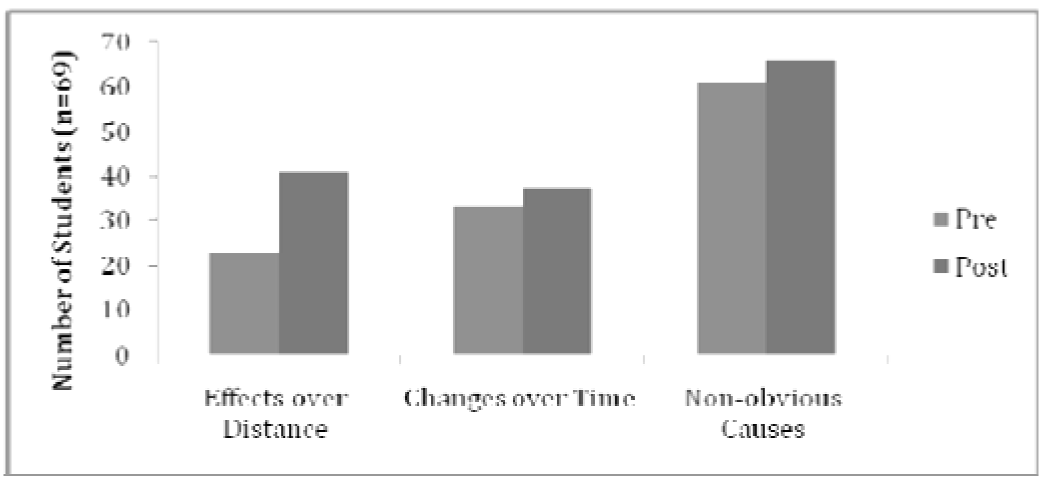


Figure 13. Harvard University study of EcoMUVE. The study shows that EcoMUVE helped students to learn about causality

Unlike the Harvard study however, ancillary findings for this research showed that *changes over time* showed the largest, most significant increase in mean scores from pretest to posttest. Figure 14 below shows this.

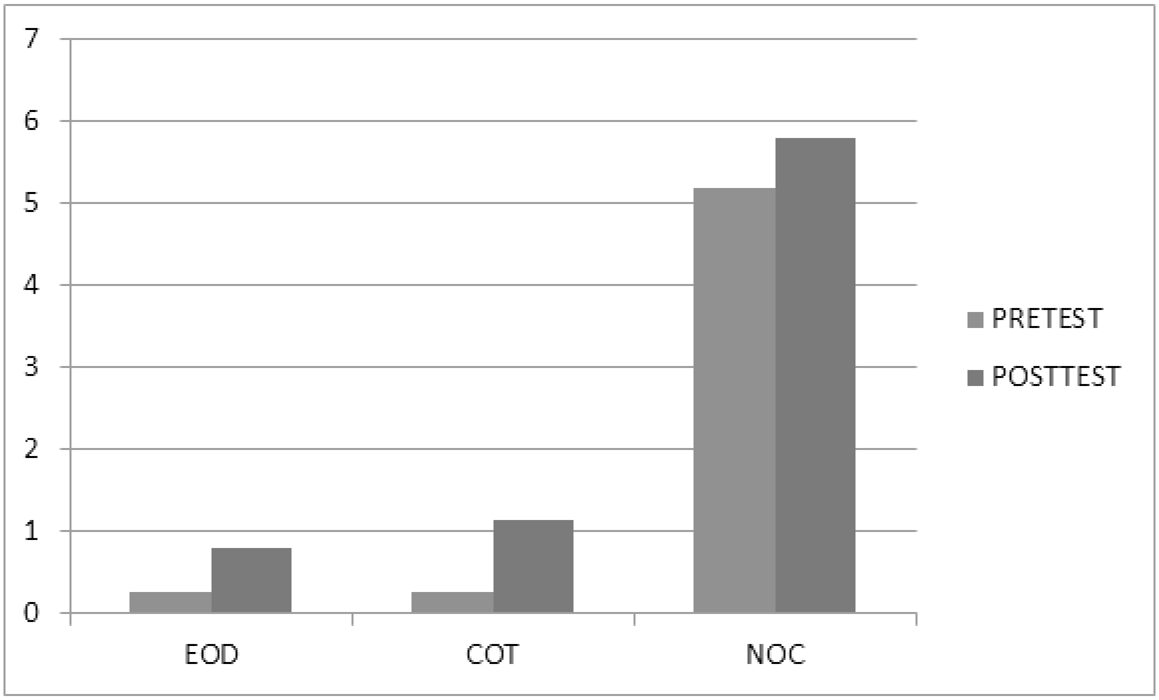


Figure 14. University of the West Indies study of the effect of EcoMUVE on aspects of student causal reasoning ability

From the findings of this research, it may be concluded that EcoMUVE not only is a good teaching tool to enhance student causal reasoning ability, but it is especially effective at teaching the concept of changes over time. This may help students appreciate how their interaction with the environment can have a result at a later date. This can be extrapolated to the concept of conservation and sustainable development which are terms that are to also be taught and values to be endeared in the interaction between science and society. EcoMUVE can be recommended to other teachers at School B to be taught for the unit of work on the environment.

Effect of EcoMUVE on student ecological worldview. Pretest-Posttest findings from structural equation modeling and analysis of research questions 1 to 3 seem to indicate an interesting find. There was a 34 percentage point increase across pretest to posttest ecological worldview scores. 100% of the variance in the scores was attributable to ecological worldview yet there was negligible change in the actual ecological worldview scores of which the EcoMUVE intervention had a 1%, non-significant impact. Translating the statistical jargon to narrative, EcoMUVE seemed to have subtly invoked a strong response from students as they used the software and engaged in the activities throughout the unit. Students may have had an acute, heightened and sustained sense of awareness of their ecological worldview which informed their performance on the instrument (which was high) but all of this resulted in negligible change in their ecological worldview scores after the EcoMUVE intervention. Rampersad and Solomon argue that student's prior knowledge is resilient (Herbert, 2004, p. 2). Looking at the theoretical framework, and considering the results of the research, it may be concluded that student resiliency occurs in the face of new/formal content where prior knowledge takes precedent—as if to shield or guard against some inner core values and beliefs about the environment. This corroborates the findings of the literature about the propensity of learning which seems to occur at the point of ecological worldview. Perhaps this was also due to the abstract nature of the program which may have led to a sentiment by a student who indicated that a field trip may reinforce learning.

The EcoMUVE strategy was not at all effective on affecting student's ecological world view. It hardly puts a dent on ecological worldview. If it did it was insignificant. This makes sense since the game does not incorporate morals or a tendency to influence student to take a moral position. In the current structure of the program it is up to the teacher to in cooperate this by infusing other teaching strategies to compensate. Only then can a quest to develop ecological worldview be had. The good news was that the class of Form 3 students in this research had a mean positive ecological worldview of 68% which is above average but there is much room for improvement. It may be arguably said that in a country where environmental laws are not taken seriously, it is important to safeguard and sustain certain basic morals that are mal-represented at the corporate/industrial society level.

Effect of EcoMUVE on conceptual change: EcoMUVE had a large significant effect on conceptual change making it a good teaching tool to improve student learning and to facilitate border crossing. Therefore EcoMUVE can help students learn ecological concepts. It can be assumed that there was significant border crossing taking place (Aikenhead & Jegede, 1999).

Relationship among student causal reasoning ability, ecological worldview, and conceptual change. The findings of correlational tests suggest that there was a strong negative correlation between causal reasoning ability and ecological worldview but a small positive correlation with ecological worldview and conceptual change. This tells a story of the particular group of students displaying an ecological worldview (which was resilient) that allowed them to commit to border crossing and accept formal science content. The negative correlation between causal reasoning ability and ecological worldview is opposite to that which the theory suggests. This may either indicate a weakness in the research or (since a range of controls were enacted) it could mean that other factors in the model were coming into play (self, relationship, other) or the program was of an abstract nature which did not really put ecological worldview into perspective.

Recommendations

1. EcoMUVE can be used by the teachers of the science department at School B.
2. Incorporate an affective theme into the EcoMUVE program which can target developing student ecological worldview.
3. The Use of EcoMUVE can be supplemented with other traditional teaching methods to reinforce learning.
4. If future research is to be done, the pretest and posttest should be done using equivalency testing to remove testing effects, that is having a different looking test for pretest and posttest but both tests will be testing the same skills.
5. If future research into EcoMUVE is to be done, perhaps an experimental design (which is carefully crafted so as not to infringe upon the rights of the subjects) could be considered.
6. A culturally sensitive version of the software or a new culturally sensitive environmental program can be made to cater for the local/regional may have a more meaningful impact to students. This should come in a package with curriculum and assessments included.

Researcher's closing thoughts:

Using the EcoMUVE program opened up many windows of insight and it was indeed insightful. I can see myself delving more into research along the learning via ICT theme. The program can be helpful in teaching students about causation. The underlying philosophy is very valuable as well and that is learning how to think, learning about science being evidence-based...knowing what to believe or not to believe...critical thinking. I think that the program can be developed further by incorporating, as mentioned, a culturally sensitive theme and more importantly, helping student learn how to care. At the same time we must be careful not to create bias so that it may be meaningful, but all-inclusive learning can occur. Some students just plain and simple...do not care. I still have concerns about the half of the class who did not benefit in a wholesome way from the experience and in the face of it their choice was to defect from it. I think that in terms of the newness of the strategy itself, there should be a gradual infusion if it because it cannot be assumed that all students would be interesting in an educational computer game because of the mere fact that it is a game. Considerations for abilities and feelings should also inform how to ease in the use of ICT which no doubt has favorable benefits. A computer software alone cannot do job it must be a simultaneous thrust by all stakeholders to facilitate the end-users if we are to achieve the goals of the curriculum and furthermore in an authentic and moral sense, goals of life. Teaching students how to think about basic moral values or science concepts is an important responsibility and should be undertaken with scientific care.

The virtual reality game is a good system once it is catered for the individuals' needs. Those needs could be firstly determined by creating a large scale socio-cultural database and doing research into it in order to inform action at this large scale because the time and energy to create a program of this nature may be too much for it be affecting too few in too small of a context.

I will close by saying that I believe that my practice has been enlightened and I will reflect-for-action before another implementation of the EcoMUVE in the study of ecosystems.

References

Abd-El-Khalick, F., Waters, M., & Le, A.-P. (2007). Representations of Nature of Science in High School Chemistry Textbooks over the Past Four Decades. *Journal of Research in Science Teaching*, 835-855.

Aikenhead, G. S., & Jegede, O. J. (1999). Cross-Cultural Science Education: A Cognitive Explanation. *Journal of Research in Science Learning*.

Bell, B. (2005). *Learning in Science: the Waikato research. .* NY: RoutledegeFalmer.

Campbell, D. T., & Stanley, J. C. (1963). *Experimental & quasi-experimental designs for research.* Boston: Houghton Mifflin Company.

Caribbean Examinations Council. (2008). *Human & Social Biology May/Jun2 2008 Report.* St. Michael's: Caribbean Examinations Council.

Cohen, J. (1992, July 1). *A Power Primier.* Retrieved from University of North Carolina at Chapel Hill: http://dx.doi.org/10.1037/0033-2909.112.1.155

Cohen, L., Manion, L., & Morrison, K. (2007). *Research Methods in Education.* New York, NY: Routledge.

Costa, V. B. (1995). When science is “another world”: Relationships between worlds of family, friends, school, and science. *Science Education*, 313-333.

CXC. (2008). *Human & Social Biology May/June 2008: Paper 2 - General Proficiency.* Caribbean Examinations Council.

Dede, C., & Grotzer, T. (2012). *EcoMUVE pond teacher guide.* Retrieved from Havard University: http://www.ecomuve.gse.harvard.edu

Dieterle, E., & Clarke, J. (2005). Multi-User Virtual Environments for Teaching and Learning. In *Encyclopedia of multimedia teachnology and networking* (pp. 1-11). Hershey, PA: Idea

Group, Inc. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.84.7064&rep=rep1&type=pdf

Dunlap, R., Van Liere, K., Mertig, A., & Jones, R. (2000). Measuring Endorsement of the New Ecological Paradigm: a revised NEP scale. *Journal of Social Issues, 56*(3), 425-442.

Elliott, J. (1991). *Action Research for Educational Change.* Philadelphia, PA: Open Universitiy Press.

Fischer , A., & Scriven, M. (1997). *Critical Thinking – Its Definition and Assessment.* Norwich, UK: Centre for Research in Critical Thinking.

George, J., & Glasgow, J. (1999). The boundaries between belief and practice and convential science: implications for science educationin the Caribbean. (L. Quamina-Aiyejina, Ed.) *Assessment 2000 monograph series*.

Grotzer, T., Tutwiler, S., Dede, C., Kamarainen, A., Metcalf, S., & Jeong, D. (2011). Helping students learn more expert framing of complex causal dynamics in ecosystems using EcoMUVE. *National Association of Research in Science Teaching (NARST).* Orlando.

Grotzer, T., Tutwiler, S., Dede, C., Kamarainen, A., Metcalf, S., & Jeong, D. (2011). Helping students learn more expert framing of complex causal dynamics in ecosystems using EcoMUVE. *National Association of Research in Science Teaching (NARST).* Orlando.

Harvard University. (2012). *EcoMUVE* . Retrieved from EcoMUVE: advancing ecosystems science via situated collaborative learning in multi-user virtual environments: http://ecomuve.gse.harvard.edu/

Herbert, S. (2004). Lessons from Assessment: experiences of a cross-cultural unit of work in science. *Evaluation and Research in Education*, 139-157.

Huber, A., & Snider, R. (2005). *Influencing through argument: updated edition.* Retrieved from University of Vermont: Debate Central: http://debate.uvm.edu/dcpdf/Influencing%20through%20argument.pdf

Hume, D. (1739). *A Treatise of Human Nature: being an attempt to introduce the experimental method of reasoning into moral subjects.* Retrieved from davidhume.org: http://www.davidhume.org/texts/thn.html

Kearney, M. (1984). *World view.* Novato, CA: Chandler and Sharp.

Krathwohl, D. R. (2002). A Revision of Bloom's Taxonomy: an overview. *Theory into practice*, 212-218.

Kuhn, T. S. (1962). *The Structure of Scientific Revolutions.* Chicago, IL: University of Chicago Press.

Lin, J., & Oxford, R. (2012). *Transformative eco-educatoin for human and planetary survival.* Charlotte, NC: Information Age Publishing.

Mayer, R. E. (2002). Rote Versus Meaningful Learning. *Theory into practice*, 226-232.

McComas, W. F. (2002). *The Nature of Science in Science Education Rationales and Strategies.* New York, NY: Kluwer Academic Publishers.

Ministry of Education. (2003). *Educatin Policy Paper - National Task Force of Education (White Paper).*

Ministry of Education. (2008, September). *Secondary School Curriculum - Integrated Science.* Retrieved from Government of the Republic of Trinidad & Tobago - Ministry of Education: http://www.moe.gov.tt/Curriculum_pdfs/Science_Curriculum.pdf

Ministry of Education. (2012). *Education sector strategic plan: 2011-2015.* Retrieved from Ministry of Education: Government of the Republic of Trinidad and Tobago: http://www.moe.gov.tt/spotlightPDFs/MOE_Stategic_Action_Plan_2011_2015.pdf

Monk, M., & Dillon, J. (2010). How Science Works: what is the nature of scientific knowledge. In M. Monk, & J. Osbourne, *Good Practice in Science Teaching: what research has to say (second edition)* (pp. 20-45). Berkshire: Open University Press.

Popper, K. (2002). *The Logic of Scientific Discovery.* London: Routledge.

Schon, D. A. (1987). *Educating the Reflective Practitioner: towards a new design for teaching and learning in the profesions.* San Francisco, CA: Jossey-Bass Publishers.

Shope III, R. E. (2006). *Teaching for conceptual change: towards a proposed taxonomy of diagnostic teaching strategies to gauge students' personal science concepts.* Ann Arbor, MI: ProQuest Information and Learning Company.

The Critical Thinking Company. (2004). Cornel Test X Manual [Computer Software]. Seaside, CA., USA.

The EcoMUVE Project Team. (2012). *EcoMUVE Post-Survey.* Retrieved from EcoMUVE: advancing ecosystems science via situated collaborative learning in multi-user virtual environments: http://ecomuve.gse.harvard.edu/documentation/EcoMUVE_PondPostsurvey_Jan2011.pdf

Thinking Worlds. (2011). Retrieved from Thinking Worlds: Seriously. Creating Sims & Games Rapidly: http://www.thinkingoworlds.com

Tho, L. H., Goh, N. K., & Ho, P. L. (1997). *New Lower Secondary Science 1: Teacher's edition.* Singapore: Pan Pacific Publications.

Appendix A

Unit Planning

Documents used. The main curriculum documents used were:

- Lower Secondary Integrated Science Curriculum 2008 (Ministry of Education, 2008, pp. 77-78).
- Education Policy Paper (1993 – 2003)/National Task Force of Education (White Paper) (Ministry of Education, 2003).

Related goals of documents

INTEGRATED SCIENCE CURRICULUM	WHITE PAPER
• Understanding of the nature of science • Empowerment, attained through their knowledge of the role of science in addressing • the complex social issues related to the environment • Mastery of the skills and knowledge required for scientific enquiry • Willingness to acquire and apply scientific and technological knowledge to the • mutual benefit of self, society, and the environment	• That every child has the ability to learn and that we must build on this positive assumption. • That every child has an inalienable right to an education that facilitates the achievement of personal goals and the fulfilment of obligations to society. • That education is fundamental to the overall development of Trinidad and Tobago. • That students vary in natural ability and that school therefore should provide, for all students, programmes which are adapted to varying abilities, and which provide opportunity to develop differing personal and socially useful talents. • That we must be alert to new research and development in all fields of human learning and to the implications of these developments for more effective teaching and school improvement. • That from a psychological perspective, education is a means of looking out beyond the boundaries of the immediate. It can be the viable means that creates individuals with the intellect and capacity to develop and lead societies, communities, villages, and/or neighbourhoods and families of the future. It should be responsive to and stimulate the searing human spirit and the emphatic quest for human communication, interaction, love and trust. • That learning is cumulative and that every stage in the educational process is as important and critical for the learner's development as what has gone before it and what is to come. As such we must view educational programming and development in the round, recognizing the importance of every rung on the ladder of delivery by intensifying our efforts throughout the system.

Comparative analysis between integrated science curriculum and EcoMUVE curriculum ecological content

Comparative analysis between integrated science and EcoMUVE curriculum ecological content

STANDARD TOPIC	Related Instructional Objective	Integrated Science Curriculum Content	EcoMUVE Curriculum Content	Related content covered with Form 3 class?
Feeding Relationships	• **Relate feeding relationships to the transfer of energy from the Sun through plants to other organisms** (Ministry of Education, 2008, p. 38).	• Observe different ecosystems such as the school garden, a pond, or aquarium, etc. and list organisms and their feeding habits. (Ministry of Education, 2008, p. 38).	**Lesson 1**: • Identify organisms in a pond habitat. (Dede & Grotzer, 2012, p. 22).	YES
		• Use information collected to construct food chains. • Link the food chains to form food webs. (Ministry of Education, 2008, p. 38)	**Lesson 2:** • Arrange organisms in a food web that represents the transfer of energy. (Dede & Grotzer, 2012, p. 25)	YES
	• **Explain the role of microorganisms as decomposers in an ecosystem** (Ministry of Education, 2008, p. 39)	• Understand that decomposition is one of the important processes carried out by micro-organisms. (Ministry of Education, 2008, p. 39)	**Lesson 2:** • Learn the roles of decomposers within an ecosystem. (Dede & Grotzer, 2012, p. 25)	YES
Classification	• **Organize information based on patterns of similarities or differences** (Ministry of Education, 2008, p. 41)	• Understand that classification is a system of organizing things based on similarities and differences. (Ministry of Education, 2008, p. 41)	**Lesson 2:** • Learn the roles producers and consumers within an ecosystem and categorize organisms accordingly. (Dede & Grotzer, 2012, p. 25)	YES
Man's Effect on the Environment	• **Explain how human activities are changing the environment globally, with serious consequences** (Ministry of Education, 2008, p. 77)	• Human activities are altering the environment in dramatic and far-reaching ways. ➢ Changes in the natural balance of the ecosystem ➢ A decrease in some plant and animal populations to dangerously low levels. (Ministry of Education, 2008, pp. 77-78)	**Lesson 3:** • Notice, measure and document changes in biotic factors over time. • Notice, measure and document changes in abiotic factors over time. (Dede & Grotzer, 2012, p. 30)	NO

		• Work in groups to research a topic and do a presentation, e.g., on the effects of any one of man's activities on the environment. (Ministry of Education, 2008, p. 77)	**Lesson 4:** • To investigate what are the causes behind an environmental issue. • Hypothesize why an environmental issue occurred. (Dede & Grotzer, 2012, p. 34)	NO
Structure and properties of matter	• Describe the structure of the atom. • Distinguish among elements, molecules, and compounds (Ministry of Education, 2008, pp. 43-44)	• The atom is the basic unit of matter. • Atoms bond together to form elements, molecules, and compounds. (Ministry of Education, 2008, pp. 43-44)	**Lesson 5:** • Understand that atoms are neither created nor destroyed (the principle of conservation of matter). (Dede & Grotzer, 2012, p. 42)	YES
Photosynthesis	• Outline the process of photosynthesis. • Identify the products of photosynthesis. (Ministry of Education, 2008, p. 37)	• Light energy is used to combine carbon dioxide and water to produce glucose and oxygen. • Glucose and oxygen are the two end products of photosynthesis. Glucose is then converted to starch. (Ministry of Education, 2008, p. 37)	**Lesson 5:** • Understand that, through ecological processes, molecules can be broken apart and atoms rearranged to form different molecules. ➢ Carbon Cycle ➢ Oxygen Cycle ➢ Phosphorous Cycle • Understand that atoms by themselves are abiotic, but through the processes of photosynthesis and respiration, atoms become a part of living things (there is a strong relationship between abiotic and biotic parts of an ecosystem). (Dede & Grotzer, 2012, p. 42) **Lesson 6:** • Connect knowledge of atoms to ecological processes like photosynthesis, respiration, and decomposition. (Dede & Grotzer, 2012, p. 52)	PARTIALLY (Did not cover Phosphorous Cycle)
Human Body Systems	• Outline the process of respiration. (Ministry of Education, 2008, p. 51)	• Oxygen is used to release energy from food. (Ministry of Education, 2008, p. 51)		
Man's effect on the environment	• **Human activities are altering the environment in dramatic and far-reaching ways** (Ministry of Education, 2008, p. 77)	• Causes of alteration of the environment. ▪ Work in groups to research a topic and do a presentation, e.g., on the effects of any one of man's activities on the environment. (Ministry of Education, 2008, p. 77)	**Lesson 7:** • Understand how to represent complex causal relationships using a concept map. (Dede & Grotzer, 2012, p. 54)	NO

			Lesson 8: • Interpret graphs of variables changing over time. • Recognize the importance of using data and evidence to support a scientific claim. (Dede & Grotzer, 2012, p. 58)	
			Lesson 9: • Work in groups to represent a final hypothesis for the team and create a group concept map. (Dede & Grotzer, 2012, p. 61)	
			Lesson 10: • To communicate a hypothesis and offer evidence to support their claim. (Dede & Grotzer, 2012, p. 63)	
			Lesson 11: • Understand how complex causality occurs in areas beyond ecosystem science. (Dede & Grotzer, 2012, p. 65)	

- Lessons 1 and 2 involve content (students' knowledge of food webs, and the roles of decomposers, producers and consumers) that was already covered in the previous term's work. These lessons were included in the unit plan as a prelude to the core of the intervention (from Lesson 3) for students to become acquainted with the virtual environment. This allowed the strategy to be implemented seamlessly and in its entirety.
- Part of Lesson 5 (Atoms) was also covered (in Form 1), but was included in the unit plan for reinforcement and because it was viewed as a core part of the EcoMUVE intervention in appreciating non-obvious causes. This allowed the strategy to be implemented seamlessly and in its entirety.

- Unit sections are also aligned with the US National Science Education Standards (NSES) as it pertains to Life Science – Content Standard C (Populations and Ecosystems), and Science in Personal and Social Perspectives – Content Standard F (Populations, Resources, Environments, and Natural Hazards) (Dede & Grotzer, 2012, pp. 72-73).
- The unit plan takes on a hybrid or infused format: linking the national lower secondary science curriculum to the EcoMUVE pond curriculum (and by extension the US National Science Education Standards). ‘
- The classifications of objectives were guided by the Revised Bloom’s Taxonomy.

The Unit plan

SCIENCE STANDARD TOPIC: Man's Effect on the Environment

UNIT: How human activities are altering the environment in far-reaching ways.

- **Understand that there are interrelationships in an ecosystem.**

  1.1 Identify for organisms in a pond habitat. [REMEMBERING]

  2.1 Arrange organisms in a food web which represents the transfer of energy. [ANALYZING]

  2.2 Learn the roles of producers, consumers and decomposers in an ecosystem and categorize organisms accordingly. [ANALYZING]

  {COGNITIVE DOMAIN: REMEBERING = 1; ANALYZING = 2}

- **Understand that changes in the natural balance of ecosystems can occur.**

  3.1 Notice, measure and document changes in biotic factors over time. [APPLYING]

  3.2 Notice, measure and document changes in abiotic factors over time. [APPLYING]

  4.1 Investigate causes behind an environmental issue. [ANALYZING]

  4.2 Hypothesize why an observed environmental issue occurred. [CREATING]

  {COGNITIVE DOMAIN: APPLYING = 2; ANALYZING = 1; CREATING = 1}

- **Understand that ecological processes involve cyclical factors.**

  5.1 Understand that atoms are neither created nor destroyed (the principle of conservation of matter). [UNDERSTANDING]

  5.2 Understand that, through ecological processes, molecules can be broken apart and atoms rearranged to form different molecules. [UNDERSTANDING]

5.3 Understand that atoms by themselves are abiotic, but through the processes of photosynthesis and respiration, atoms become a part of living things (there is a strong relationship between abiotic and biotic parts of an ecosystem). [UNDERSTANDING]

6.1 Connect knowledge of atoms to ecological processes like photosynthesis, respiration, and decomposition. [APPLYING]

{COGNITIVE DOMAIN: UNDERSTANDING = 3; APPLYING = 1}

- **Understand that causes in nature can be complex.**

7.1 Understand how to represent complex causal relationships using a concept map. [CREATING]

8.1 Interpret graphs of variables changing over time in an ecosystem. [APPLYING]

8.2 Recognize the importance of using data and evidence to support a scientific claim. [UNDERSTANDING]

9.1 Work in groups to represent a final hypothesis for the team and create a group concept map. [ANALYZING/CREATING]

10.1 To communicate a hypothesis and offer evidence to support their claim. [EVALUATING]

11.1 Understand how complex causality occurs in areas beyond ecosystem science. [APPLYING]

{COGNITIVE DOMAIN: UNDERSTANDING = 1; APPLYING = 2; ANALYZING = 1; EVALUATING = 1; CREATING = 2}

Table of specifications

Content/Domain Knowledge Table of Specifications

CONTENT/ GENERAL OBJECTIVES	COGNITIVE DOMAIN						TOTAL SKILLS	% TOTAL SKILLS PER GENERAL OBJECTIVE
	REMEMBERING	UNDERSTANDING	APPLYING	ANALYZING	EVALUATING	CREATING		
Understand that there are interrelationships among organisms in an ecosystem.	**1**	**0**	**0**	**2**	**0**	**0**	*3*	17% [ROUNDED UP]
Understand that changes in the natural balance of ecosystems can occur.	**0**	**0**	**2**	**1**	**0**	**1**	*4*	22%
Understand that ecological processes involve cyclical factors.	**0**	**3**	**1**	**0**	**0**	**0**	*4*	22%
Understand that causes in nature can be complex.	**0**	**1**	**2**	**1**	**1**	**2**	*7*	39%
TOTAL SKILLS	*1*	*4*	*5*	*4*	*1*	*3*	***18***	100%
% TOTAL SKILLS FOR UNIT	6%	22%	28%	22%	6%	16% [ROUNDED DOWN]	100%	

Appendix B

Lesson Plans

LESSON: 1
TEACHER: KESTER COKER
DATE: 5/03/2011
CLASS: FORM 4 BIOLOGY
TIME: 40 MINUTES
Periods: 1
UNIT: How human activities are altering the environment in far-reaching ways

TOPIC: *Making Discoveries in the Ecosystem*

REFERENCES (exclude class text Include page numbers).

EcoMUVE Pond Curriculum – Lesson 1 (Dede & Grotzer, 2012, pp. 22-24)

PRE REQUISITES

Knowledge:
Students should know that:

- There is a diversity of organisms in the environment.
- Organisms can be classified into different taxonomic groups.

Skill:

Students should know how to:

- Identify different organisms.
- Use a computer to navigate software and save files.

MATERIALS & RESOURCES

For Teacher	For each group/student
▪ Laptop w/ EcoMUVE pond software installed ▪ Multimedia Projector ▪ Whiteboard	▪ Laptop w/ EcoMUVE pond software installed

CONCEPT OR PRINCIPLE

There are a wide variety of organisms in the environment which live in a given habitat.

OBJECTIVES	**Classification**
At the end of the lesson, student will be able to:	
Explore and identify organisms in a pond habitat.	REMEMBERING

PROCESS SKILLS

During this lesson, student will be engaged in:

Identifying/formulating a problem	☐
Designing and Planning an experimental procedure	☐
Setting-up and executing experimental work	☐
Observing and measuring	☐
Recording of data and observations	☑
Interpreting and evaluating data and observations	☐
Communicating scientific ideas, observations and arguments	☐
Applying scientific ideas and methods to solve qualitative and quantitative problems	☐
Decision-making on examination of evidence and arguments	☐
Extracting from available information data relevant to a particular situation	☐

ACTIVITIES

- **Analyze:** students describe what an ecosystem is.
- **Expand:** students learn how to operate EcoMUVE program.
- **Explore:** students see how much different organisms they can find.
- **Review/Extend/Apply:** students name one organism they found and share their discoveries with class.

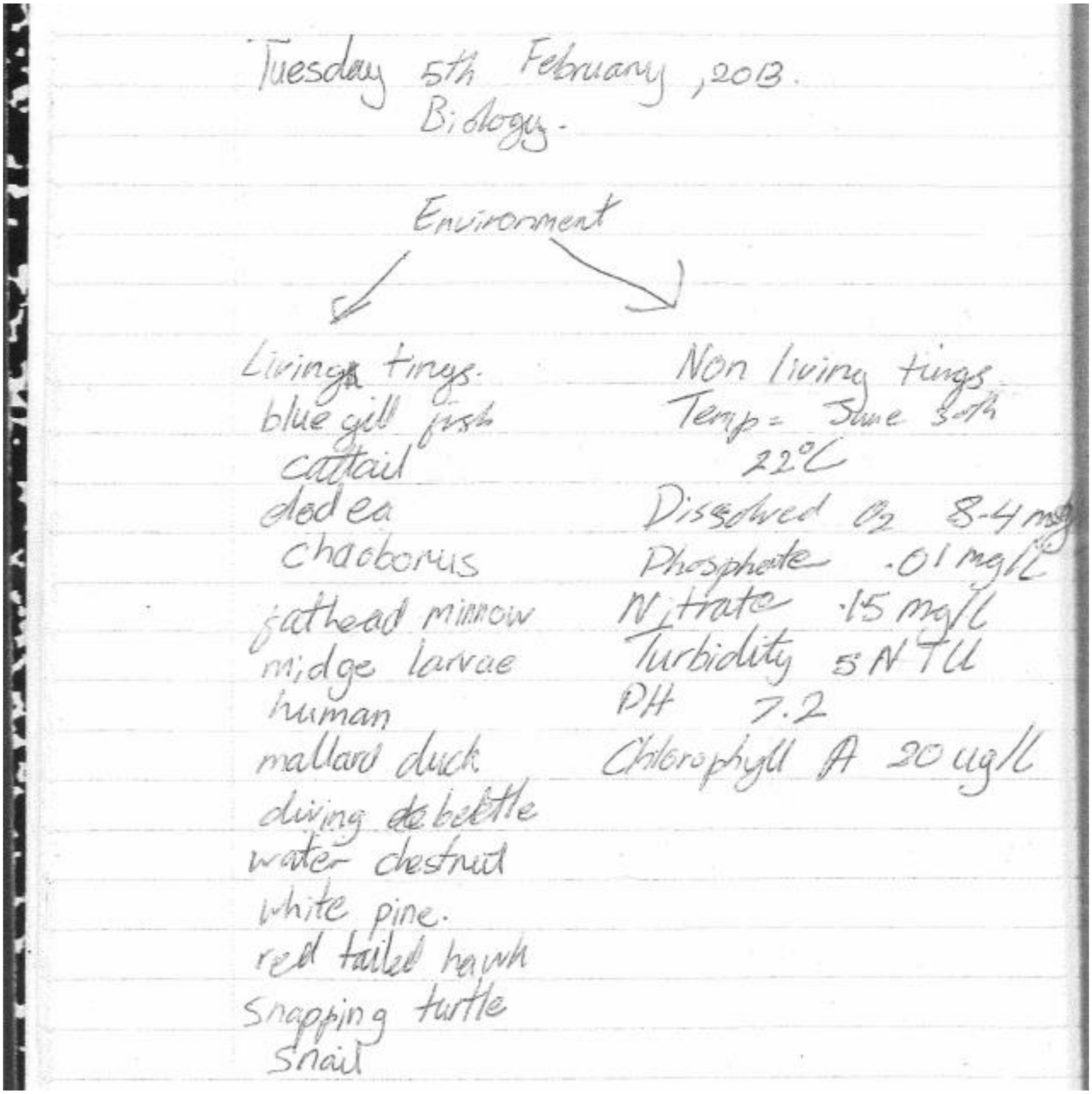
TEACHER’S EVALUATION OF THE LESSON:

- Questioning
- Discussion
- Recording concerns

TUTOR'S COMMENTS

- The students were excited about using the software.
- Student cooperated in getting the software installed, up and running.
- They made a lot of discoveries using the tools in the game and were at awe at the amount of information they got on each organism. They were sometimes found with eyes glued to the screen with enthusiasm.

Artifact from Lesson 1: Student notes



Tuesday 5th February, 2013.
Biology.

Environment

Living tings.	Non living tings.
blue gill fish	Temp = June 30th 22°C
cattail	
dadea	Dissolved O_2 8.4 mg
chaoborus	Phosphate .01 mg/L
fathead minnow	Nitrate .15 mg/L
midge larvae	Turbidity 5 NTU
human	PH 7.2
mallard duck	Chlorophyll A 20 ug/L
diving bettle	
water chestnut	
white pine.	
red tailed hawk	
snapping turtle	
snail	

LESSON: 2
TEACHER: KESTER COKER
DATE: 5/03/2011
CLASS: FORM 4 BIOLOGY
TIME: 40 MINUTES
Periods: 1
UNIT: How human activities are altering the environment in far-reaching ways

TOPIC: *Food webs and energy transfer.*

REFERENCES (exclude class text Include page numbers).

EcoMUVE Pond Curriculum – Lesson 2 (Dede & Grotzer, 2012, pp. 25-29)

PRE REQUISITES

Knowledge:
Students should know that:

- There is a diversity of organisms in the environment.
- Organisms can be classified into different taxonomic groups.

Skill:

Students should know how to:

- Use EcoMUVE to identify different organisms in a pond habitat.

MATERIALS & RESOURCES

For Teacher	**For each group/student**
▪ Laptop w/ EcoMUVE pond software installed ▪ Multimedia Projector ▪ Whiteboard	▪ Laptop w/ EcoMUVE pond software installed

CONCEPT OR PRINCIPLE

Feeding relationships in an ecosystem can be represented by a food web. There are different trophic levels in an ecosystem.

OBJECTIVES	**Classification**
At the end of the lesson, student will be able to:	
1. Arrange organisms in a food web which represents the transfer of energy.	ANALYZING
2. Learn the roles of producers, consumers and decomposers in an ecosystem and categorize organisms accordingly.	ANALYZING

PROCESS SKILLS

During this lesson, student will be engaged in:

Identifying/formulating a problem	☐
Designing and Planning an experimental procedure	☐
Setting-up and executing experimental work	☐
Observing and measuring	☐
Recording of data and observations	☑
Interpreting and evaluating data and observations	☐
Communicating scientific ideas, observations and arguments	☐
Applying scientific ideas and methods to solve qualitative and quantitative problems	☑
Decision-making on examination of evidence and arguments	☐
Extracting from available information data relevant to a particular situation	☑

ACTIVITIES

- **Analyze:** students given definition of producer, consumer, and decomposer and asked to group organisms correctly.
- **Expand:** students learn how to use online food web tool and learn about feeding relationships using pond field guide; students given food web activity sheets.
- **Explore:** students construct food webs using online food web tool.

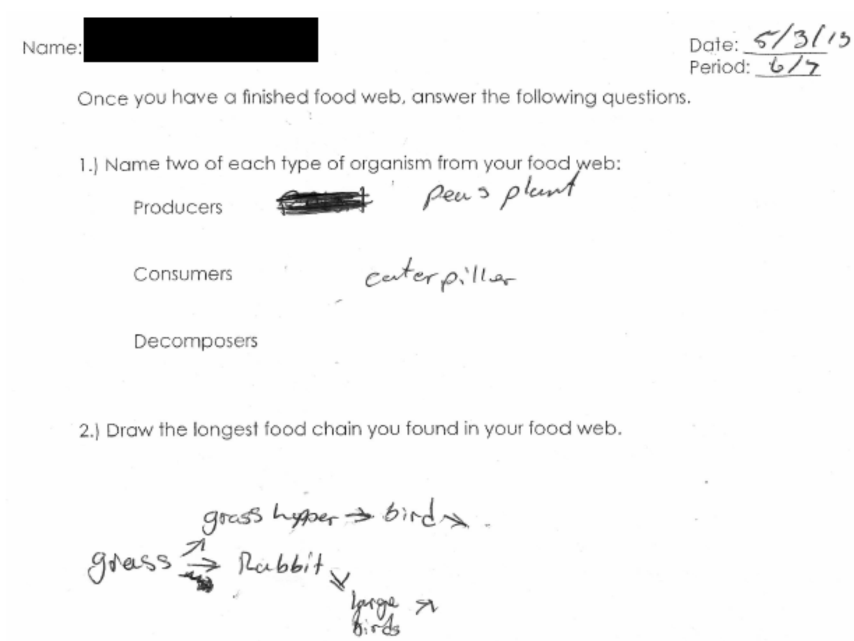
- **Review/Extend/Apply:** students review and discuss implications of removing an organism from the food web and learn about food and energy transfer.

TEACHER'S EVALUATION OF THE LESSON:

- Review food web activity worksheet and trophic level worksheet.

<u>TUTOR'S COMMENTS</u>

- There was no internet connection. Few students had their laptops so they had to work in big groups. There was an issue with one laptop with restrictions. The IT technician was called to see about it but he was busy. The students had to watch on from a distance. This part of the lesson should be familiar to them as we did the topic of food webs last term. The students were very interested in getting information that described how the organisms interacted with each other. Some students were giving trouble. They saw the new format as an opportunity to "ole talk".
- Artifacts from Lesson 2: Food web activity sheet


Name: [redacted]

Date: 5/3/13
Period: 6/7

Once you have a finished food web, answer the following questions.

1.) Name two of each type of organism from your food web:

Producers peas plant

Consumers caterpiller

Decomposers

2.) Draw the longest food chain you found in your food web.

Name: [redacted]

Date: 05/09/13
Period: ______

Once you have a finished food web, answer the following questions.

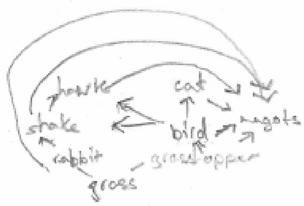
1.) Name two of each type of organism from your food web:

Producers - Plants and grass

Consumers - Rabbit, snake, hawk, cat, bird grasshopper

Decomposers - Magot

2.) Draw the longest food chain you found in your food web.



3.) Where does the energy in the food web come from?

The grass

LESSON: 3
TEACHER: KESTER COKER
DATE: 8/03/2011
CLASS: FORM 4 BIOLOGY
TIME: 40 MINUTES
Periods: 1
UNIT: How human activities are altering the environment in far-reaching ways

TOPIC: *Biotic and abiotic factors.*

REFERENCES (exclude class text Include page numbers).

EcoMUVE Pond Curriculum – Lesson 3 (Dede & Grotzer, 2012, pp. 30-33)

PRE REQUISITES

Knowledge:
Students should know that:

- There are feeding relationships in an ecosystem.
- Organisms feed at different trophic levels.

Skill:

Students should know how to:

- Use the measuring tools in EcoMUVE.

MATERIALS & RESOURCES

For Teacher	For each group/student
▪ Laptop w/ EcoMUVE pond software installed ▪ Multimedia Projector ▪ Whiteboard	▪ Laptop w/ EcoMUVE pond software installed

CONCEPT OR PRINCIPLE

The environment consists of a living (biotic) component and a non-living (abiotic) component, factors of which interact with each other.

OBJECTIVES	**Classification**
At the end of the lesson, student will be able to:	
1. Notice, measure and document changes in biotic factors over time.	APPLYING
2. Notice, measure and document changes in abiotic factors over time.	APPLYING

PROCESS SKILLS

During this lesson, student will be engaged in:

Identifying/formulating a problem	☐
Designing and Planning an experimental procedure	☐
Setting-up and executing experimental work	☐
Observing and measuring	☑
Recording of data and observations	☑
Interpreting and evaluating data and observations	☐
Communicating scientific ideas, observations and arguments	☐
Applying scientific ideas and methods to solve qualitative and quantitative problems	☐
Decision-making on examination of evidence and arguments	☐
Extracting from available information data relevant to a particular situation	☐

ACTIVITIES

- **Analyze:** students list biotic and abiotic factors from what they have observed and discuss its relevance; students learn about scientists who study ecosystems (ecologists, water chemists, biologists) and their measurement tools; students fill in the water measurement learning quest.
- **Expand:** students learn how to use the measurement tools in EcoMUVE.
- **Explore:** students use calendar tool to go to July 28th and note their observations

- **Review/Extend/Apply:** students share their observations about July 28th and discuss what they would like to find out on the next pond visit.

TEACHER'S EVALUATION OF THE LESSON:

- Worksheet printed out and given for homework.

TUTOR'S COMMENTS

Students seem to be getting the hang of using the measurement tools in the game. They seem to be picking up fast. Some students were petrified at the fish kill in the game on July 28th. Immediately some expressed that the fish died because pollution. Some were bewildered as to how the fish died. A few students from the last class who were not involved became a bit more interested as students were looking at all the dead fish. I administered the pretests to the boys. They were eager to do the first one (causal features assessment). The ecological worldview pretest was well accepted as well. It seemed to have them thinking. The conceptual change pretest however had some students visibly turned off because of it looked bulky. A student express "Whey sir, so much pages? We have to do it now?" Students had no internet connection in the classroom to the pond activity was given for homework.

LESSON: 4
TEACHER: KESTER COKER
DATE: 11/03/2011
CLASS: FORM 4 BIOLOGY
TIME: 40 MINUTES
Periods: 1
UNIT: How human activities are altering the environment in far-reaching ways

TOPIC: *Science team roles.*

REFERENCES (exclude class text Include page numbers).

EcoMUVE Pond Curriculum – Lesson 4 (Dede & Grotzer, 2012, pp. 34-41)

PRE REQUISITES

Knowledge:
Students should know that:

- There are feeding relationships in an ecosystem.
- Organisms feed at different trophic levels.
- An ecosystem has biotic and abiotic factors which interact.

Skill:

Students should know how to:

- Use the measuring tools in EcoMUVE.

MATERIALS & RESOURCES

For Teacher	**For each group/student**
▪ Laptop w/ EcoMUVE pond software installed ▪ Multimedia Projector ▪ Whiteboard	▪ Laptop w/ EcoMUVE pond software installed

CONCEPT OR PRINCIPLE

There are many variables in the environment which we can measure. This data can be used to investigate environmental issues. Scientific inquiry involves making observations and hypotheses.

OBJECTIVES	**Classification**
At the end of the lesson, student will be able to:	
1. Investigate causes behind an environmental issue.	ANALYZING
2. Hypothesize why an observed environmental issue occurred.	CREATING

PROCESS SKILLS

During this lesson, student will be engaged in:

Identifying/formulating a problem	☑
Designing and Planning an experimental procedure	☐
Setting-up and executing experimental work	☐
Observing and measuring	☑
Recording of data and observations	☑
Interpreting and evaluating data and observations	☐
Communicating scientific ideas, observations and arguments	☐
Applying scientific ideas and methods to solve qualitative and quantitative problems	☐
Decision-making on examination of evidence and arguments	☐
Extracting from available information data relevant to a particular situation	☑

ACTIVITIES

Jigsaw approach—students separated into specialist science teams: microscopic specialists, private investigator, water chemist, and naturalist**:**

- **Analyze:** teams brainstorm 4 ideas (hypotheses) about why the fish may have died.
- **Expand:** teams briefed about their roles and organize who will be doing what in the group.

- **Explore:** teammates in their respective roles use EcoMUVE to explore and record evidence of why the fish may have died.
- **Review/Extend/Apply:** teams discuss findings.

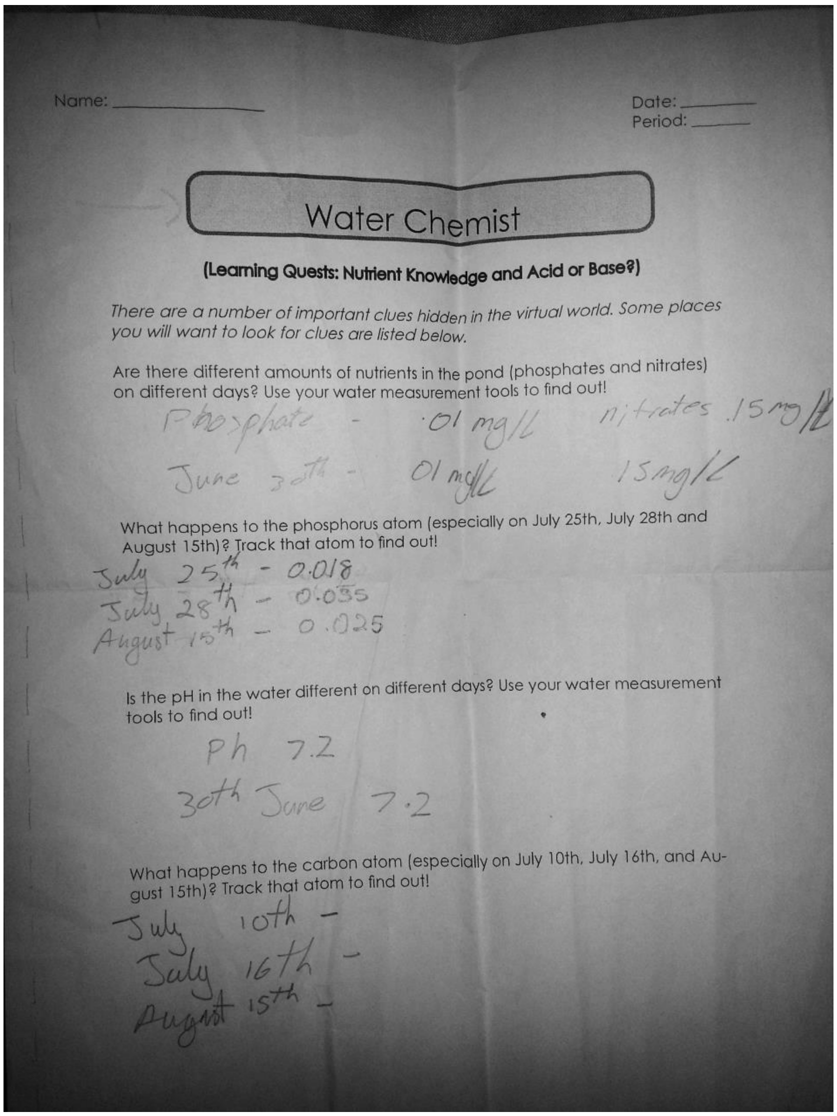
TEACHER'S EVALUATION OF THE LESSON:

Review of group role sheets (an extended formative assessment) and individual specialist role sheets.

TUTOR'S COMMENTS

The students became excited about assuming the role of a scientist doing an investigation. They seem to take pride in their avatar and showed confidence in themselves. There were a few students who continue to try to defy the activity. I can see the pouting. I can feel the resistance. I made arrangements (with permission from my HOD [head of department]) with another teacher to take her classes so I can get extra with the students. Some students were visibly upset about this. I thought immediately about the "discomfort" hindrance to collateral learning as described by Aikenhead and Jegede in 1999. I knew that this would not be good for their learning causal relationships or anything coming from me for that matter. So I tried to get speak to them in a pacifying manner and got them involved in the activities. I walked around and helped students with little issues of navigating the software but everything seemed like it was on automatic. I didn't have to do much. It was like the students were so absorbed in gathering data in their roles that sometimes I felt as though they didn't think I was there! I realized that this activity was a good one as students seem own the data. They spoke with authority on what they found and what they thought could have been the cause of the fish kill. The groups make hypotheses but they suggested that they would like more time to finalize their investigations. I did not pressure them but asked that they share their thoughts about why they thought the fishes died. Healthy contributions were given. Some students were very observant and had identified the fertilizer issue from the farm. They said the farmer was dumping fertilizer that poisoned the fish. Some students offered the hypothesis that the water had less oxygen (because they noticed the drop in oxygen just before the July 28th fish kill) but they could not say why. I explained to them that a hypothesis is a theory, explanation or an educated guess that must be tested or confirmed. It's just a way of investigating things in science. We move on to the next lesson this afternoon.

Artifact from Lesson 4:



Name: ______

Date: ______
Period: ______

Water Chemist

(Learning Quests: Nutrient Knowledge and Acid or Base?)

There are a number of important clues hidden in the virtual world. Some places you will want to look for clues are listed below.

Are there different amounts of nutrients in the pond (phosphates and nitrates) on different days? Use your water measurement tools to find out!

Phosphate - .01 mg/L nitrates .15 mg/L

June 30th - .01 mg/L .15 mg/L

What happens to the phosphorus atom (especially on July 25th, July 28th and August 15th)? Track that atom to find out!

July 25th - 0.018
July 28th - 0.035
August 15th - 0.025

Is the pH in the water different on different days? Use your water measurement tools to find out!

Ph 7.2

30th June 7.2

What happens to the carbon atom (especially on July 10th, July 16th, and August 15th)? Track that atom to find out!

July 10th -
July 16th -
August 15th -

LESSONS: 5 & 6 [FUSED]
TEACHER: KESTER COKER
DATE: 11/03/2011
CLASS: FORM 4 BIOLOGY
TIME: 80 MINUTES
Periods: 2
UNIT: How human activities are altering the environment in far-reaching ways

TOPIC: *Ecosystem processes at the atomic level.*

REFERENCES (exclude class text Include page numbers).

EcoMUVE Pond Curriculum – Lesson 5 (Dede & Grotzer, 2012, pp. 42-51)

EcoMUVE Pond Curriculum – Lesson 6 (Dede & Grotzer, 2012, pp. 52-54)

PRE REQUISITES

Knowledge:
Students should know that:

- There are feeding relationships in an ecosystem.
- Organisms feed at different trophic levels.
- An ecosystem has biotic and abiotic factors that interact.

Skill:

Students should know how to:

- Use the measuring tools in EcoMUVE.
- Make hypotheses

MATERIALS & RESOURCES

For Teacher	**For each group/student**
▪ Laptop w/ EcoMUVE pond software installed ▪ Multimedia Projector ▪ Whiteboard	▪ Laptop w/ EcoMUVE pond software installed

CONCEPT OR PRINCIPLE

An ecosystem is governed by many biological processes. The fundamental biological processes are photosynthesis, respiration, and decomposition. Nutrients are cycled through nature.

OBJECTIVES	**Classification**
At the end of the lesson, student will be able to:	
1. Understand that atoms are neither created nor destroyed (the principle of conservation of matter).	UNDERSTANDING
2. Understand that, through ecological processes, molecules can be broken apart and atoms rearranged to form different molecules.	UNDERSTANDING
3. Understand that atoms by themselves are abiotic, but through the processes of photosynthesis and respiration, atoms become a part of living things (there is a strong relationship between abiotic and biotic parts of an ecosystem).	UNDERSTANDING
4. Connect knowledge of atoms to ecological processes like photosynthesis, respiration, and decomposition.	APPLYING

PROCESS SKILLS

During this lesson, student will be engaged in:

Identifying/formulating a problem	☑
Designing and Planning an experimental procedure	☐
Setting-up and executing experimental work	☐
Observing and measuring	☑
Recording of data and observations	☑
Interpreting and evaluating data and observations	☐
Communicating scientific ideas, observations and arguments	☐
Applying scientific ideas and methods to solve qualitative and quantitative problems	☐
Decision-making on examination of evidence and arguments	☐
Extracting from available information data relevant to a particular situation	☑

ACTIVITIES

- **Analyze** students learn what an atom is and how to use the atom tracker tool in EcoMUVE. Teams use one computer to collate data collected, look at trends over time and decide on what other evidence may be needed to furnish the hypothesis they brainstormed in Lesson 1.
- **Expand** students use the atom tracker tool to track carbon, phosphorous, and oxygen; record their findings on the atom tracker worksheets and work on the atom tracker reflection sheet. Whole-class discussion on trends of atoms which occur over time and how atoms are rearranged to form new molecules in ecological processes; students allowed to move to computers.
- **Explore:** whole class discussion on trends in atoms tracked; students' understanding probed about the role of atoms in ecosystems. Students collect data in EcoMUVE based on new team discussions about the link between atoms and ecological processes; students share teammate data files and explore findings.
- **Review/Extend/Apply:** students suggest how the atoms played a role in the Scheele ecosystem.

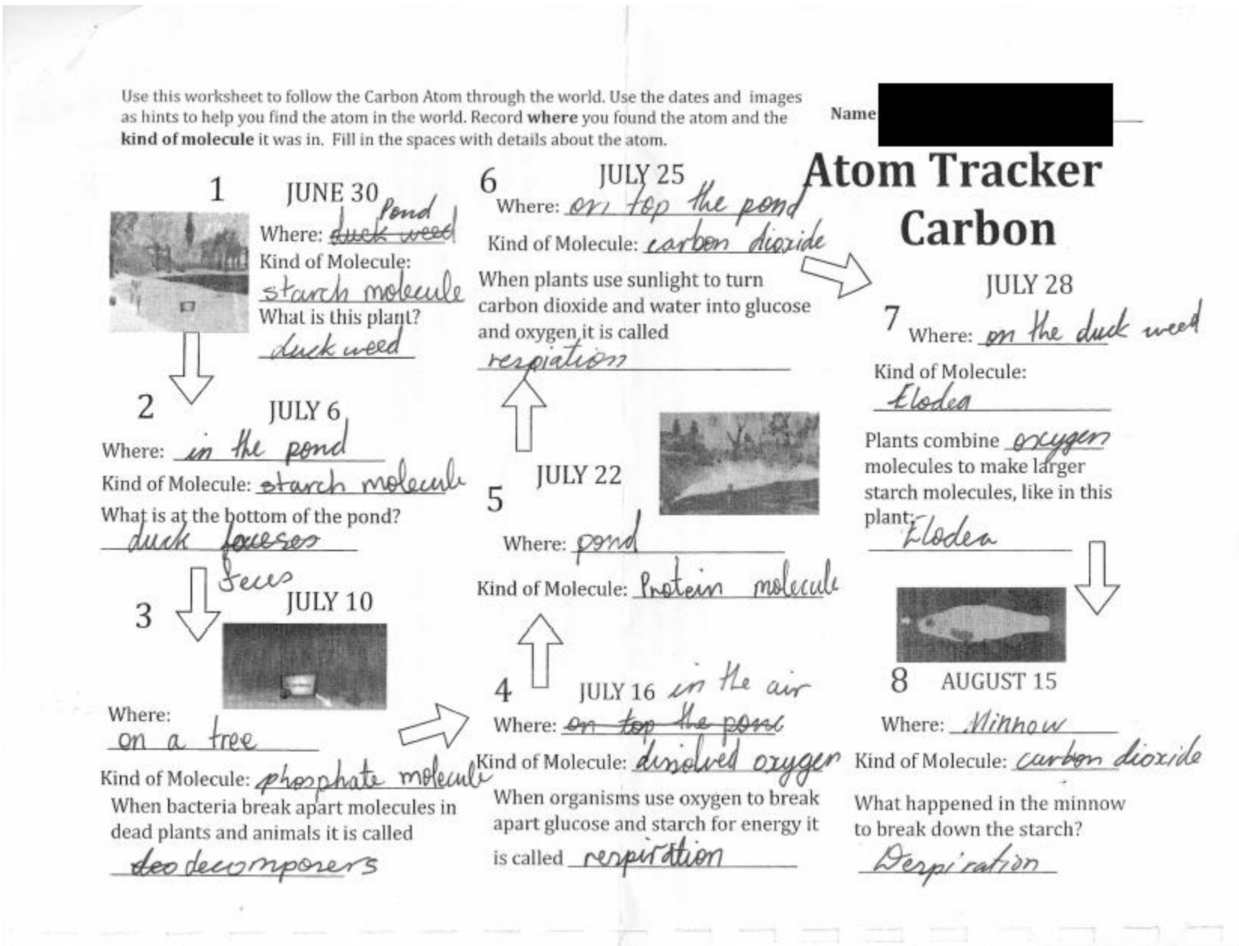
TEACHER'S EVALUATION OF THE LESSON:

- Review of atom tracker sheet
- Guided discussions to bring about linkage between atoms and ecological processes within EcoMUVE.
- Observations and guidance with collating and interpreting data.

TUTOR'S COMMENTS

I decided to fuse lessons 5 & 6 because they were very similar in nature. Thought that this would be a tough session for the students because we were going to get a bit more technical about the environment. But the students held their own and completed the atom tracker tasks successfully. I really get the feeling that this worked well for students who got the hang of the program. I noticed that there was not enough time for students to fill in the information for all of the worksheet. They seem to take their time and rather meticulously scour the software to get data than rush to complete the worksheets. I notice that there were a few students who seem to marginalize themselves, saying that they did not have their laptop and who are scarcely involved. I also notice the absence of a few other students. I noticed that there was one student in particular who was amazingly, rather exceptionally spot on with what the desired explanation was for the fish kill. However in his pretest, he did not articulate it in writing as well as he came and articulated it to me verbally. Had I not interacted with him by way of discussion, his scores would have told a different story to me. I see him taking charge of his group and leading the way with discussions about how the atoms go from one form to the next in its cycle. I am wondering if his was a case of anxiety or did it represent something else...makes me wonder if there are many more like him who silently become enlightened by the software lesson format and can articulate the content in discussion but not written expression. Is this thing a matter of writing expression or causal reasoning? My goodness...I will continue to observe and reflect. At least there is a constant buzz of interest and productive activity form most of the boys. For one thing though, this EcoMUVE seems to really have an “immersive” effect.

- Artifact from Lessons 5&6:



Use this worksheet to follow the Carbon Atom through the world. Use the dates and images as hints to help you find the atom in the world. Record **where** you found the atom and the **kind of molecule** it was in. Fill in the spaces with details about the atom.

Name [redacted]

Atom Tracker Carbon

1 JUNE 30
Where: ~~duck weed~~ Pond
Kind of Molecule: starch molecule
What is this plant? duck weed

2 JULY 6
Where: in the pond
Kind of Molecule: ~~starch~~ molecule
What is at the bottom of the pond? duck ~~faeses~~ feces

3 JULY 10
Where: on a tree
Kind of Molecule: phosphate molecule
When bacteria break apart molecules in dead plants and animals it is called ~~deo~~ decomposers

4 JULY 16
Where: ~~on top the pond~~ in the air
Kind of Molecule: disolved oxygen
When organisms use oxygen to break apart glucose and starch for energy it is called respiration

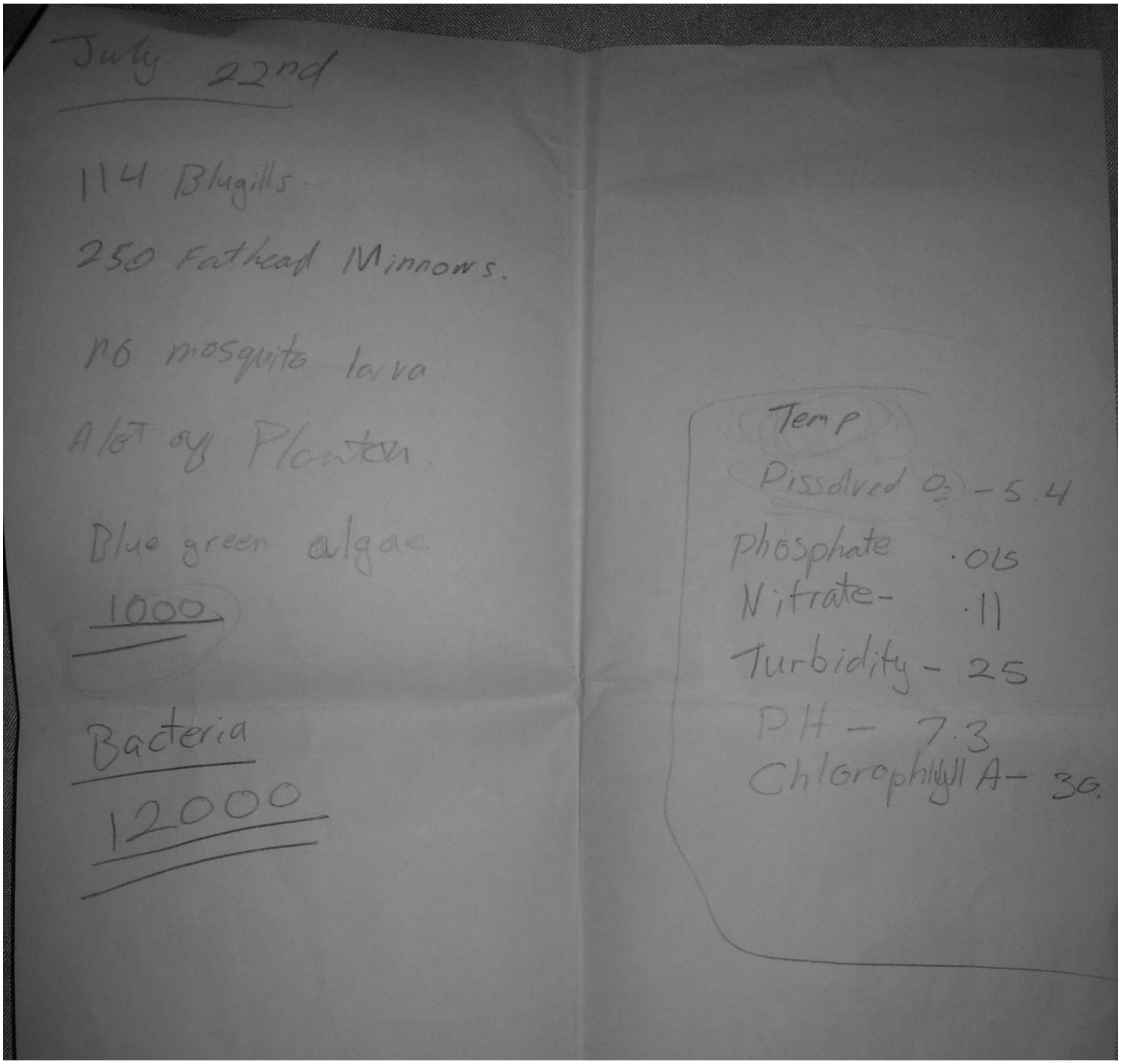
5 JULY 22
Where: pond
Kind of Molecule: Protein molecule

6 JULY 25
Where: on top the pond
Kind of Molecule: carbon dioxide
When plants use sunlight to turn carbon dioxide and water into glucose and oxygen it is called respiation

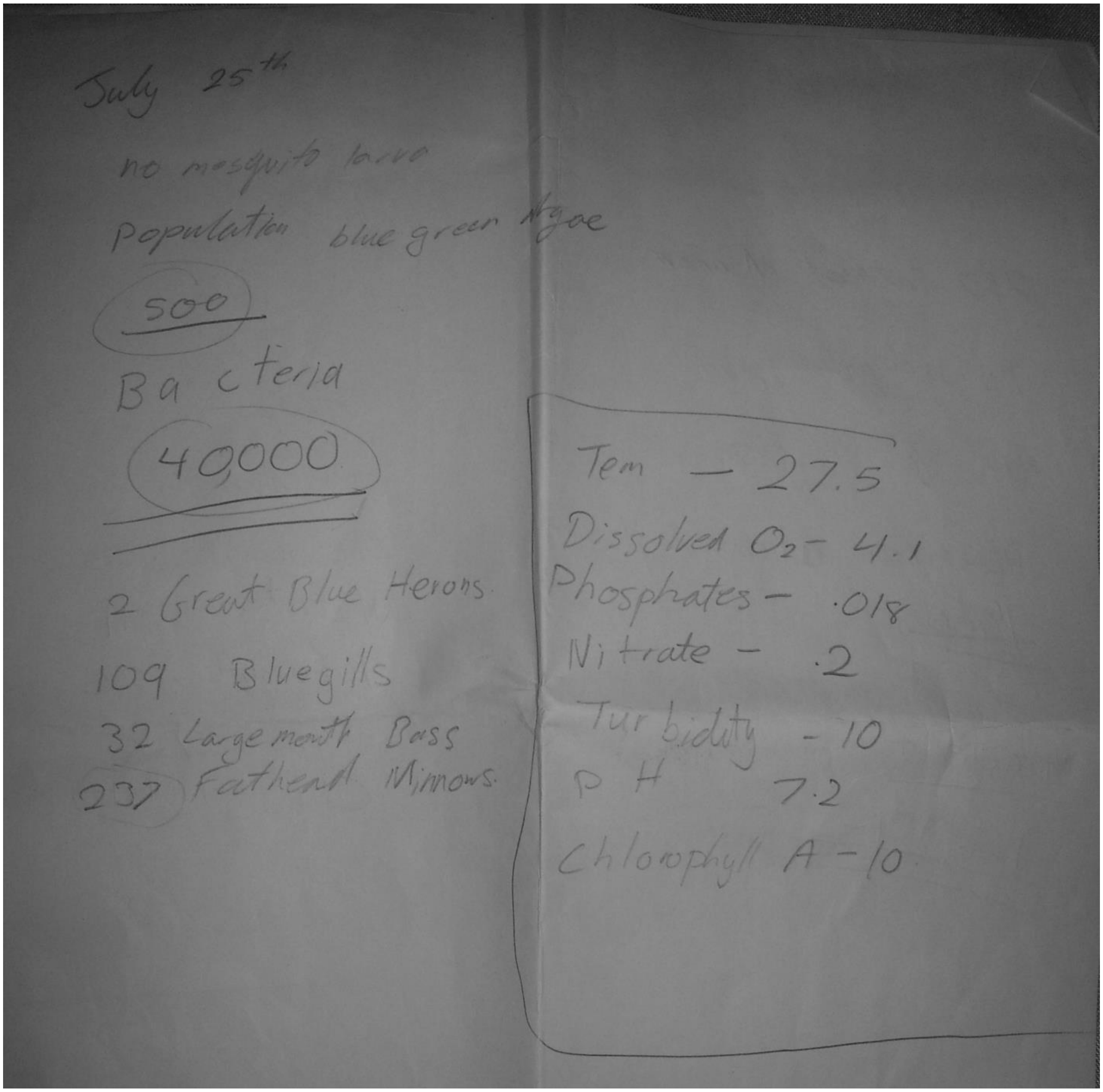
7 JULY 28
Where: on the duck weed
Kind of Molecule: Elodea
Plants combine oxygen molecules to make larger starch molecules, like in this plant: Elodea

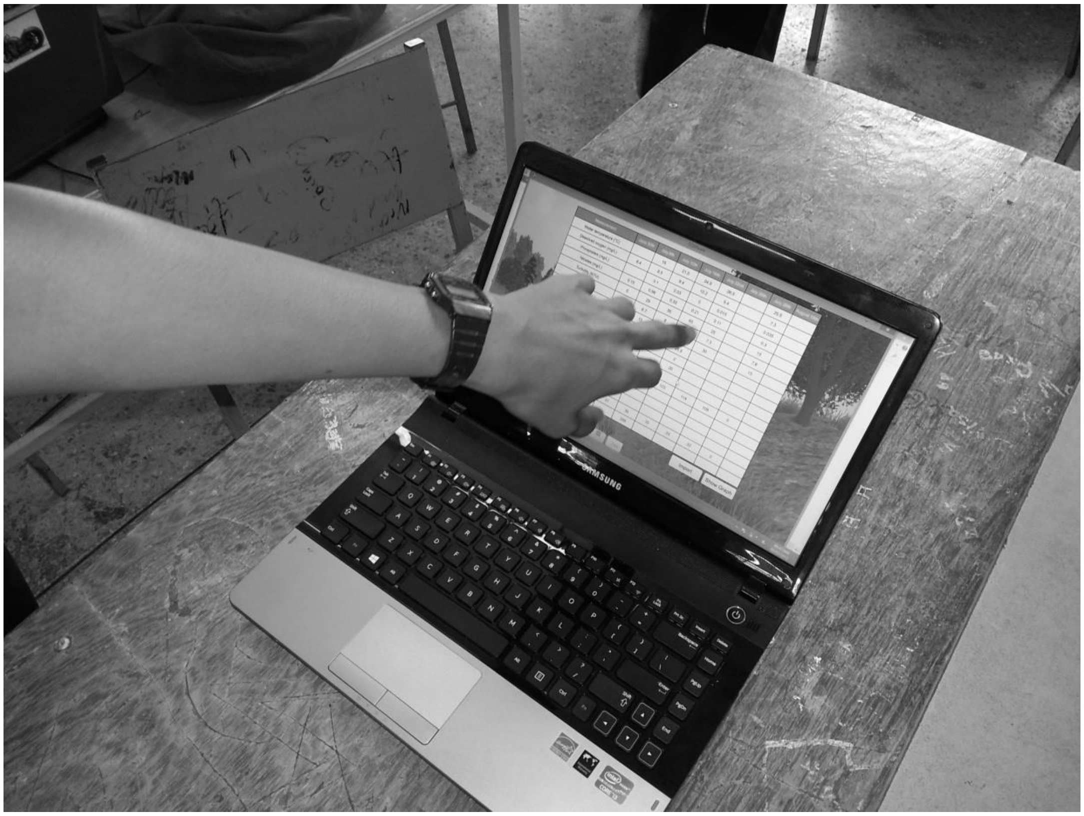
8 AUGUST 15
Where: Minnow
Kind of Molecule: carbon dioxide
What happened in the minnow to break down the starch? Respiration

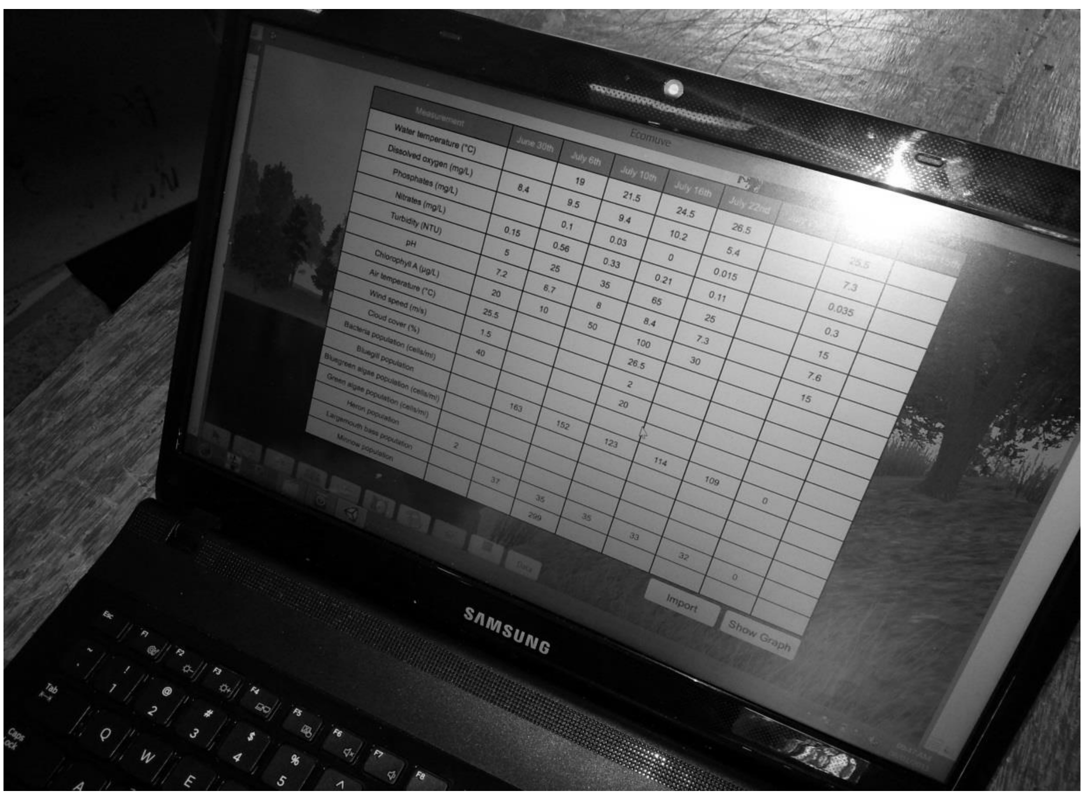
- Artifacts from Lessons 7 & 8: Student measurements to support their hypotheses.



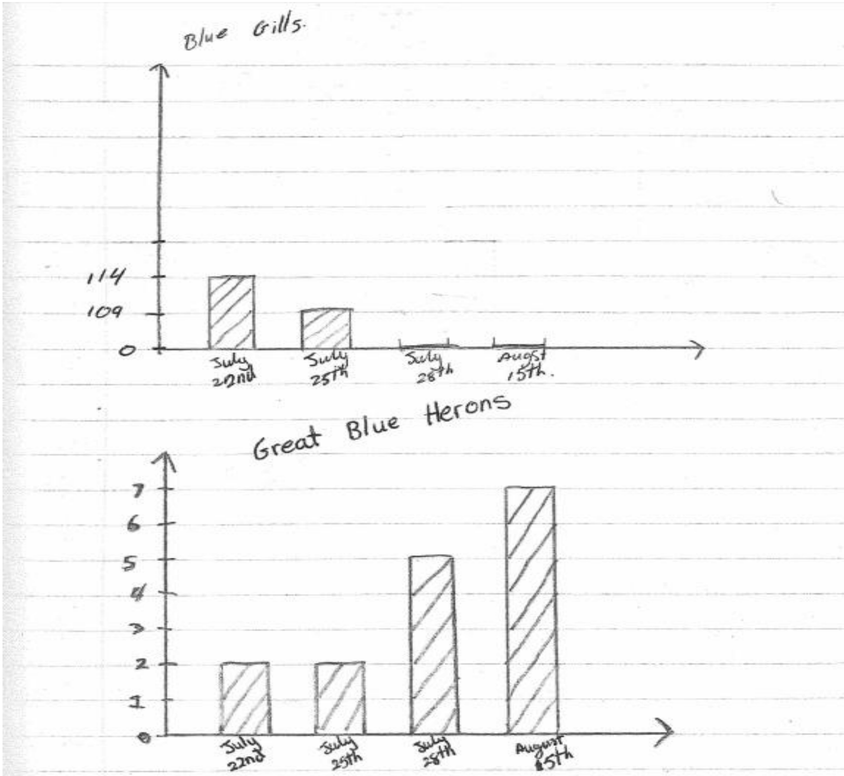
- Artifacts from Lessons 7 & 8: The same student noticed that there were changes to non-obvious factors what occurred over time.

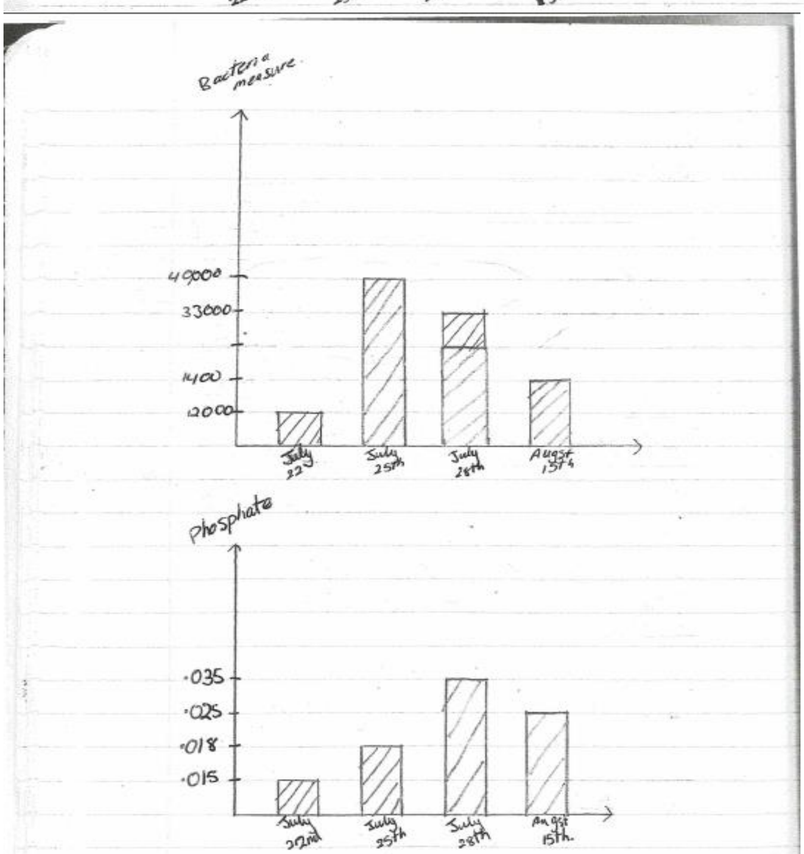



SAMSUNG

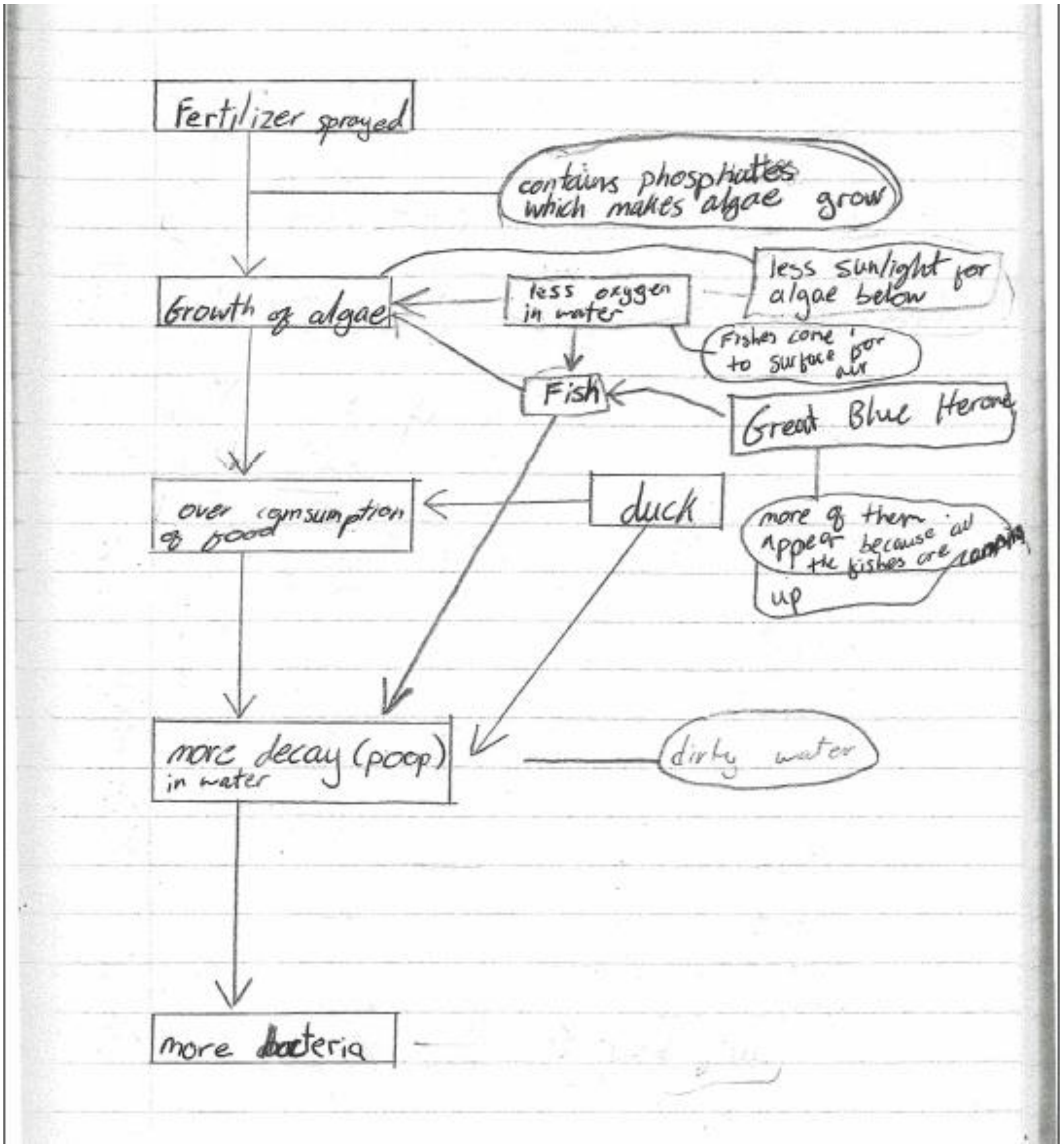

Measurement
Water temperature (°C)
Dissolved oxygen (mg/L)
Phosphates (mg/L)
Nitrates (mg/L)
Turbidity (NTU)
pH
Chlorophyll A (µg/L)
Air temperature (°C)
Wind speed (m/s)
Cloud cover (%)
Bacteria population (cells/ml)
Bluegill population
Bluegreen algae population (cells/ml)
Green algae population (cells/ml)
Heron population
Largemouth bass population
Minnow population
June 30th
July 6th
July 10th
July 16th
Import
Show Graph
SAMSUNG

- Artifacts from Lessons 7 & 8: The same student plots the data on bar graphs.





- Artifacts from Lessons 9 & 10: A student's concept map showing their hypothesis elaborated, the patterns of which were based on evidence they gathered.



Appendix C

(i) Raw data. The following is the raw data obtained from the results of causal reasoning ability, ecological worldview, and conceptual change instruments administered to students before and after the intervention.

Causal reasoning ability raw data

STUDENT	SCORE (%)					
	CAUSAL1	CAUSAL2	EWORLDVIEW1	EWORLDVIEW2	CONCEPTUAL1	CONCEPTUAL2
STUDENT A	43.75	62.50	72.00	62.67	33.30	43.30
STUDENT B	0.00	56.25	60.00	62.67	30.00	23.30
STUDENT C	31.25	25.00	82.67	84.00	46.70	56.70
STUDENT D	75.00	87.50	64.00	61.33	30.00	40.00
STUDENT E	25.00	31.25	68.00	64.00	46.70	40.00
STUDENT F	37.50	37.5	68.00	68.00	40.00	53.30
STUDENT G	56.25	56.25	68.00	57.33	3.30	56.70
STUDENT H	56.25	37.50	64.00	65.33	33.30	66.70
STUDENT I	25.00	56.25	61.33	64.00	26.70	56.70
STUDENT J	31.25	43.75	65.33	62.67	30.00	66.70
STUDENT K	37.50	75.00	70.67	73.33	23.30	60.00
STUDENT L	12.50	37.50	62.67	64.00	46.70	60.00
STUDENT M	31.25	50.00	65.33	62.67	43.30	26.70
STUDENT N	25.00	37.50	74.67	78.67	20.00	50.00
STUDENT O	50.00	31.25	76.00	84.00	10.00	16.70

(ii) Assumptions for parametric tests. This section shows how all the datasets in the research measured up to basic parametric assumptions in validating them for use with parametric tests. The following assumptions were met:

- **Level of measurement:** Continuous data
- **Sampling:** Random
- **Independence of observations:** Individual student effort.
- **Normal distribution:** Sample size, n = 15. This is less than the recommended sample size for a normal distribution (n = 30). Note that once most of the other assumptions are met, parametric tests should be robust enough to treat with violation of this assumption—this violation was acknowledged when comparing means of datasets by using the Wilcoxon's Sign Rank non-parametric test for related samples to triangulate findings from the parametric paired samples t-test.

  - ***Frequencies tables of datasets in the research:***

Statistics

		CAUSAL1	CAUSAL2	EWORLDVIEW1	EWORLDVIEW2	CONCEPTUAL1	CONCEPTUAL2
N	Valid	15	15	15	15	15	15
	Missing	1	1	1	1	1	1
Mean		35.8333	48.3333	68.1778	67.6444	30.8867	47.7867
Std. Deviation		18.67047	17.43397	6.14877	8.36420	13.07183	15.67395
Variance		348.586	303.943	37.807	69.960	170.873	245.673
Skewness		.223	.864	.935	1.166	-.640	-.763
Std. Error of Skewness		.580	.580	.580	.580	.580	.580
Kurtosis		.511	.315	.703	.156	.015	-.457
Std. Error of Kurtosis		1.121	1.121	1.121	1.121	1.121	1.121

CAUSAL1

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	1	6.3	6.7	6.7
	12.50	1	6.3	6.7	13.3
	25.00	3	18.8	20.0	33.3
	31.25	3	18.8	20.0	53.3
	37.50	2	12.5	13.3	66.7
	43.75	1	6.3	6.7	73.3
	50.00	1	6.3	6.7	80.0
	56.25	2	12.5	13.3	93.3
	75.00	1	6.3	6.7	100.0
	Total	15	93.8	100.0	
Missing	System	1	6.3		
Total		16	100.0		

CAUSAL2

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	25.00	1	6.3	6.7	6.7
	31.25	2	12.5	13.3	20.0
	37.50	4	25.0	26.7	46.7
	43.75	1	6.3	6.7	53.3
	50.00	1	6.3	6.7	60.0
	56.25	3	18.8	20.0	80.0
	62.50	1	6.3	6.7	86.7
	75.00	1	6.3	6.7	93.3
	87.50	1	6.3	6.7	100.0
	Total	15	93.8	100.0	
Missing	System	1	6.3		
Total		16	100.0		

EWORLDVIEW1

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	60.00	1	6.3	6.7	6.7
	61.33	1	6.3	6.7	13.3
	62.67	1	6.3	6.7	20.0
	64.00	2	12.5	13.3	33.3
	65.33	2	12.5	13.3	46.7
	68.00	3	18.8	20.0	66.7
	70.67	1	6.3	6.7	73.3
	72.00	1	6.3	6.7	80.0
	74.67	1	6.3	6.7	86.7
	76.00	1	6.3	6.7	93.3
	82.67	1	6.3	6.7	100.0
	Total	15	93.8	100.0	
Missing	System	1	6.3		
Total		16	100.0		

EWORLDVIEW2

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	57.33	1	6.3	6.7	6.7
	61.33	1	6.3	6.7	13.3
	62.67	4	25.0	26.7	40.0
	64.00	3	18.8	20.0	60.0
	65.33	1	6.3	6.7	66.7
	68.00	1	6.3	6.7	73.3
	73.33	1	6.3	6.7	80.0
	78.67	1	6.3	6.7	86.7
	84.00	2	12.5	13.3	100.0
	Total	15	93.8	100.0	
Missing	System	1	6.3		
Total		16	100.0		

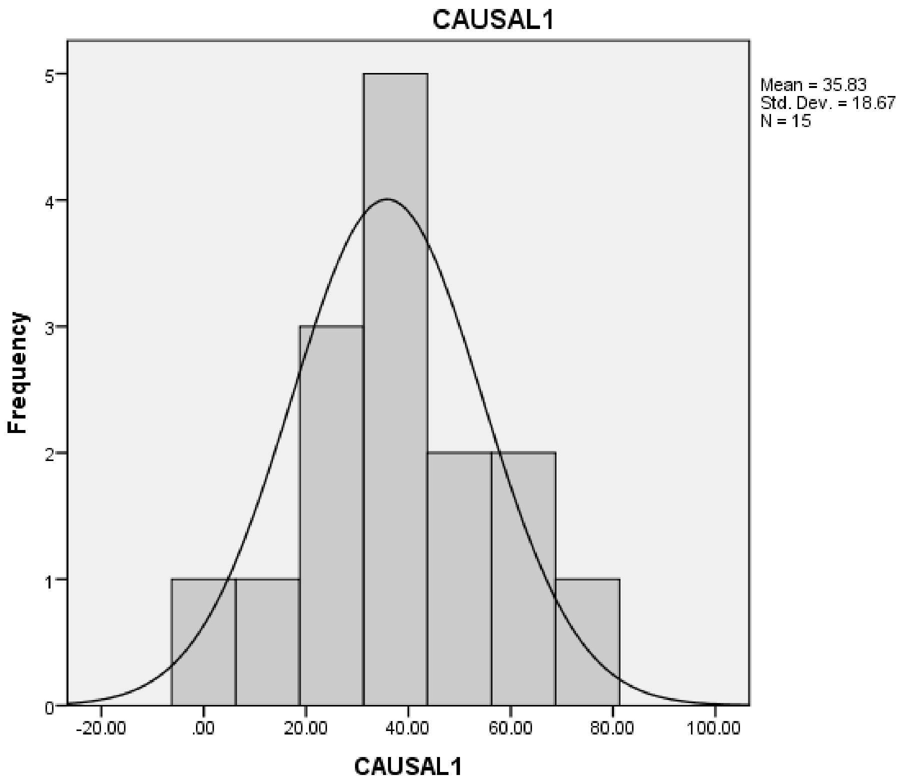
CONCEPTUAL1

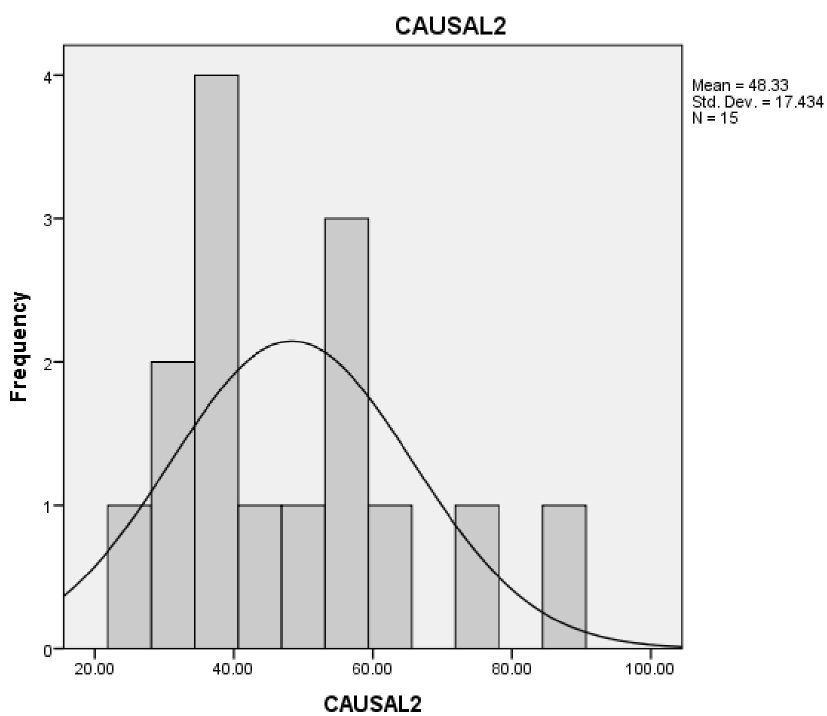
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3.30	1	6.3	6.7	6.7
	10.00	1	6.3	6.7	13.3
	20.00	1	6.3	6.7	20.0
	23.30	1	6.3	6.7	26.7
	26.70	1	6.3	6.7	33.3
	30.00	3	18.8	20.0	53.3
	33.30	2	12.5	13.3	66.7
	40.00	1	6.3	6.7	73.3
	43.30	1	6.3	6.7	80.0
	46.70	3	18.8	20.0	100.0
	Total	15	93.8	100.0	
Missing	System	1	6.3		
Total		16	100.0		

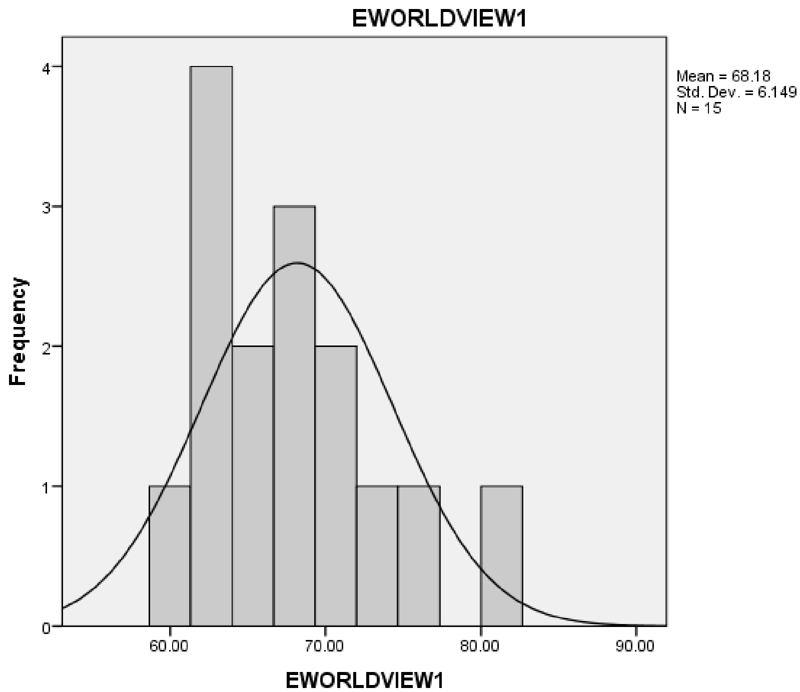
CONCEPTUAL2

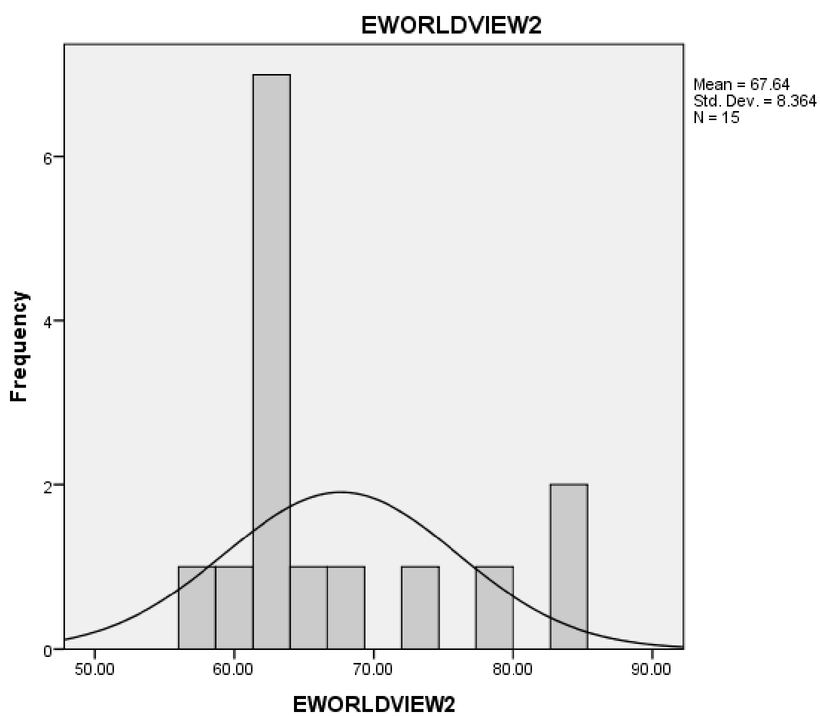
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	16.70	1	6.3	6.7	6.7
	23.30	1	6.3	6.7	13.3
	26.70	1	6.3	6.7	20.0
	40.00	2	12.5	13.3	33.3
	43.30	1	6.3	6.7	40.0
	50.00	1	6.3	6.7	46.7
	53.30	1	6.3	6.7	53.3
	56.70	3	18.8	20.0	73.3
	60.00	2	12.5	13.3	86.7
	66.70	2	12.5	13.3	100.0
	Total	15	93.8	100.0	
Missing	System	1	6.3		
Total		16	100.0		

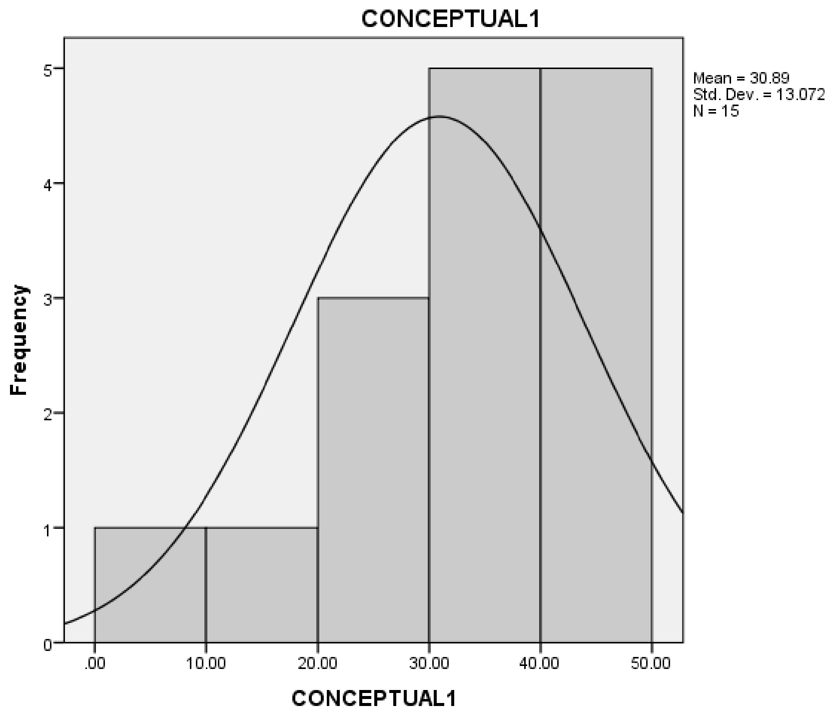
- ***Histograms of datasets in the research***

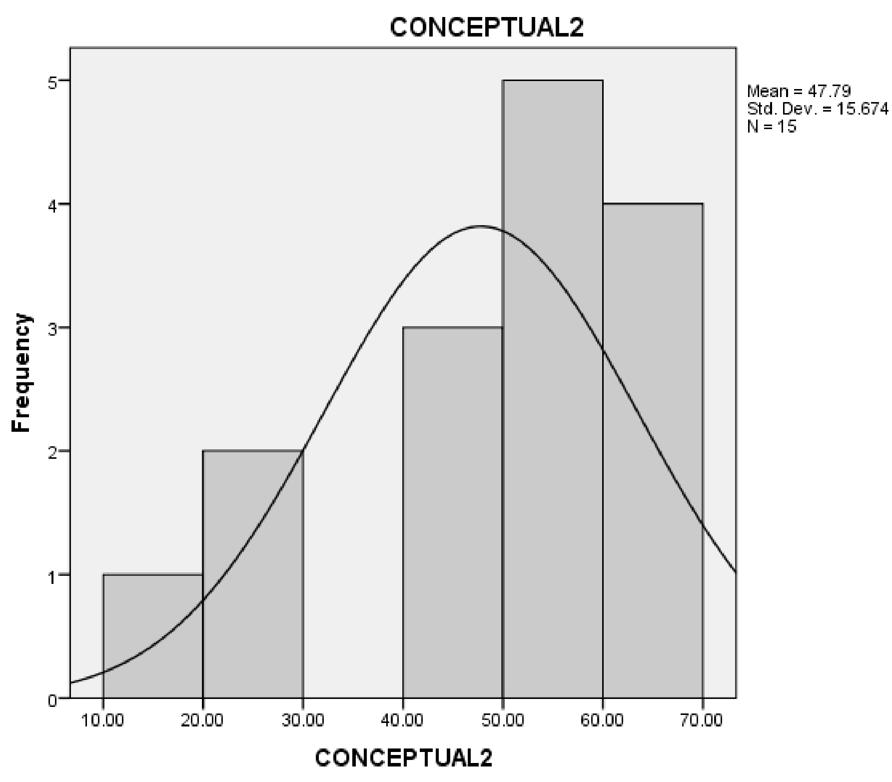





EWORLDVIEW1
Mean = 68.18
Std. Dev. = 6.149
N = 15
Frequency
0
1
2
3
4
60.00
70.00
80.00
90.00
EWORLDVIEW1


EWORLDVIEW2
Mean = 67.64
Std. Dev. = 8.364
N = 15
Frequency
0
2
4
6
50.00
60.00
70.00
80.00
90.00
EWORLDVIEW2


CONCEPTUAL1
Mean = 30.89
Std. Dev. = 13.072
N = 15
Frequency
0
1
2
3
4
5
.00
10.00
20.00
30.00
40.00
50.00
CONCEPTUAL1


CONCEPTUAL2
Mean = 47.79
Std. Dev. = 15.674
N = 15
Frequency
0
1
2
3
4
5
10.00
20.00
30.00
40.00
50.00
60.00
70.00
CONCEPTUAL2

- **Homogeneity of variances:**
    - *Results from F-tests done in Microsoft Excel 2010*

Variable Comparisons	**FTEST p-value**	**Inference**	**TEST**
CAUSAL 1 & CAUSAL2	.80	$p > \alpha$ (=.05) ▪ This implies no significant differences in variances. ▪ Meets assumption of homogeneity of variances	▪ Due to its robustness against violation of normality ($n < 30$), the paired samples t-test was used to compare means. [parametric] ▪ Results were triangulated with the Wilcoxon Sign Rank test. non-parametric]
EWORLDVIEW1 & EWORLDVIEW2	.26		
CONCEPTUAL1 & CONCEPTUAL 2	.51		
CAUSAL2 & CONCEPTUAL2	.70	$p < \alpha$ (=.05) ▪ This implies significant differences in variances. ▪ Violates assumption	▪ Due to their robustness against violations of normality, the Kendall tau-b & Spearman's rho correlation tests were used. [non-parametric] ▪ Due to its weakness to violations of normality, the Pearson's product-moment correlation results were not used but the test was still done and the results were monitored.
CAUSAL2 & EWORLDVIEW2	.01		
CONCEPTUAL2 & EWORLDVIEW2	.03		

Appendix D

Ancillary Findings

(i) Paired samples t-test statistics.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	CAUSAL2	48.3333	15	17.43397	4.50143
	CAUSAL1	35.8333	15	18.67047	4.82069
Pair 2	EWORLDVIEW2	67.6444	15	8.36420	2.15963
	EWORLDVIEW1	68.1778	15	6.14877	1.58761
Pair 3	CONCEPTUAL2	47.7867	15	15.67395	4.04700
	CONCEPTUAL1	30.8867	15	13.07183	3.37513

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	CAUSAL2 & CAUSAL1	15	.368	.177
Pair 2	EWORLDVIEW2 & EWORLDVIEW1	15	.811	.000
Pair 3	CONCEPTUAL2 & CONCEPTUAL1	15	.103	.715

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	CAUSAL2 - CAUSAL1	12.50000	20.32108	5.24688	1.24656	23.75344	2.382	14	.032
Pair 2	EWORLDVIEW2 - EWORLDVIEW1	-.53333	4.93256	1.27358	-3.26489	2.19823	-.419	14	.682
Pair 3	CONCEPTUAL2 - CONCEPTUAL1	16.90000	19.34787	4.99560	6.18551	27.61449	3.383	14	.004

(ii) Impact of EcoMUVE on causal concepts. The causal concepts measured in this research were: *effects over distance (EOD), changes over time (COT), and non-obvious causes (NOC).* Collectively they indicate student causal reasoning ability and individually they represent facets of causal reasoning ability which would be of interest to observe in order to inform the use of the EcoMUVE intervention according to the students' learning needs. The table below shows the raw data obtained for each causal concept variable, before and after the EcoMUVE teaching intervention.

Causal concepts raw data

STUDENT	SCORE (%)					
	EOD1	EOD2	COT1	COT2	NOC1	NOC2
STUDENT A	0	2	1	2	6	6
STUDENT B	0	3	0	1	0	5
STUDENT C	0	0	0	1	5	3
STUDENT D	1	0	2	2	9	12
STUDENT E	0	0	0	0	4	5
STUDENT F	0	1	0	1	6	4
STUDENT G	0	1	0	0	9	8
STUDENT H	0	0	0	2	9	4
STUDENT I	0	2	0	1	4	6
STUDENT J	2	0	1	1	2	6
STUDENT K	0	2	0	4	6	6
STUDENT L	1	0	0	0	1	6
STUDENT M	0	1	0	0	5	7
STUDENT N	0	0	0	1	4	5
STUDENT O	0	0	0	1	8	4

Causal concepts posttest-pretest paired samples t-test comparison of means

Variable name	**Variable comparisons**	**p-value**	**Inference**
EFFECTS OVER DISTANCE	EOD2 & EOD1	.15	p (=.15) > α (=.05) ▪ This implies no significant differences in effects over distance causal concept scores
NON-OBVIOUS CAUSES	NOC2 & NOC1	.46	p (=.46) > α (=.05) ▪ This implies no significant differences in *non-obvious causes* causal concept scores
CHANGES OVER TIME	COT2 & COT1	.01	p (=.01) < α (=.05) ▪ This implies significant differences in *changes over time* causal concept scores

From the results in the table above, it can be concluded that the EcoMUVE teaching intervention had a significant impact on increasing the causal concept scores for *changes over time*.

(iii) Details of structural model statistics for Figure 11:

Notes for Model (Default model)
Computation of degrees of freedom (Default model)

Number of distinct sample moments:	27
Number of distinct parameters to be estimated:	21
Degrees of freedom (27 - 21):	6

Result (Default model)
Minimum was achieved
Chi-square = 4.626
Degrees of freedom = 6
Probability level = .593

Regression Weights: (Group number 1 - Default model)

			Estimate	S.E.	C.R.	P	Label
CONCEPTUAL	<---	EWORLDVIEW	-.522	.622	-.839	.401	
CONCEPTUAL	<---	CAUSAL	-.365	.472	-.773	.439	
CAUSAL2	<---	CAUSAL	1.000				
CAUSAL1	<---	CAUSAL	.446	.464	.961	.337	
CONCEPTUAL1	<---	CONCEPTUAL	1.000				
CONCEPTUAL2	<---	CONCEPTUAL	.469	.865	.543	.587	
EWORLDVIEW2	<---	EWORLDVIEW	1.000				
EWORLDVIEW1	<---	EWORLDVIEW	.598	.217	2.753	.006	

Standardized Regression Weights: (Group number 1 - Default model)

			Estimate
CONCEPTUAL	<---	EWORLDVIEW	-.650
CONCEPTUAL	<---	CAUSAL	-.892
CAUSAL2	<---	CAUSAL	.940
CAUSAL1	<---	CAUSAL	.391
CONCEPTUAL1	<---	CONCEPTUAL	.513
CONCEPTUAL2	<---	CONCEPTUAL	.201
EWORLDVIEW2	<---	EWORLDVIEW	.998
EWORLDVIEW1	<---	EWORLDVIEW	.813

Intercepts: (Group number 1 - Default model)

	Estimate	S.E.	C.R.	P	Label
CAUSAL2	48.333	4.501	10.737	***	
CAUSAL1	35.833	4.821	7.433	***	
EWORLDVIEW2	67.644	2.160	31.322	***	
EWORLDVIEW1	68.178	1.588	42.944	***	
CONCEPTUAL1	30.887	3.375	9.151	***	
CONCEPTUAL2	47.787	4.047	11.808	***	

Covariances: (Group number 1 - Default model)

	Estimate	S.E.	C.R.	P	Label
EWORLDVIEW <--> CAUSAL	-62.817	40.046	-1.569	.117	

Correlations: (Group number 1 - Default model)

	Estimate
EWORLDVIEW <--> CAUSAL	-.492

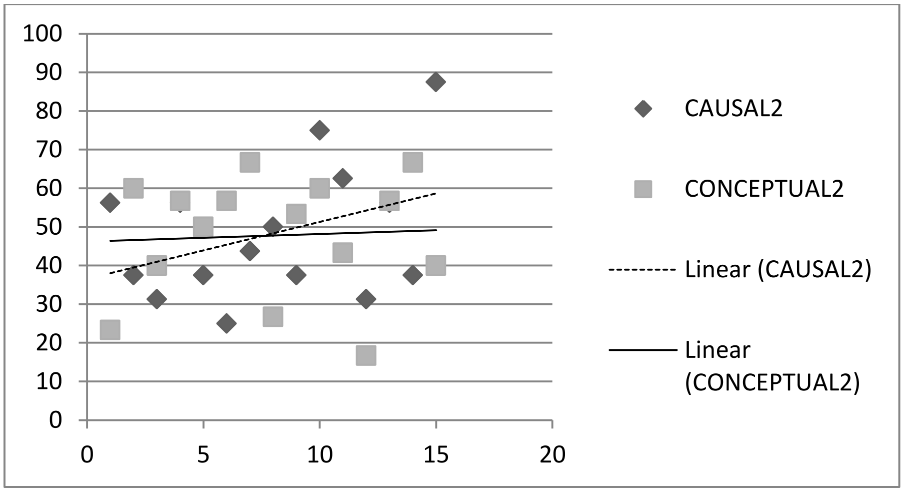
Variances: (Group number 1 - Default model)

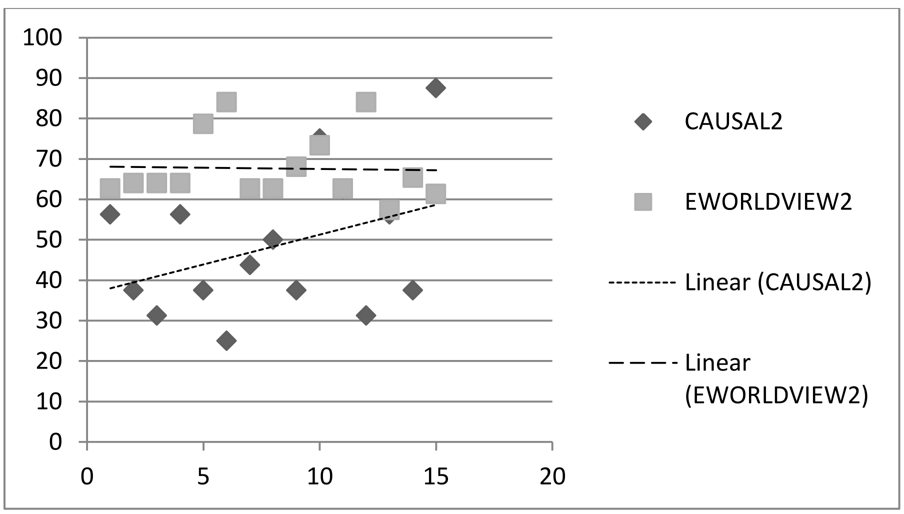
	Estimate	S.E.	C.R.	P	Label
CAUSAL	250.767	239.436	1.047	.295	
EWORLDVIEW	65.079	31.809	2.046	.041	
E7	14.783	108.480	.136	.892	
E2	32.914	214.808	.153	.878	
E1	275.498	112.517	2.449	.014	
E4	.216	20.068	.011	.991	
E3	11.991	8.494	1.412	.158	
E5	117.518	113.989	1.031	.303	
E6	220.050	86.327	2.549	.011	

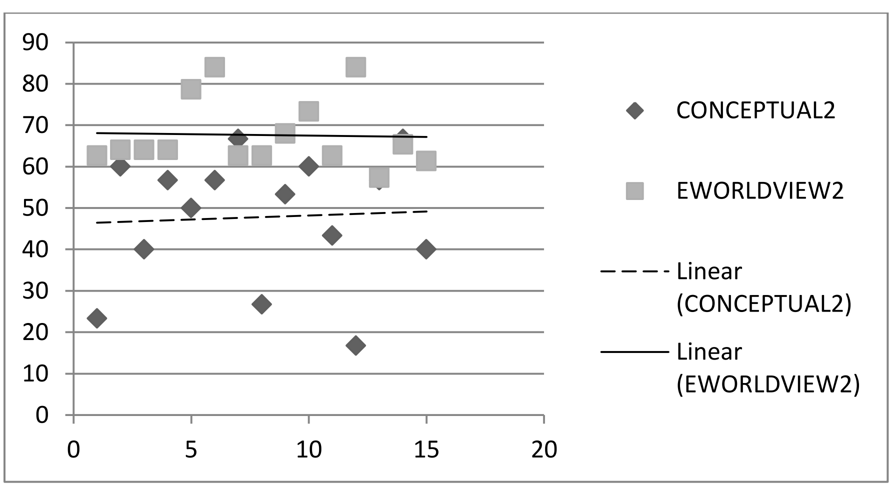
Squared Multiple Correlations: (Group number 1 - Default model)

	Estimate
CONCEPTUAL	.648
CONCEPTUAL2	.040
CONCEPTUAL1	.263
EWORLDVIEW1	.660
EWORLDVIEW2	.997
CAUSAL1	.153
CAUSAL2	.884

(iv) Scatterplots of CAUSAL2, EWORLDVIEW2, and CONCEPTUAL2 datasets.







Appendix E

Qualitative Member Check

Method

Students were approached after their last NCSE exam when they were in a stress-free mode. The researcher targeted the students who showed an increase in scores and asked them if they would like to participate in a feedback session. The researcher gave the students the option of being anonymous with their responses and also the option of not participating. The some few decided to participate and their responses were accepted.

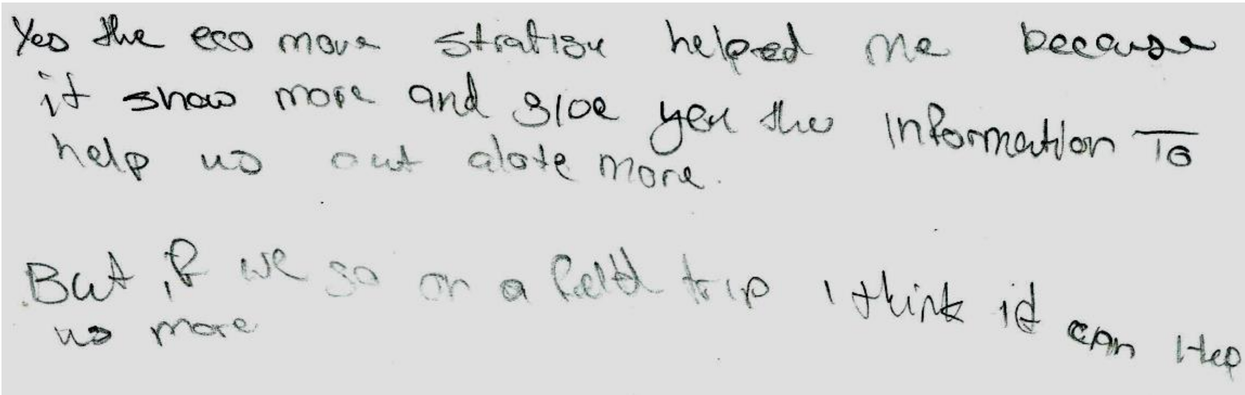
Questions

1. In your honest opinion, was it EcoMUVE that caused you to learn and improve on your scores, or was it something else? Explain.

2. In your honest opinion, do you think you would rather learn ecosystems via EcoMUVE or another teaching strategy? Explain.

Student Responses

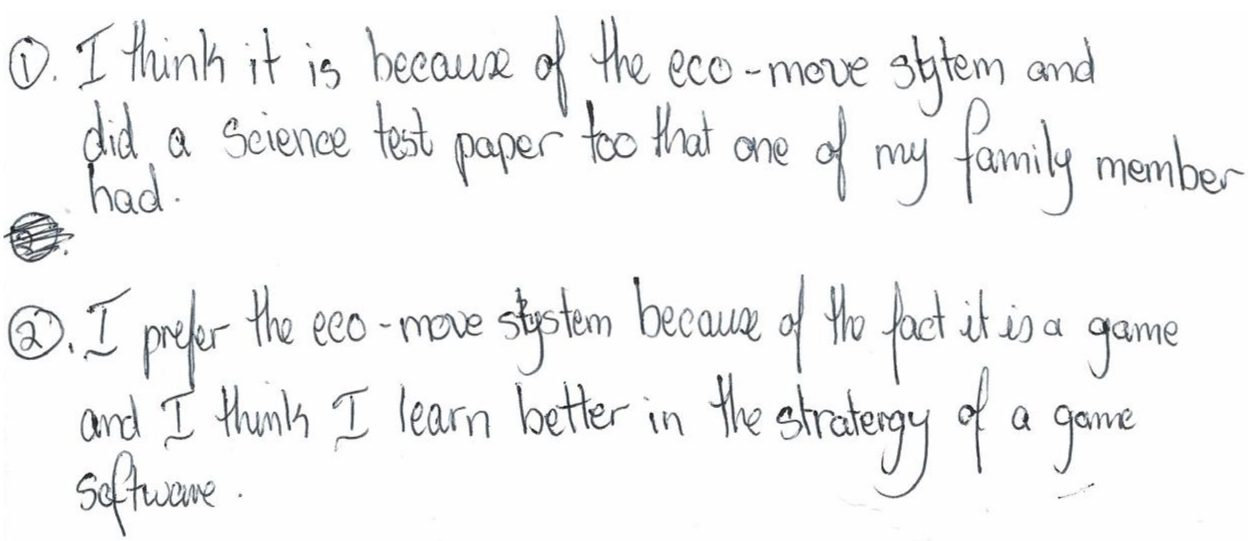
Student 1.


Yes the eco move stratisu helped me because it show more and sloe yeu the information To help us out alote more.

But if we go on a feild trip I think id can Hep us more

Transcribed: **"**Yes the EcoMUVE strategy helped me because it show more and show you the information to help us out a lot more. But if we go on a field trip I think it can help us more"

Student 2.


1. I think it is because of the eco-move stytem and did a science test paper too that one of my family member had.

2. I prefer the eco-move stystem because of the fact it is a game and I think I learn better in the stratergy of a game software.

Transcribed: "1. I think it is because of the EcoMUVE system and did a science test paper too that one of my family member had. 2. I prefer the EcoMUVE system because of the fact it is a game and I think I learn better in the strategy of a game"

Student 3.

Yes I beleive the Eco Muve stystem did contribute to most of my marks but ~~of~~ it was a combination of the both ~~the~~ which caused the increase in marks.

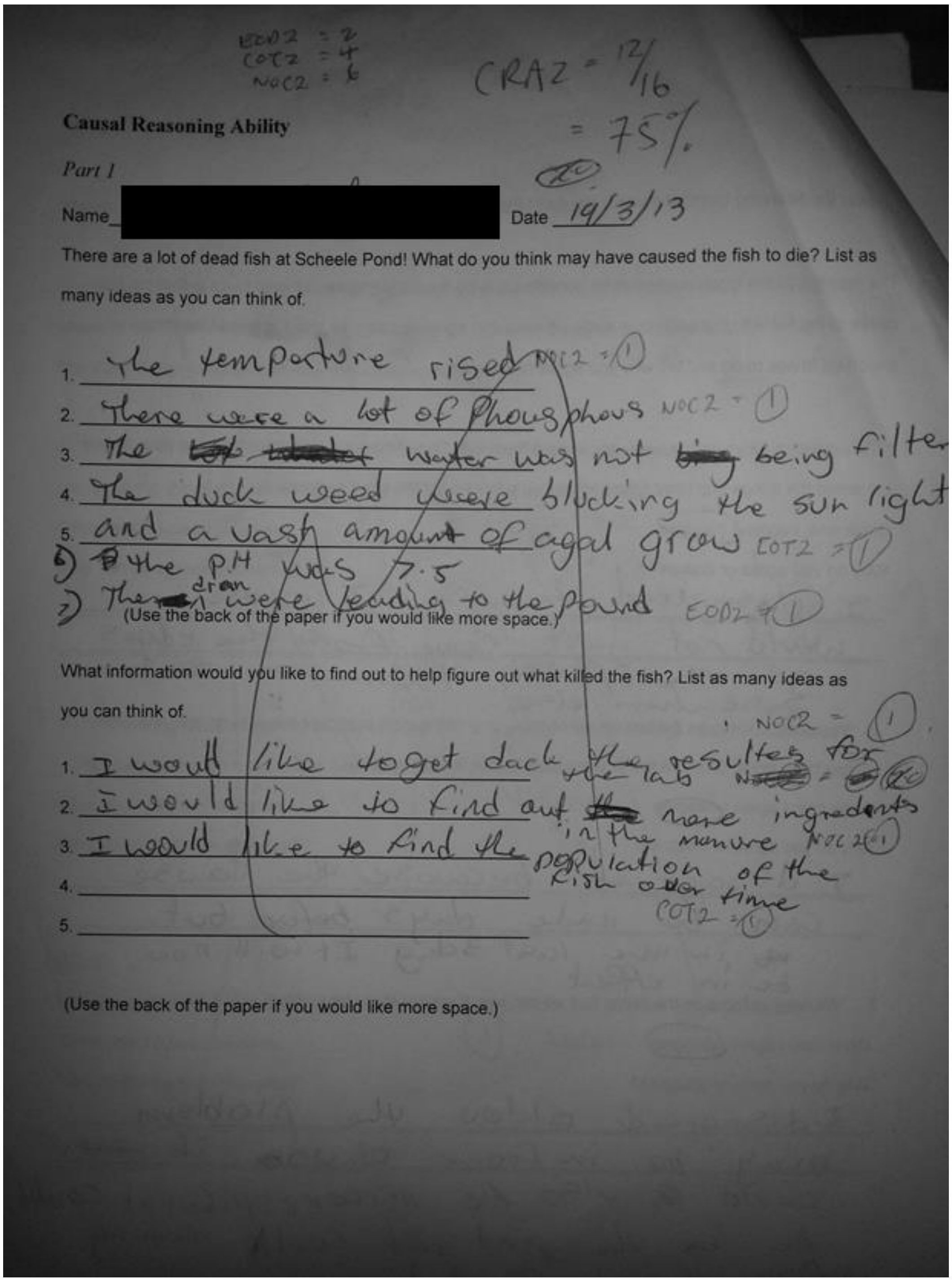
The Eco Mouve system takes away the stress of a feild trip and is more convient.

Transcribed: "Yes, I believe the EcoMUVE system did contribute to most of my marks but it was a combination of the both which caused the increased marks. The EcoMUVE system takes away the stress of a field trip and is more convenient"

Appendix F

Other Artifacts

Causal Reasoning Ability Posttest Sample


EOD2 = 2
COT2 = 4
NOC2 = 6
CRA2 = 12/16 = 75%

Causal Reasoning Ability

Part 1

Name [redacted] Date 19/3/13

There are a lot of dead fish at Scheele Pond! What do you think may have caused the fish to die? List as many ideas as you can think of.

1. the temporture rised NOC2 = 1
2. There were a lot of Phousphous NOC2 = 1
3. The water was not being filter
4. The duck weed were blocking the sun light
5. and a vash amount of agal grow COT2 = 1
6. the pH was 7.5
7. There dran were leading to the pound EOD2 = 1

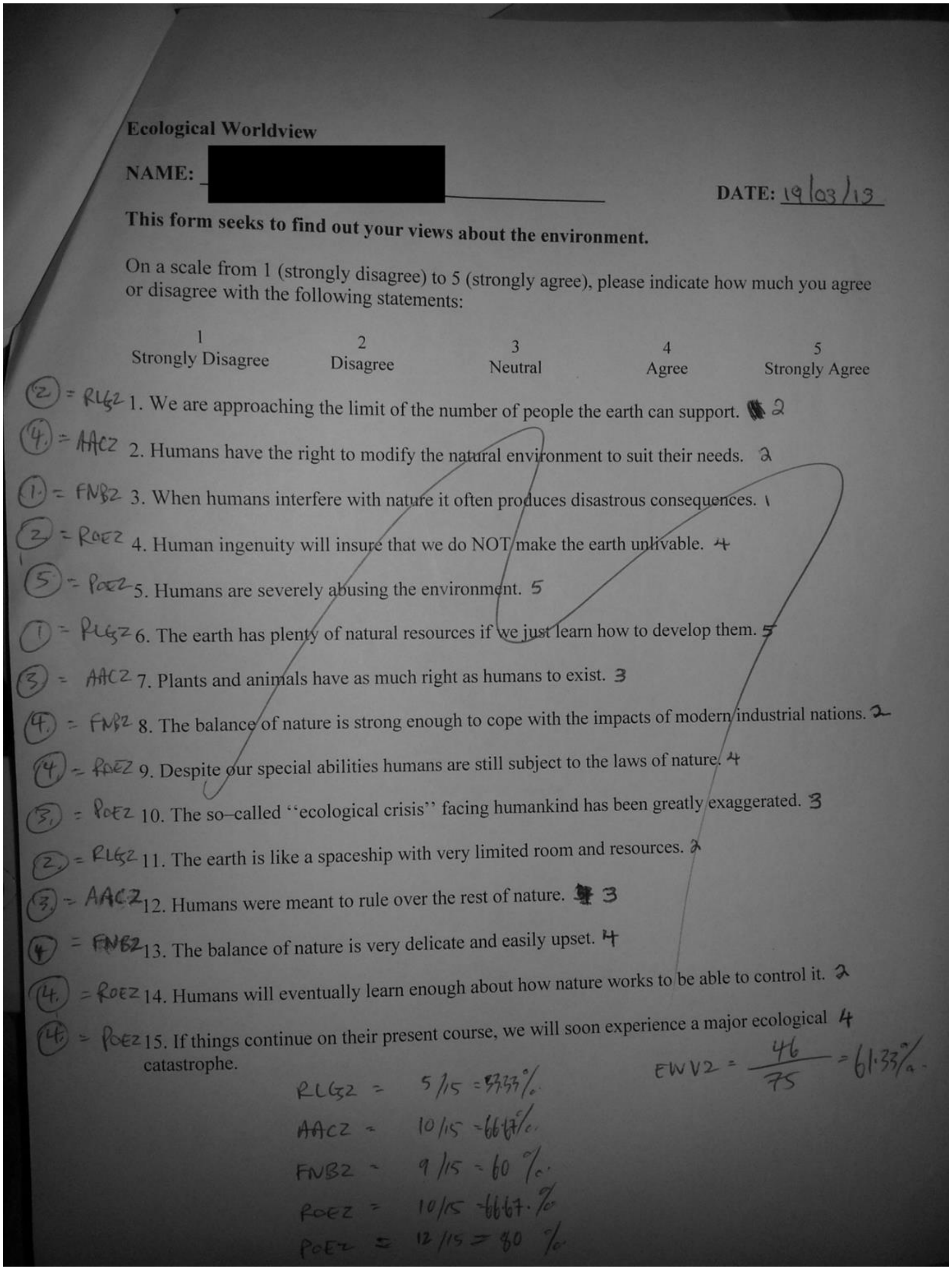
(Use the back of the paper if you would like more space.)

What information would you like to find out to help figure out what killed the fish? List as many ideas as you can think of.

1. I would like to get back the results for the lab NOC2 = 1
2. I would like to find out more ingredents in the manure NOC2 = 1
3. I would like to find the population of the fish over time COT2 = 1
4.
5.

(Use the back of the paper if you would like more space.)

Ecological World View Posttest Sample



Ecological Worldview

NAME: [redacted] **DATE:** 19/03/13

This form seeks to find out your views about the environment.

On a scale from 1 (strongly disagree) to 5 (strongly agree), please indicate how much you agree or disagree with the following statements:

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

(2) = RLGZ 1. We are approaching the limit of the number of people the earth can support. 2

(4) = AACZ 2. Humans have the right to modify the natural environment to suit their needs. 2

(1) = FNBZ 3. When humans interfere with nature it often produces disastrous consequences. 1

(2) = ROEZ 4. Human ingenuity will insure that we do NOT make the earth unlivable. 4

(5) = POEZ 5. Humans are severely abusing the environment. 5

(1) = RLGZ 6. The earth has plenty of natural resources if we just learn how to develop them. 5

(3) = AACZ 7. Plants and animals have as much right as humans to exist. 3

(4) = FNBZ 8. The balance of nature is strong enough to cope with the impacts of modern industrial nations. 2

(4) = ROEZ 9. Despite our special abilities humans are still subject to the laws of nature. 4

(3) = POEZ 10. The so–called ''ecological crisis'' facing humankind has been greatly exaggerated. 3

(2) = RLGZ 11. The earth is like a spaceship with very limited room and resources. 2

(3) = AACZ 12. Humans were meant to rule over the rest of nature. 3

(4) = FNBZ 13. The balance of nature is very delicate and easily upset. 4

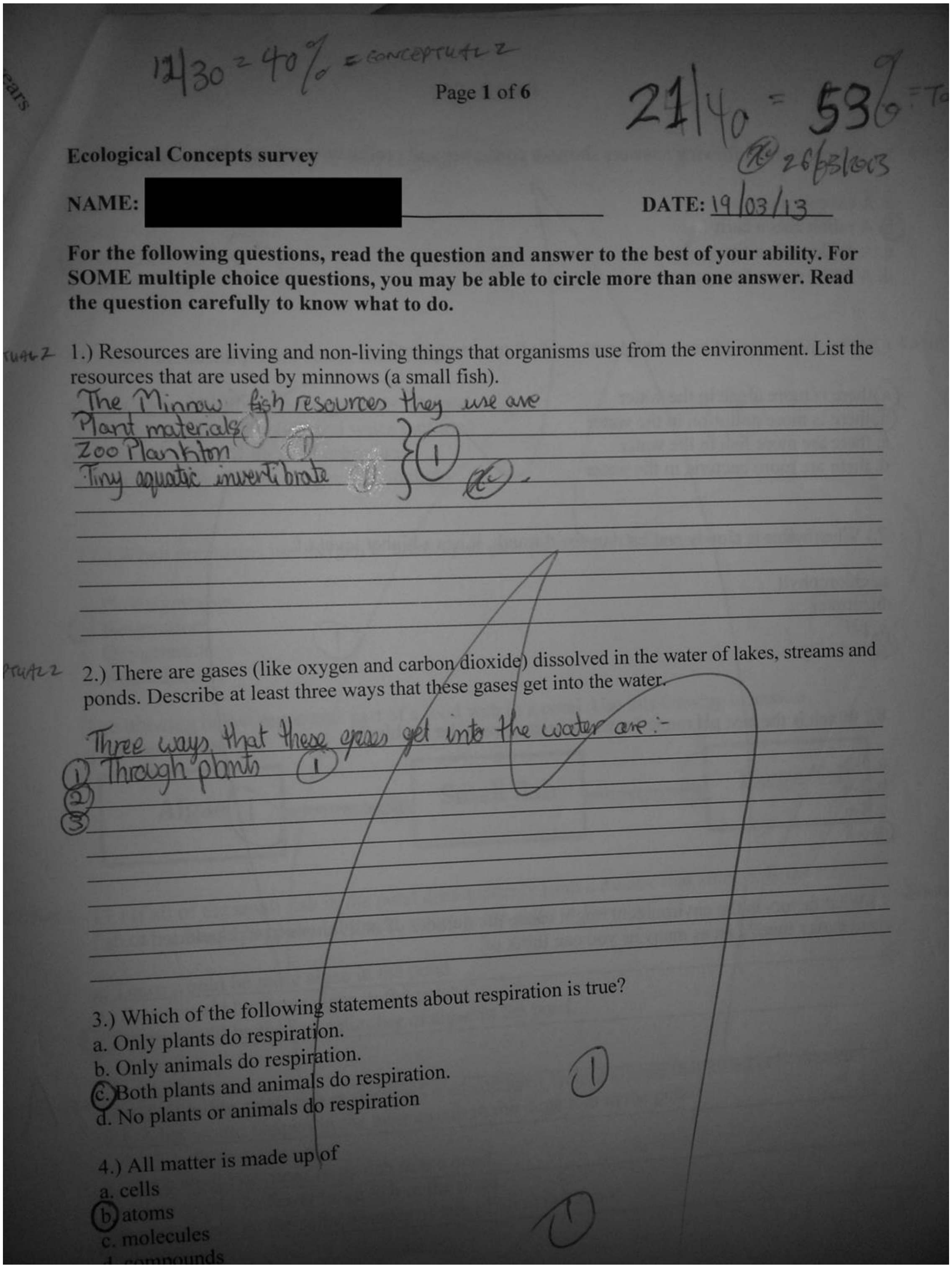
(4) = ROEZ 14. Humans will eventually learn enough about how nature works to be able to control it. 2

(4) = POEZ 15. If things continue on their present course, we will soon experience a major ecological catastrophe. 4

RLGZ = 5/15 = 33.33%
AACZ = 10/15 = 66.67%
FNBZ = 9/15 = 60 %
ROEZ = 10/15 = 66.67 %
POEZ = 12/15 = 80 %

EWV2 = 46/75 = 61.33%

Conceptual Change Posttest Sample



12/30 = 40% = CONCEPTUAL 2

Page 1 of 6

21/40 = 53%

26/03/2013

Ecological Concepts survey

NAME: [redacted] **DATE:** 19/03/13

For the following questions, read the question and answer to the best of your ability. For SOME multiple choice questions, you may be able to circle more than one answer. Read the question carefully to know what to do.

1.) Resources are living and non-living things that organisms use from the environment. List the resources that are used by minnows (a small fish).

The Minnow fish resources they use are
Plant materials
Zoo Plankton
Tiny aquatic invertibrate

2.) There are gases (like oxygen and carbon dioxide) dissolved in the water of lakes, streams and ponds. Describe at least three ways that these gases get into the water.

Three ways that these gases get into the water are:-
1) Through plants
2)
3)

3.) Which of the following statements about respiration is true?
a. Only plants do respiration.
b. Only animals do respiration.
c. Both plants and animals do respiration.
d. No plants or animals do respiration

4.) All matter is made up of
a. cells
b. atoms
c. molecules
d. compounds