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Integrated Techniques to Increase Systems Thinking for Sustainability Education of High School Science Students Using Educational Design Research

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INTEGRATED TECHNIQUES TO INCREASE SYSTEMS THINKING FOR SUSTAINABILITY EDUCATION OF HIGH SCHOOL SCIENCE STUDENTS USING EDUCATIONAL DESIGN RESEARCH

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DEDICATION

To all of the little children I have worked with in preschools and elementary schools, including my own precious children and grandchildren; you have kept me seeing the natural world with awe and excitement. To all of the students I have taught in high school and college whom I have tried to share my love of science and nature; you have inspired me to be a lifelong learner. To all of the teachers I have worked with in training and professional development; you have challenged me to be a better teacher.

This is also in memoriam to my father Dr. George Edward Wire, Jr. who embodied what it means to be a Renaissance man. His life as a brave Marine in WWII, his pursuit of higher education as a physician, his courage as a Navy doctor in Viet Nam and his personal faith when terminally ill gave me a role model for my life. Finally in loving memory of my late brother, best friend and hero George Walter Wire, whose sense of humor and support kept me motivated.

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Last but not least I want to thank my family: my husband Paul who has never failed to give me encouragement, tell me he is proud of me and help keep me going. Thanks to my children Hillary and Tyler and their families for supporting me in this late in life venture. I found my greatest inspiration playing with my sweet grandchildren: August, Fritzy, Thomas, Carter, and Leah. Knowing that one day I could tell them about my journey and encourage them to value their own education made this all worthwhile.

ABSTRACT

This study used a design research framework to teach secondary high school science students about environmental sustainability. A high school teacher and researcher collaborated to design a two week environmental science unit to help students make sense of complex environmental sustainability issues. This dissertation study sought to answer the following research questions: Using Design Research and various instructional tools, how do students develop an understanding of systems thinking and relate it to environmental sustainability; How does analyzing personal and classroom data on paper or plastic usage and recycling influence high school science students' understanding of global environmental sustainability issues through the lens of systems thinking; and How do students come to understand the impact of the effects of individual behaviors on broader issues of environmental sustainability? Supported by a constructivist learning theory, various instructional strategies and learning activities were presented to the students to help them build on their knowledge of sustainability and to reinforce their understanding of environmental systems. The instructional activities were grouped into several learning schemes including: foundational knowledge about systems thinking and environmental systems such as biogeochemical cycles, metacognition and use of graphic organizers, graphing and modeling skills for data collection and predicting, inquiry/experimental design, and real world connectedness: making environmental sustainability personal and something students care about. This study helped to fill a gap in the literature by designing and testing a series of teaching strategies that emphasized

student learner responses related to systems thinking and environmental systems while involving students in activities that stimulated problem solving of environmental sustainability issues and increased self-awareness.

Students were surveyed throughout the study to assess their understanding of systems thinking, and sustainability as well as to determine their level of engagement, and which of the activities were most beneficial. An effort to affect a change in student attitudes and personal behaviors as they relate to sustainability was also attempted through the learning experiences, especially students' independent inquiry investigation of paper or plastic use and opportunities to reflect on their own perspectives. Students presented their findings to their classmates, participated in class discussion and two small focus groups. A critical component of this educational design research project was daily checklists and feedback from the classroom teacher to reflect on how student activities met the learning objectives and research questions. During the project the classroom teacher and researcher developed a design research curriculum that could be modified or amplified for future iterations. Student work samples and responses to surveys and focus group interviews suggested the students increased their understanding of systems thinking as it relates to environmental systems by examining a complex sustainability issue (paper or plastic manufacture and use), they have improved graphing and experimental inquiry techniques, and also generated greater concerns about their values and behaviors regarding sustainability. The results of the project suggest that a series of classroom activities can be designed to both develop greater systems thinking, particularly related to environmental systems while also engaging students in meaningful and enjoyable learning.

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LIST OF ABBREVIATIONS

CSSE .... Complex Systems in Science Education

EDR .... Educational Design Research

EfS .... Education for Sustainability

ESD .... Education for Sustainable Development

IB .... International Baccalaureate

NOS .... Nature of Science

RRR .... Reduce, Reuse, Recycle

SD .... Sustainable Development

SLE .... Sustainable Learning and Education

STHM .... Systems Thinking Hierarchical Model

CHAPTER 1

INTRODUCTION

As a result of increased technological and economic development, combined with exponential world population growth, the earth is increasingly facing both environmental and social issues. An overarching question of how to achieve appropriate sustainable development has emerged as one of the most critical questions that humanity needs to answer. Because the topic of sustainability is so broad and complex, identifying and recognizing the scope for integrating the concepts, issues and values of Education for Sustainable Development (ESD) in the curriculum is challenging for teachers (Rao, 2014). The importance of teaching students about sustainability has been widely recommended but methods for integrating this subject in science classes are not well delineated. One way to teach about sustainability is to introduce students to “Systems Thinking” or “Linking Thinking” (sometimes referred to as “Holistic Thinking”) which enables them to connect individual science topics into a larger scheme. Additionally there are limited resources describing how to make systems thinking an analytical process part of classes, and there are few concrete teaching approaches that are given to assist classroom teachers who want to attempt to use systems thinking concepts. In this project it was proposed that students could be encouraged to develop systems thinking techniques which would lead to positive impacts on sustainable development through experimental design, data analysis, graphing and other teaching strategies.

Science education focused on sustainability can help today's students make an impact on present and future generations by helping make decisions that will positively impact available resources. Education for Sustainable Development (ESD) as a concept was first pointed out by the United Nations Conference on Environment and Development (1992) Agenda 21 in with four aims: (1) improve basic education, (2) reorient existing education to address sustainable development, (3) develop public understanding, awareness, and (4) training. Education for Sustainable Development (ESD) has several lofty goals. One is to help students improve thinking skills, values and perceptions to maintain sustainable activities in their lives, helping them understand why they should engage in activities that promote sustainability. Another objective is to help them develop ethical and personal values that promote these actions. Finally, there is focus on educational reform to create educational programs which address sustainability issues.

While the importance of education in helping achieve sustainable development has been emphasized, not much progress has occurred in affecting change in the teaching of science or science education curriculum and teacher professional development in this area. In most cases, changes are minor adjustments to existing curricula, texts, and teacher training but there are not larger reforms such as whole school or interdisciplinary learning (Pigozzi, 2010). The ESD paradigm requires that teachers and students have the ability to make associations with components of a system, because sustainability issues are linked and one must understand how the parts fit into the whole. To that end, system thinking has been recommended as an approach to help students conceptualize dimensions that are environmental, social and economic (UNESCO, 2012). System thinking has also been underscored by the *Framework for K-12 Science Education* which promotes this kind of thinking skill for many different age groups and is emphasized in the Cross Cutting Concepts as concept 4: "Systems and System Models" (National Research Council, 2012). Teaching sustainability is difficult because it requires explaining and experiencing complex phenomena, including complicated interactions with humans and nature.

Teachers need concrete suggestions to accomplish ESD and system thinking methods, but there is little being done to connect these two areas. I proposed integrating several instructional methods to help teachers develop ESD and systems thinking simultaneously. As a teacher I consider myself a pragmatist and constructivist and I have developed many teaching strategies in the field of environmental science, including guided inquiry and open inquiry components. In development of this study, I wanted to also combine an investigation or experimental design (inquiry) in which students conducted "hands on" collection and manipulation of data, and then extrapolated and analyzed their data to recognize larger environmental trends. Nature of Science (NOS) is an aspect of the experimental design component since it refers to characteristics of scientific knowledge derived from the way characteristics of knowledge is constructed through scientific inquiry and science practices. A goal of helping students understand NOS is to gear instruction by planning, and assesing and encouraging reflection of classroom activities and what scientists do (Lederman & Lederman, 2012). The authors suggest we do not "do" nature of science, and it is constantly changing as theories are modified and we learn more about the natural world, also describing the conflation of Nature of Science "NOS" and Scientific Inquiry in recent years. Other teaching strategies included direct whole class instruction about systems thinking and environmental systems specifically, brainstorming, using graphic organizers, subject-specific research, design of a possible future student project implementing "Reduce-Reuse-Recycle," reflection and writing in addition to data analysis, and graphing of their experimental design results.

I became interested in conducting educational design research several years ago after completing a collaborative graduate course for doctoral students through University of North Carolina-Charlotte, University of South Carolina and Middle East Technical University in Ankara, Turkey. "Educational design research is a genre of research in which the iterative development of solutions to practical and complex educational problems provides the setting for scientific inquiry" (McKenney & Reeves, 2013, p. 131). Educational design research uses scientific knowledge and other knowledge such as teaching "craft" understanding to position design work and even produce scientific knowledge while striving to develop both interventions in practice and reusable knowledge. Because scientific advances are achieved ultimately by the standards of a scientific community over time, the goal of design research cannot be to develop a single ideal curriculum (Clements, 2007).

My interests in environmental science, thinking/learning processes, and design research are blended in this project. This design research project involved the following four distinct topics synthesized into one overarching construct: sustainable development, systems or linking thinking, inquiry, and integration of teaching strategies. Since students designed their own paper or plastic collecting methods and data analysis, this incorporated experimental design, inquiry and Nature of Science which are the major foundations of revised science curriculum as detailed in *A Framework for K-12 Science Education* (National Research Council, 2012). This study employed the *System Thinking Hierarchical Model (STHM)* (Assaraf & Orion, 2005), a cognitive model with eight hierarchical stages of system thinking skills development. The goal was to enable students to make broader connections into global sustainability issues by examination of their own, and classmates' data.

BACKGROUND OF THE PROBLEM

In general, constructivist learning theory is student-centered and experiential are considered to be effective in teaching science. Active learning, creative discussion and critical reflection, interdisciplinary and multidisciplinary approaches, use of computer technology, problem-based learning (PBL) or problem solving, and collaborative project work are often suggested as best practices for teaching science disciplines (Loucks-Horsley, 1998). Science teachers have difficulty helping students make sense of science activities, which enable them to understand the natural world and connect with everyday experiences. Windshitl et al. suggest teachers are overly concerned with the format of instruction and students merely participate in activity without understanding (2007). It is unclear whether this problem is related to the design of the activity, how the teacher instructs and discusses the topic, or if it is an issue of student engagement. Senen (2013) notes that even if a teacher provides an environment where students can participate in critical scientific questioning and reasoning, students often lack the requisite background knowledge to do so effectively. We need to move beyond problem solving to help students link their knowledge through metacognition to address whether teaching strategies are working.

Weiss et al. (2003) found that appropriate opportunities for students to make sense of the science ideas being taught were rarely coupled with hands-on, practical, and experiential studies. Classroom learning continues to be undemanding, routine and disconnected from the development of deeper understanding (Banilower, et al., 2012). In a study of 500 classroom videos from five countries, Roth and Garnier (2007) noted that teachers in the United States did not incorporate "various activities to support the development of content ideas in ways that were coherent and challenging for students" (p. 20), which results in activity without understanding. However, Loucks-Horsely, et al. concluded "When students have accumulated a rich array of images, however, they are able to see the concept in the events associated with the specific phenomena; the phenomena become the metaphor for the concept" (1998, p. 35).

My personal teaching philosophy about Science Education is that it should incorporate curriculum that combines student inquiry and research, and secondly helps students develop greater understanding about sustainable development, and their role as stewards of the environment both in a local and global context. I considered several current topics that could be used as the "umbrella" focus for my project including energy sources and use, global climate change, and global agricultural methods. After considering the possible topics, I decided to concentrate the systems approach on paper and plastic manufacture and usage. I previously conducted a pilot classroom study using topic of paper manufacture and use and found it was a topic the students could understand and find personally valuable (unpublished by author, October, 2017). The topics are also aligned with content standards for Earth Systems as well as Ecosystems: Interactions, Energy, and Dynamics which are found from second grade through High School in *Next Generation Science Standards* (NGSS Lead States, 2013). A basic scheme of this design research project involved having students plan a method of collecting and identifying their family's paper or plastic consumption, while researching the production and use of these products while viewing these studies in the lens of systems thinking and environmental sustainability. Student research and other instructional activities on these topics were then related back to different biogeochemical cycles and earth systems which stem from prior student learning.

While developing the instructional plan for this design research I considered discrete approaches so that students were encouraged to: 1-develop system thinking by considering the effect of paper consumption in a holistic manner; 2-use knowledge and skills from different disciplines; and 3- be active learners by thinking critically about their data collected. Activities and sequences followed guidelines suggested in *Handbook on methods used in environmental education and education for sustainable development* (Scoullos & Malotidi, 2004). By introducing a systems thinking study using a real-world context of their use of paper or plastic and recycling I hoped to capture students' interests. Integrating inquiry into activities and using graphs to teach systems thinking is a reasonable method to assimilate data collection, analysis and interpretation on a broader scale. Relevant Internet data sets for teaching bar graphs and line graphs of environmental concepts within earth systems in a classroom setting provided ample opportunities for peer evaluation, practice and reflection by students and their classmates. My hope is that by combining research, inquiry/experimental design, graphing and data analysis united with an introduction to systems thinking I may provide a good model for teaching sustainability education.

PROBLEM STATEMENT

Education for Sustainable Development (ESD) has been recognized as an important part of global science education (UNESCO, 2012), however determining the scope of combining concepts, issues and values of ESD in science curriculum can be difficult for teachers. Few concrete, methods are available for classroom teachers to help them improve and scaffold their teaching of sustainable education and help students understand local and global impacts on environmental practices. System thinking has been emphasized as a means to promote thinking skills for many different age groups in the *Framework for K-12 Science Education* (National Research Council, 2012). Teaching through inquiry is also widely recognized as a method to improve cognition and higher-level thinking, as well as improving student engagement and ownership of learning. This study was designed to provide teachers with identifiable methods to encourage students to develop systems thinking techniques which can lead to positive impacts on sustainable development. Through the development of the curriculum in this study that involves students in data analysis and graphing schemes, while also incorporating science inquiry and Nature of Science, active research and technology components, teachers will be provided with useful tools and assessments to successfully integrate ESD into their programs and courses.

PURPOSE OF THE STUDY

The purpose of this mixed methods design research study was to investigate how to best integrate techniques for teaching sustainability education in secondary science classes. Educational Design Research (EDR) is a process that takes original ideas with a basis in theory. The design should also try to answer a research question that is going to have applications for instructional methods as well as contributing to the greater understanding about learning processes. The National Science Foundation (NSF) supports educational design research or design-based research approach, referring to it as Design and Development Research (Research Type #3), describing its goal related to developing educational solutions as improving student engagement or mastery of skills. They note these types of projects draw on existing theory and evidence to design and iteratively develop interventions or strategies. This study sought to develop a design research project that will included a two week unit that engaged students in collecting data on their own paper or plastic usage and recycling. This provided data collection through which students engaged in systems thinking, or linking thinking on a broader scale. The intent was to use graphing of individual and class data, and other teaching strategies as tools to assist high school science students make connections between their own paper or plastic consumption and the greater role of this local issue on global environmental issues such as deforestation, soil degradation, water usage, climate change and other concepts such as the hydrologic and atmospheric cycles.

This study used both qualitative and quantitative methods because student and teacher observations, interviews, and surveys will be combined with actual student work related to the assessed learning goals. Qualitative data included observations of students interacting in the classroom both with each other and their instructor and explored the perceptions of sustainability education and potential growth in understanding of the links of their own paper or plastic usage to global environmental consequences. Other qualitative data included student surveys both pre- and post- study about their understanding of systems thinking and efficacy of specific learning strategies they encountered. Daily teacher de-briefing and informal discussions, along with her daily observation checklists, as well as pre- and post- study interviews with the students were also qualitative in nature.

Because the classroom teacher was an integral researcher in this project, she helped develop and refine the iteration of implementation before, during and after the project. Small focus groups also completed the qualitative aspect of the research. Quantitative data was obtained from reviewing student work such as graphic organizers, experimental designs, graphs, summary questions, Reduce-Reuse-Recycle project, and writing assignments. Other quantitative evaluations included responses to short student Mentimeter questions and online survey monkeys throughout the project.

INTELLECTUAL GOALS

The intellectual or scholarly goal of this study was to learn whether high school science students can make connections to global environmental cycles, systems and issues by research and design of an inquiry project on paper or plastic consumption and use, collecting their own data, construction and analysis of graphs of that data and then analyzing this through the lens of a systems approach to sustainability. I wanted to also understand how students integrate their knowledge of a set of quantitative data (paper usage/recycling) into a broader realm of understanding of the environment in a reflective and more qualitative analysis of their data by examining social and economic aspects. So in addition to the science concepts that they learned, students also reflected on their own consumption practices and behaviors. Additionally, students and the teacher-researcher evaluated various teaching strategies through the course of the design research project and assessed the efficacy of those tactics on student ESD learning. The expected outcome was to demonstrate improved learning of science subject matter on environmental sustainability, but also improved competence with experimental design/inquiry and graphing skills. Also, it was anticipated the project contributed to the understanding and teaching of sustainability education through its application pertaining to personal, social and global contexts.

RESEARCH QUESTIONS

This study investigated the following research questions:

1. Using Design Research and various instructional tools, how do students develop an understanding of systems thinking and relate it to environmental sustainability?
2. How does analyzing personal and classroom data on paper or plastic usage and recycling influence high school science students' understanding of global environmental sustainability issues through the lens of systems thinking?
3. How do students come to understand the impact of the effects of individual behaviors on broader issues of environmental sustainability?

SIGNIFICANCE OF THE STUDY

The proposed design research involves the following three distinct topics that I wanted to synthesize into one overarching construct: sustainable development, systems or linking thinking and the use of various teaching strategies. This project was grounded in constructivist theory, and also reflected the theory of conceptual change. Both of these consider Piaget's notions of assimilation where students use existing concepts to deal with new phenomena, and accommodation in which students must replace or reorganize their central concepts (Piaget & Inhelder, 2000). To build on these ideas and develop more scientific literacy there should be less focus on memorization and more on conceptual understanding of content. Students should apply concepts to new situations and still explain the science. I wanted them to generate and evaluate evidence to build explanations of the natural world and also reflect on their own knowledge. It was expected that using a stepwise approach to systems thinking along with concrete, quantitative data students will be able to make sustainable environmental associations. Many topics that can be considered in the scope of sustainability like climate change, consumption and production patterns, energy, fresh water availability and usage are already included in science curricula, but they are usually treated only as specific subject matter to be taught without contributing to the larger concept of ESD. As previously mentioned, there are few practical teaching tools for classroom teachers to assist students in developing a systems approach to their own learning. This study permitted students to enhance sustainability education as a consequence of using design research techniques combined with system thinking and sequenced teaching strategies.

While there are several different system thinking theories, the *System Thinking Hierarchical Model (STHM)* by Assaraf & Orion (2005) describes a stepwise approach to systems thinking that supports this study. STHM includes eight characteristics as follow: identifying the components and processes of a system; identifying simple relationships among a system's components; identifying dynamic relationships within a system; organizing the system's components, their processes, and their interactions, within a framework of relationships; identifying matter and energy cycles within a system; recognizing the hidden dimensions of a system; making generalizations about a system; and thinking temporally (employing retrospection and prediction). This model was originally developed as a result of teaching earth science to elementary students in the context of hydrologic cycle, but the sequence is also applicable to this design research. Scherer, Holden, & Hebert (2017) hypothesized that there are multiple ways in which systems thinking in the context of Earth systems is discussed in the geoscience education research literature, and that these studies are inherently influenced by the conceptual framework within which the researcher or educator is operating. This research falls into "Authentic complex Earth and environmental systems" conceptual framework because it deals with real-world systems, has ties to environmental science community and supports environmental decision making (p. 482).

DEFINITION OF TERMS

Educational design research (EDR) or Design research: The term “Design Research” was coined relatively recently and is most closely associated with Ann Brown (1992). Educational Design Research focuses on the development of theoretical insights while planning for an experiment within a classroom or laboratory setting. The purpose when experimenting in the classroom is not to try to demonstrate that the initial design formulated in advance of the experiment works but rather it is to test and improve the initial design as guided by both ongoing and retrospective analyses of classroom activities and events (Cobb, 2003). Thus, design research becomes iterative in nature.

Education for sustainable Development (ESD): ESD encompasses environmental education but sets it in the broader context of socio-cultural and the socio-political issues of equity, poverty, democracy and quality of life.

Sustainability: This refers to the ability of the earth’s different systems, including human cultures and economies to survive and adapt to changing environmental conditions over an indefinite period.

Systems Thinking/Linking Thinking: This term represents thinking as a whole through identifying and analyzing the relationship between the parts of a system. With respect to this study, the term applies to environmental systems such as hydrologic, biogeochemical, atmospheric, ecological and others.

ASSUMPTIONS, LIMITATIONS, AND DELIMITATIONS

Assumptions

There are several assumptions associated with this design research related to both the students who participated as well as the teacher who was my collaborator. In general, I assumed that the students would be fully engaged in the classroom activities, any work completed at home, and that they would also answer all pre- and post-surveys and questions honestly and completely. I assumed the teacher will was completely "on board" with the project and would give input for every activity. I expected her to lead the classroom teaching. It was also assumed the classroom teacher had a strong background in teaching sustainable education concepts, the science and math required for the activities and had an understanding of systems thinking.

One importance of qualitative inquiry is the search for meaning where a major interest is in how different people make sense of their lives. With a study such as this, where individual students will be attempting to interpret their findings to a broader understanding of environmental sustainability, there may be differing interpretations of the impacts because of students' backgrounds. I have a broad knowledge of different cultures and socioeconomic groups because I grew up in Asia and have travelled extensively. I bring situated or experiential knowledge to this area of science education that I assumed would help me interpret the findings of this study. My own education and teaching in environmental science aided me in designing appropriate aspects of the classroom activities for instructing students through various teaching methods to incorporate system thinking and sustainable environmental education. My understanding of design research iterations helped impact the methods used to observe and record the classrooms and teacher efficacy.

Limitations

There may have been limitations in the interpretation of student learning. The cooperating teacher assisted in evaluating student work and whether students had mastered skills such as graphing techniques, and whether they had adequately conducted their independent inquiry projects on paper or plastic consumption. The teacher also helped assess whether students had made significant improvement in understanding of environmental systems and sustainability by helping to create rubrics for scoring their inquiry investigations, their Reduce-Reuse-Recycle implementation projects as well as their reflection essays. The teacher also gave her own daily written reflections about how the daily activities went and made comments about four learning goals. The teacher appeared to make honest appraisals and genuine comments. Every attempt was made to make the evaluations of student work objective but it is possible she and I both wanted the activities to be useful and the students to be successful. Additionally, students were expected to give their honest answers in surveys, lab report summaries, and reflection essays but there may have been subjectivity by the students who may have written what they thought was expected of them.

Delimitations

For this study a class of high school seniors in International Baccalaureate Higher Level Biology was selected as the participant group. These students had already studied about biogeochemical cycles and had a general knowledge about ecology and interconnectedness of environmental systems in an earlier unit. I worked with a similar group of 11^{th} and 12^{th} grade International Baccalaureate Environmental Systems and Society students in a pilot study in 2017 which helped determine the preferred level of students to work with in this project. Despite the apparent homogeneous grouping of the study group, there is tremendous variation in socioeconomic strata within this small geographic area of South Carolina where the research was conducted. There are children of wealth and privilege who drive expensive European cars but many other students live in poverty, and some are even homeless. This school district has the highest percentage of Hispanic and non-English speaking students in the state, and there is also a population of other immigrants from Eastern Europe and Asia, as well as approximately 15-20% African American which represents substantial ethnic diversity. This group of non-native speakers of Hispanic origin was widely represented in the class. While I was interested in making the study as broad as possible relative to different ages, ethnicities, socioeconomic backgrounds as well as educational levels, I worked closely with the classroom teacher of one grade level to judge the efficacy of the teaching strategies on the particular group. Any further reiterations of the research may involve subsets of students to begin to investigate alternative demographic parameters which might impact student learning.

In order to monitor the impact of my subjectivity and positionality during the research I employed multiple data collection strategies. I developed the classroom activities and teacher roles with the collaborating teachers before the study begins so that she became a teacher-researcher and had a strong contribution which resulted in greater "buy in" as well as trustworthiness. I acted as an observer participant in which I had limited interaction with the students. In terms of my positionality in this project, I believe I was perceived as an older veteran teacher when in the classrooms to conduct the study. Since I am a Caucasian woman, and most teachers in this area fall into the same category I was racially similar to the teacher I worked with

I took field notes, and transcribed videotapes of actual class observations and will also had daily reflection interviews and planning sessions with the classroom teacher.

The cooperating teacher also completed daily observation checklists to note the efficacy of activities related to learning goals. I solicited the input of another veteran teacher to help make evaluations of the student interactions related to their graph interpretations, systems thinking and engagement in the activities and to also review coding of the notes, focus groups and class videos. I worked diligently to address my appearance, behavior, discretion, sensitivity, patience, friendliness, and attentiveness to help ensure I was viewed by both the teacher and students as more of an "insider." Research and review of literature helped me employ strategies to consider experiences from the students' perspectives. My role as researcher was to do research and be rigorous about my data collection while keeping my subjectivity at a minimum. This was done through reflective thinking, journaling and memos to self while note-taking, discussions with colleagues, and input from the cooperating teacher.

While there are a number of possible topics for use in teaching sustainability and systems thinking, the topic of paper or plastic production, use and consumption was selected for the independent inquiry project because it is something relevant to students, with ample research available as to the manufacture and distribution of various products and environmental impacts. The initial research and brainstorming by students allowed them to select either paper or plastics. This generated student discussion, interest and helped to inform their views on sustainability. In the pilot study the students all studied paper usage.

This design research investigation occurred over a two week period, as the final unit of the school year for students. In the previous iteration or pilot study of this project some of the same instructional strategies were implemented with the same teacher over a four-day period. The original test group was eleventh and twelfth grade International

Baccalaureate Environmental Systems, and each class period was ninety minutes. In this study there was ample time to conduct pre- and post-surveys, conduct whole class instruction, collect data and graph, as well as review and practice with actual online data using Excel spreadsheets. For this study additional class/laboratory periods were added so the students had more time for class discussions, experimental design, research, writing and completion of more surveys.

CONCLUSION

The purpose of this study was to develop a design research project that implemented a multi-day unit on sustainability for secondary students in which they specifically view paper usage and recycling as the data collection through which students engage in systems thinking, or linking thinking on a broader scale. A goal for science education is it should incorporate curriculum that helps students develop greater understanding about sustainable development, and their role as stewards of the environment both in a local and global context. One method to help them achieve this is to introduce “Systems Thinking” or “Linking Thinking” which enables them to connect individual science topics into a larger scheme. There is little research being done to make this analytical process part of science classes today, and there are few concrete teaching approaches that are given to actually assist classroom teachers who want to attempt to use systems thinking concepts. The intent of this project was to use integrated teaching strategies and inquiry skills where students first brainstormed and researched about worldwide paper production, evaluate, graph and interpret environmental data sets. Students also design an inquiry investigation protocol to collect data on their paper or plastic use and consumption, followed by graphing of individual and class data as a tool to assist students make connections between their own paper consumption and the larger role of this local issue on global environmental issues. Topics such as deforestation, soil degradation, water usage, climate change and other concepts such as the hydrologic and atmospheric cycles will be incorporated as part of the systems thinking process.

This design research involved the following distinct topics to synthesize into one all-encompassing study: sustainable development, systems or linking thinking and the use of integrated, organized teaching strategies. Since students designed their own paper or plastic collecting methods and data analysis, this incorporated experimental design, inquiry and Nature of Science which are the major foundations of revised science curriculum as detailed in *A Framework for K-12 Science Education* (National Research Council, 2012). "Analyzing and interpreting data" from National Research Council notes that "scientific investigations produce data that must be analyzed in order to derive meaning and scientists use a range of tools including tabulation, graphical interpretation, visualization, and statistical analysis to identify the significant features and patterns in the data" (2012, p. 51). The goal was to enable students to make broader connections of their own, and classmates' data into global sustainability issues.

CHAPTER 2

REVIEW OF RESEARCH

RESEARCH FOCUS

As a result of increased technological and economic development combined with exponential world population growth, the Earth is facing environmental and social problems both locally and globally. An overarching question of how to achieve appropriate sustainable development has emerged as one of the most critical questions that humanity needs to answer. If used properly, education and science education more specifically can help us in establishing a better world both for society today and for future generations. There are limited resources about how to make this analytical process part of science classes, and there are few concrete teaching approaches that are given to assist classroom teachers who want to attempt to use systems thinking concepts. The focus of this research review will be to: first, examine the worldwide importance of teaching sustainability; second, to link using systems thinking as a process for teaching sustainability; third, to review suggested teaching strategies to be employed; and fourth, to contextualize the notion of implementing a novel Design Research project to evaluate the efficacy of the proposed system thinking and teaching strategies.

A main objective for Education for Sustainable Development (ESD) is to help students acquire skills, beliefs and perceptions to maintain sustainable activities in their lives. I wanted students to understand why they should engage in activities that promote

Sustainability, and hoped they would gain ethical and personal values that promote these actions. There is also a focus on educational reform creating educational programs to address sustainability issues. While the importance of education in helping achieve sustainable development has been emphasized, not much progress in affecting change in science education has been seen. In most cases, changes are minor adjustments to existing curricula, texts, and teacher training but there are not larger reforms such as whole school or inter-disciplinary learning focused on sustainable development in science (Pigozzi, 2010). *Education for Sustainable Development Lens: A Policy and Practice Review Tool* (2010) notes that ESD encourages the use of teaching methods that strengthen transformative learning such as action competence approaches. These involve students in exploring knowledge of the nature and scope of problems, how they arose, who and what is affected by the problems and what are alternative solutions. These methods should also consider beliefs that are needed to help students develop different futures and make predictions while also developing social, critical and creative thinking skills. Additionally these approaches should involve students in experiences of real-life situations where they develop decision-making skills. This publication gives rubrics to assist teachers, schools, districts and other entities in determining the value of an instructional method, but does not provide anything specific for teachers to use.

UNESCO has launched the series "ESD Learning & Training Tools" to increase the availability of teaching, training, learning and resource materials on Education for Sustainable Development (ESD) issues (*Exploring Sustainable Development: A Multiple-Perspective Approach*, 2012). Many of these suggested resources refer to using videos, newscasts, local museums and arboretums or other available destinations for students, or they describe strategies such as Problems Based Learning (PBL) but overall it does not include specific instructional activities.

CONCEPTUAL OR THEORETICAL FRAMEWORK

The basis of this research lies in a constructivist theoretical perspective. I suggested that students can be encouraged to develop systems thinking techniques which will lead to positive impacts on sustainable development through experimental design (inquiry), data analysis and graphing. Integrating inquiry into activities and using graphs to teach systems thinking is a logical method to integrate data collection, analysis and interpretation on a broader scale. Appropriately sequenced activities can support student learning as they build on their knowledge. By introducing a systems thinking study using a real-world context of their use of paper or plastic and recycling I hoped to capture students' interests. Relevant data sets for teaching bar graphs and line graphs of environmental concepts within the systems thinking construct within a classroom setting provided ample opportunities for peer evaluation, practice and reflection by students and their classmates. Combining inquiry, graphing and data analysis with an introduction to systems thinking and other integrated teaching strategies provided this model for teaching sustainability education.

REVIEW OF LITERATURE

The Review of Literature for this project involves several different areas which can be viewed independently but commingle for the over-arching concepts of the study. First, a review of the case for teaching sustainable development must be made as a priority for topic selection. Second, an examination of the concept of systems thinking is made and related to the teaching and learning of sustainable development. Third, specific teaching strategies that were employed will be reviewed and considered for their value in supporting student learning through systems thinking, and education for sustainable development. Finally, the use of Design Research as a method for implementing the study is considered.

The combination of these different components into one project represents a novel approach for teaching and learning of sustainability education. A review of empirical educational studies of Complex Systems in Science Education (CSSE) from 1995-2015 by Yoon, Goh and Park (2018) highlighted 75 studies that met their parameters focusing on the teaching and learning or understanding of scientific systems that are complex in nature. Of these 75, twelve related at least in part to high school students in subjects covered in this project including ecology and earth science, but only three of these had elements of Design Based Research (DBR) which was used in this project. Most of the studies investigated student learning or understanding of complex systems, but the authors generally felt there was limited comparative research design and recommended more quantitative and scaled-up investigations. Environmental education and sustainability are often treated as stand-alone subjects and not integrated into the curriculum or included within school-wide learning initiatives (Benavot, 2014). The unique instructional unit of this study included teaching foundational knowledge about systems thinking and environmental systems, metacognition and use of graphic organizers, graphing and modeling skills for data collection and predicting, inquiry/experimental design and real world connectedness: making environmental sustainability personal and something students care about.

The case for teaching sustainable development

Roberts (2007) noted that curriculum should incorporate both science subject matter, and its role in life situations. Bybee (2010) argued that science education must embrace personal, social and global contexts as well. Addressing these concerns has also been emphasized by international educational organizations by assessing science skills, understanding, and attitudes related to health and environment (Organization for Economic Cooperation and Development, 2007, 2013). The goal of incorporating science education to help minimize human impacts on earth systems through sustainable development (SD) concepts is not new, having been outlined by the Bruntland Commission Report in which SD is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Bruntland, 1987, p 43). Thus, teaching sustainability must include environmental, economic and social aspects (McKeown, 2002). Education for Sustainable Development (ESD) as a concept was first pointed out by United Nations Conference on Environment and Development (1992) Agenda 21 in Chapter 36 with four aims: (1) improve basic education, (2) reorient existing education to address sustainable development, (3) develop public understanding, awareness, and (4) training. The educational reforms outlined suggest that students learn the requisite scientific knowledge about the environment but ESD should help them gain insights and beliefs to promote their personal actions. UNESCO (2005) further outlined values that should be promoted including: respect for the dignity and human rights of all people throughout the world and a commitment to social and economic justice for all; respect for the human rights of future generations and a commitment to intergenerational responsibility; respect and care for the greater community of life in all its diversity which involves the protection and restoration of the Earth's ecosystems; and respect for cultural diversity and a commitment to build locally and globally a culture of tolerance, non-violence and peace.

It can be argued that a model for sustainability education could be conceptualized by thinking as a whole yet understanding the relationships between environmental, social and economic dimensions. The *UN Decade of Education for Sustainable Development: 2005-2014* (UNESCO, 2005) to emphasized ESD is for all schools and all learning settings from industrialized to developing countries. In order to facilitate this transition in science curriculum, countries worldwide have been in search of good implementation strategies of ESD in education. Sustainability education is part of environmental education that responds to calls for improving K–12 student problem solving capacities (Schmidt, 1996). However, ESD differs from typical environmental education because critical thinking and problem solving are stressed in order to lead to confidence in addressing the dilemmas and challenges of sustainable development. Environmental problems have a cultural and social context and the goal cannot be to develop a single ideal curriculum (Clements, 2007). Henderson & Tilbury (2004) further suggested that ESD builds on typical environmental education by combining complex social issues, such as the links between environmental quality, natural resource allocations, human equality, and human rights. Thus, a model for sustainability education must include environmental, economic and social aspects that work together (McKeown, 2002) and which could be conceptualized by holistic thinking with an understanding of the relationships between environmental, social and economic dimensions.

Many countries have started to look for methods, such as training programs for teachers in informal education settings, to introduce and strengthen ESD in their curricula. For example, China has implemented ESD projects to enhance curriculum, improve teacher professional development and help change students' attitudes towards sustainability issues (Zhang, 2010). This curriculum includes "Four Respects": respect for nature, science, cultural diversity, and for all. The Chinese curriculum also attempts to simplify and localize issues according to the needs of the community while integrating core values and is an aim for ESD (Qiaoling, 2011). Africa has many obstacles to achieving sustainable development from vulnerability to climate change, degradation of natural resources, poverty and widespread diseases which make implementation of ESD challenging (Wals & Kieft, 2010). Mainstreaming Environment and Sustainability into Higher Education in Africa (MESA) is a university training program developed to provide leadership and curriculum materials. In Europe there are many examples of ESD projects, and national action plans to integrate the UNESCO recommendations, particularly reflected by the German National Committee for ESD which also emphasizes student apprenticeships (Hierche, 2012). Turkish science curriculum is moving from little ESD in units of biology and geography at the secondary level to incorporating knowledge and sustainability issues in the elementary grades as well (Tanrıverdi, 2009). Teaching sustainability is also acknowledged in the United States within *A framework for K-12 Science Education*: *practices, cross cutting concepts and core ideas* (National Research Council, 2012).

To be most impactful, education and lifelong learning should be part of an integrated approach that also includes changes in governance, legislation, research, financing and regulation towards greater environmental sustainability. This is highlighted in *Transforming our World: The 2030 Agenda for Sustainable Development* (United Nations, 2015) which embraces a comprehensive set of 17 Sustainable Development Goals (SDGs), containing one on education (SDG 4). The new agenda calls on countries to rethink the aims, and contents of education and training systems within a lifelong learning approach (Benevot, 2017). Wals (2012) described four general sets of education-related responses: nature conservation education which focused on (re)connecting people with nature, and dates back to the late 19th century; environmental education, dating back to the 1960s which emphasized developing ecological literacy and changing environmental behavior and lifestyles; sustainability education, dating to the 1992 Earth Summit which concentrated on citizen engagement and capacity building for sustainable development; and environmental and sustainability education in the last few years, which blends elements from earlier approaches and looks at humanity's place in the world and global citizenship. Wals (2012) noted that all responses co-exist but describes two complementary ways of understanding the role of education for environmental sustainability. The first is education that aims to develop specific environmental behaviors that are deemed right and necessary and is sometimes referred to as an 'instrumental' approach. The second focuses on education that develops autonomous, responsible and reflective citizens who are independent thinkers, and is also referred to as 'emancipatory' approach which tends to promote action-oriented, collaborative, participatory and transformative learning. Warner and Elser (2015, p. 2) noted that "due to its relative infancy in curriculum much ambiguity surrounds sustainability education in that teachers and administrators recognize the importance of solution-based education, but they have few tools to guide their efforts in designing sustainability programs in schools."

Environmental education has often been viewed by educators to be politically and socially "messy" because it involves environmental dilemmas, and issues-based teaching. Identifying and recognizing the scope for integrating the concepts, issues and values clarification is challenging for teachers (Rao, 2014). Many topics that can be considered in the scope of sustainability like climate change, energy sources and consumption, and fresh water resources are already included in the curriculum, but they are often treated only as content to be taught without integrating the concept of sustainability. Education for sustainable development has some properties which distinguish it from more general environmental education according to *Framework for the UNDESD International Implementation Scheme* (UNESCO, 2006). These include being interdisciplinary and holistic, values-based, and addressing critical thinking and problem solving. Further recommendations for teaching ESD include using mixed methods in which the teacher and the learners work together to acquire knowledge with different strategies through writing, art, drama, debate, experience as well as involving students in decision making about how and what they are going to learn. Other key aspects of ESD are to ensure that learning experiences are meaningful to students' daily lives, and address local issues while linking to global ones. Within the scope of this study, students are addressing all these requisite aspects of teaching ESD.

The connection between ESD and Systems Thinking

Education for Sustainable Development (ESD) involves teaching students to make connections with components of a system because sustainability issues are linked and part of a "whole". "System Thinking" or "Linking Thinking" (also referred to as "Holistic Thinking") has been proposed as an approach to help students conceptualize aspects that are environmental, social and economic (UNESCO, 2012). Research on complex systems in K-12 science education is relatively recent compared to other fields of education such as literacy, mathematics and science (Yoon et al, 2018). In *Benchmarks for Scientific Literacy* (American Association for the Advancement of Science, 1993) systems was presented as one of the four common themes for U.S. science education. Systems and their processes are considered cross-cutting concepts in the *Next Generation Science Standards* (NGSS Lead States, 2013). This NGSS vision for science education communicates to students actions of scientists in terms of solving problems confronting society and the environment.

> In the coming decades, the survival of humanity will depend on our ecological literacy–our ability to understand the basic principles of ecology and to live accordingly. This means that ecoliteracy must become a critical skill for politicians, business leaders, and professionals in all spheres, and should be the most important part of education at all levels—from primary and secondary schools to colleges, universities, and the continuing education and training of professionals (Capra, 2009, p. 248).

Penner (2000) defined systems as a collection of parts and processes that function as a whole. The ability to examine, characterize, and model the transfers and cycles of matter and energy is a tool that students can use across virtually all areas of science and engineering. This cross-cutting concept is highlighted within *A Framework for K-12 Science Education* (National Research Council, 2012, p. 95). This framework emphasizes systems and system models as tools to help students identify and analyze the interrelationships between collections of parts that function as a whole. The rationale for advancing system thinking was based on the idea that the natural world is too large and complicated to investigate and comprehend all at once. Scientists and students learn to define small portions for the convenience of investigation (National Research Council, 2012).

From a constructivist theoretical perspective, student learning is based on the construction of knowledge which builds on prior knowledge (Piaget & Inhelder, 1969/2000) while using tools to assist in the process (Vygotsky, 1978). Advanced science courses include hierarchically structured conceptual knowledge that students should know as well as understanding of scientific processes (NRC, 2002, p. 235). Strong curriculum design emphasizes interdisciplinary connections, integration, and authenticity in the relationship between learning in and out of school. These features not only make learning more challenging, exciting, and motivating, but also help students develop their abilities to make meaningful connections by applying and transferring knowledge from one problem context to another (Goodwin, 2003). Effective instruction is focused on enabling learners to uncover and formulate the deep organizing patterns of a domain, and then to actively access and create meaning around these organizing principles. Learning with understanding also helps students develop the ability to evaluate the relevance of particular knowledge to novel problems and to explain and justify their thinking. As students learn and practice these skills of critical reflection, they are able to apply knowledge in multiple contexts, develop adaptive expertise, and serve as active members within "learning communities" (NRC, 2002, p.6).

There are several models of system thinking including *System thinking hierarchical model (STHM)* (Assaraf & Orion, 2005) which is a cognitive model of eight hierarchical stages of system thinking skills development. In my view these learning stages reflect constructivist epistemology and include the following properties: (1) identifying the components and processes of a system, (2) identifying simple relationships among a system's components, (3) identifying dynamic relationships within a system, (4) organizing the system's components, their processes, and their interactions, within a framework of relationships, (5) identifying matter and energy cycles within a system, (6) recognizing the hidden dimensions of a system, (7) making generalizations about a system, and (8) thinking temporally by using retrospection and prediction. This model was developed as a result of teaching the hydrologic cycle to eighth grade earth science students. Their findings suggest the cognitive skills that are developed in each stage serve as the basis for development of the next higher-order thinking skills. Research by Hmelo, Holton, and Kolodner (2000) working with sixth graders studying human respiratory system supported Assaraf and Orion (2005), contending students have more difficulty understanding individual concepts without knowing about the entire system. In her study on teaching a unit on watersheds, Fick (2018) emphasized using the components of a system as a way of framing classroom discussions and for developing examples to advance students' thinking. Jacobson and Wilensky (2006) also examine how systems might be incorporated into student learning. Both studies focused on ways to support students as they learn about a specific system or cycle, whereas the approach to understanding systems as described in the NGSS (2013) is that the aspects of systems are more general and transferable across disciplinary core ideas.

Walker et al. (2017) outlined best teaching practices that will help schools incorporate interdisciplinary environmental topics such as sustainability and civic responsibility into their regular curriculum but note a major barrier is the fragmented curriculum, since sustainable practices go beyond single disciplines and address issues that all students need for sustainable living. The United Nations Economic Commission for Europe (UNECE) strategy for ESD (UNECE, 2003) further outlined main characteristics of the methodological approaches within ESD as: action oriented teaching and learning; developing critical thinking; providing democratic principles and processes; holistic; interdisciplinary approaches; use of modern Information Communication Technologies (ICTs); problem based learning (PBL); and project work (UNECE, 2003). This emphasized the need to teach environmental science as an integrated course with a systems approach but also by incorporating multiple teaching strategies.

Many argue that governments, corporations and institutions need to learn how to develop and use more holistic frameworks to analyze and respond to environmental issues (UNEP, 2012). “The fact that ecological sustainability is a property of a web of relationships means that in order to understand it properly, in order to become ecologically literate, we need to learn how to think in terms of relationships, in terms of interconnections, patterns, context. In science, this type of thinking is known as systemic thinking or ‘systems thinking’ (Capra, 2009, p.248). This is the same as holistic or linking thinking. Systems thinking originally emerged from biologists, psychologists, and ecologists, in the 1920s and 1930s who understood that a living system such as an organism, ecosystem, or social system is an integrated whole whose properties cannot be reduced to those of smaller parts (Capra, 2009). Donella Meadows concluded

> Systems thinking has taught me to trust my intuition more and my figuring-out rationality less, to lean on both as much as I can, but still to be prepared for surprises. Working with systems, on the computer, in nature, among people, in organizations, constantly reminds me of how incomplete my mental models are, how complex the world is, and how much I don't know," (Meadows, 2001, p. 60).

Using systems thinking represents a shift to a more qualitative approach to studying relationships and patterns, from objective knowledge to contextual knowledge, suggesting that the major problems of our time cannot be understood in isolation. Major problems are systemic which means they are all interconnected and interdependent.

Teaching for learning; using integrated teaching strategies

Several teaching strategies were employed in this project as scaffolding for student understanding of sustainability in general. They included group brainstorming, internet research, construction of graphic organizers, and reflective writing. Some of these kinds of activities are seen in online sustainable education programs like Circular Classroom (Circularclassroom.com), and Ecology Project (Ecologyproject.org), however there is no ESD program which ties together all of them. In many ways this project incorporated backward design which is an effective way of providing guidance for instruction and designing lessons, units, and courses (Wiggins & McTighe, 2005). "Teaching for learning," and "understanding by design" put the emphasis on scaffolding for learning, and not just putting together activities for students to complete. Fundamental in this process is identifying the learning goals in advance of the activities to be implemented. Two additional strategies that were uniquely emphasized in this project are inquiry-based experimental design by the individual students as well as review and implementation of graphing techniques. The goal is to help students collect and analyze their own data and make predictions about future issues of sustainability. By doing this, it was anticipated that students construct their own personal responsibilities, and augment societal accountability related to sustainability. These two approaches will be highlighted in both the study and in the research below.

Inquiry-based instruction

Several studies have investigated students' understandings of sustainability concepts (Coertjens et al., 2010; Hart & Nolan 1999; Lundholm & Davies 2013) but there are still uncertainties concerning how teachers teach about Sustainable Development (SD) and whether they give pupils the time they need to think through these complex issues. These concerns imply that teachers fall into a normative tradition by simplifying issues and finding simple solutions (Andersson, 2017). Kang, et al. (2016) outlined several categories of research that link to impacts on student achievement in science. Among these are reports on expert-developed curriculum, how teachers enact reform-based curricula, and effective instructional methods. Johnson (2009) described those effective teaching traits as common to active science inquiry teaching practices. These are found in the new science reform documents such as *Next Generation Science Standards* (NGSS) and include a shift in standards to student-centered learning, integrating inquiry and argumentation in experiments, field based science, using discourse and questions, and teaching for understanding. Researchers like McNeill, Pimentel, and Strauss (2013) studied multiple characteristics of teaching that are correlated with improved student learning. They found significant learning gains when an inquiry based curriculum was put into practice where students spent a larger amount of time in groups, sharing ideas and engaged in argumentation. These represent effective classroom instruction and assessment practices for those who generally underperform in science in traditional learning environments (Ardenez & Southerland, 2012). However the authors note that “science teachers are struggling to address the learning needs of all students while trying to accommodate the accountability needs of the systems” (Ardeniz & Southerland, 2012, p. 254) in that they are scrutinized for their teaching, while at the same time being called on to teach using methods such as problem based learning (PBL), and inquiry that have proven to support student learning.

Science teachers have difficulty in helping students make sense of science activities, which enable them to understand the natural world and connect with everyday experiences. It is unclear whether this problem is related to the design of the activity, how the teacher instructs and discusses the topic, or student engagement. Weiss et al. (2003) found that appropriate opportunities for students to make sense of the science ideas being taught were rarely coupled with hands-on, practical, and experiential studies. Classroom learning continues to be undemanding, routine and disconnected from the development of deeper understanding (Banilower, et al., 2012). In a study of 500 classroom videos from five countries, Roth and Garnier (2007) noted that teachers in the United States did not incorporate “various activities to support the development of content ideas in ways that were coherent and challenging for students” (p. 20), which results in activity without understanding. “When students have accumulated a rich array of images, however, they are able to “see” the concept in the events associated with the specific phenomena; the phenomena become the metaphor for the concept. When students think of electric current, for example, they associate a definition and equations with their experiences of making a bulb light up, hearing their battery-powered radio begin to get faint, or seeing lightning flash," (Loucks- Horsely, et al, 1998, p. 35). Lotter et al. (2007) studied teachers' conceptions and beliefs related to teaching through inquiry. In this study teachers participated in a two week summer program where they learned inquiry based teaching strategies as well as conducted research in university laboratories, followed by additional workshops during the following school year where the participants could reflect on their own inquiry lesson implementation. The results of this study demonstrated positive outcomes for teachers integrating more inquiry-based activities in their own classrooms, regardless of grade level or subject areas.

For an individual to be considered scientifically literate it requires that he/she understands subject matter, Nature of Science (NOS), and Scientific Inquiry (SI). Many current teaching methods and curricula are designed to prepare students to pass tests by rote learning, but fail to develop necessary cognitive skills needed in science. These methods can even discourage students from critical thinking and deeper learning (Willingale-Theune, et al., 2009). Capps, Crawford and Constas (2012) noted that although inquiry based instruction is not the only way to effectively teach science, it is thought to have a powerful influence on students' science learning, in part because it exposes them to the work of practicing scientists. They acknowledged that there are many definitions of science inquiry (SI) and some teachers merely use conformational (plug and chug or cookbook type) experiments which they assume because they are hands-on activities, this represent inquiry. National Science Education Standards (NSES) (NRC, 2000) consider three meanings of SI, the first two are outcomes based and the third is a teaching strategy. The outcomes are based on one's ability to "do" science such as posing questions, designing and conducting experiments, using and analyzing data while synthesizing explanations. The second meaning involves understanding of how scientists do their work, and the third meaning is a kind of training in which inquiry-based teaching concerns one's ability to use inquiry instruction in the classroom. Capps et al. (2012) evaluated five National Science Education Standards (NSES) essential features of inquiry. These suggest the learner: is involved in a scientifically oriented question, gives priority to evidence in responding to the questions, uses evidence to develop an explanation, connects explanation to scientific knowledge, and communicates and justifies the explanation (NRC, 2000). They also discussed constructivism which is based on the concept that "learners should be engaged in answering authentic scientific questions relevant to their lives" citing early works by Dewey, Brown and Schwab (p. 295). Newer teaching approaches build on the constructivist view of learning but inquiry-based science teaching focuses on actively building student knowledge that has the potential to be more relevant to students than lecture, and basic "cookbook" type laboratories. Capps et al. (2012) and Loughran (2014) also suggested that inquiry-based science teaching has the potential to engage all students including underrepresented groups by increasing understanding and helping motivate them to learn science.

Importance of graphing techniques

This dissertation study used instruction in graphing of data collected by students and provided from research data as a strategy to help them develop ESD and systems thinking simultaneously while also incorporating an inquiry, experimental desgin component. The use of graphs to teach systems thinking is a logical method to integrate data collection, analysis and interpretation on a broader scale. Introducing a systems thinking study using a real-world context of their use and recycling of paper or plastic as an inquiry investigation was used to capture students' interests. Relevant data sets for teaching bar graphs and line graphs of environmental concepts within our systems construct in a classroom setting provided ample opportunities for peer evaluation, practice and reflection by students and their classmates.

In the United States graphing is considered an important standard in the Common Core mathematics content beginning with fifth grade and re-emphasized throughout middle and high school. From *Preparing America's Students for Success,* fifth graders for example should be able to graph points on a coordinate plane to be able to solve real world problems, and by eighth grade students should be able to analyze and solve linear equations (Common Core State Standards Initiative, 2016). Graphing also corresponds with Science Practice 4-"Analyzing and interpreting data" from *National Research Council* which noted that "scientific investigations produce data that must be analyzed in order to derive meaning and scientists use a range of tool including tabulation, graphical interpretation, visualization, and statistical analysis to identify the significant features and patterns in the data" (2012, p. 51).

The progression for the science and engineering practices across the grades begins with grades K-2 stressing observations and explanations related to direct experiences, grades 3-5 introducing simple models that help explain observable phenomena, and a transition to more abstract and more detailed models and explanations across the grades 6-8 and 9-12 (National Research Council, 2012, p. 34). Models can include sketches, diagrams, mathematical relationships, simulations, and physical models to help evaluate the predictions and possibly revise the models as a result (p. 44). In middle school, in the progression for Practice 4, students should have opportunities to learn standard techniques for displaying, analyzing, and interpreting data including different types of graphs, the identification of outliers in the data set, and averaging to reduce the effects of measurement error, and using computer technology when possible (p. 63).

Students in this design study collected their paper or plastic products and created data tables to organize their different categories of paper or plastic usage. Tables may be merely a type of data display or they may represent an intermediate step for constructing graphs, but the graph maker needs to consider how to set up their table before data are collected. Bright and Friel (1998) have outlined possible benefits of focusing on transitions between tables and graphs to promote understanding. For example, "transitions to using bar graphs showing data grouped by frequencies may be made easier for students if instruction includes opportunities to transform a line plot into a bar graph and to highlight similarities and differences between these two representations" (Friel, Curcio & Bright, 2001, p. 128). They also noted that stem plots and histograms are similar in structure, but not all graphs can be transitioned to another type. For example although line graphs typically represent time series data or functional relationships, the same time series data can be expressed as a bar graph, while functional relationships are not represented this way. Friel, et al (2001) suggestd that although many researchers have studied graph comprehension through reading and interpretation, few have examined graph comprehension based on construction, invention or graph choice. The Maine Data Literacy Project (2014) provided students with a simple set of schematics in a Graph Choice Chart to help them determine what kind of graph to use for a particular question. Although the ability to use and understand graphs is essential in science and engineering we know little about how people know, understand, and learn about graphical representations (Bowen and Roth, 2002), and acknowledged that students of all ages have difficulty in using graphs.

Methods of teaching graphing and pedagogical constructs can be related to comprehension, and teachers as well as students may encounter difficulties when teaching and learning these concepts. Some researchers contend that graphing is a cognitive skill that students' difficulties arise from "deficiencies" in logical reasoning ability in the Piagetian tradition.

> Unfortunately, many of our subjects do not have the mental tools to engage in a high level construction or interpretation of graphs. A study which investigated the connection between logical thinking abilities and the ability to construct and interpret graphs, indicates that subjects with deficient logical thinking abilities such as spatial thinking and proportional reasoning have significant difficulties when attempting to interpret or construct graphs. (Berg & Smith, 1994, p.549).

Their study compared student achievement on graph interpretation using different testing formats such as multiple choice and short answer which may explain their results. Friel, Curcio and Bright (2001) suggested that perceptual processing demands are related to graph design affect graph comprehension and also that educators should attend to the three task characteristics of visual decoding, judgment task, and context when teaching graphing. A study by Roth and McGinn (1997) attributed student success in interpretation and construction of graphs to increased participation and practice, much along the same lines as practice in sports or any other skill will make one better at it. They concluded that graphing competence is explained in terms of experience and degree of participation rather than exclusively in terms of cognitive ability.

Three behaviors have been identified in graph comprehension: translation, interpretation, and extrapolation/interpolation (Jolliffe, 1991; Wood, 1968). Translation involves connecting between information in data tables and that found in a graph, and can be given as a written description. Interpretation of graphs comprises looking for relationships between categories or specifiers and the axes of the graph or pulling together two or more pieces of information. Extrapolation and interpolation are extensions of interpretation and help to note trends and possible implications of the data. Biological Sciences Curriculum Study (BSCS, 2012) suggested that students use the Identify and Interpret $(I)^2$ strategy to make sense of graphs and other visual representations by helping to break down the information into smaller parts. In step 1 identify, students use “what I see” statements to note any changes, trends, or differences and they suggest drawing arrows on the graphs. In the second step, students try to interpret each part of the “what I see” statements as “what it means,” eventually combining their thoughts into a coherent summary.

The Organization for Economic Cooperation and Development (OECD) Programme for International Student Assessment’s (PISA) (2007) identified three areas of literacy: prose literacy, document literacy, and quantitative literacy but noted that only document literacy includes graphs. It includes the knowledge and skills required to locate and use information contained in various formats, such as tables, and graphics. To be literate and have comprehension of graphs would therefore require an understanding of cognition as it relates to data collecting and representation. Researchers have suggested that question-asking on higher levels is paramount in in developing analysis, synthesis and greater interpretation of text (Graesser, Swamer, Baggett, & Sell, 1996). Curcio

(1987) outlined three different levels of graphing: elementary, which is mostly translating or extracting data from a graph; intermediate, which is mostly interpolating and finding relationships in the graph; and advanced level which extrapolates, predicts and analyzes the relationships that were identified. This could be referred to as read the data, read between the data, and read beyond the data. Friel et al. (2001) provided a table for skills necessary to answer questions that would be asked at all three levels of graphing and the third type, the advanced level requires the largest skill set with the deepest questioning. Ultimately, different levels of questioning initiate different levels of comprehension.

When considering the role of computer based graphing software in learning graphing skills, a previous iteration of this project had students conduct trend analysis using Excel spreadsheets in order to extrapolate their own paper consumption from a two day total to a one month and a one year quantity. Eventually their computer generated trend evaluated consumption for several decades and this allowed students to make an important connection for the future. A study by Deniz and Dulger (2011) compared inquiry-based instruction supported with real-time graphing software and inquiry based instruction supported with traditional laboratory equipment to assess fourth graders' ability to interpret motion and temperature graphs. The results of their study show that integrating graphing software technology showed marked improvement in the students' ability to interpret the graphs. Their report is supported by other studies (Brasell, 1987; Mokros & Tinker, 1987), which concluded that students showed significant gains in their graphing skills as a result of microcomputer-based labs and graphing software. These researchers suggest three possible reasons why there was improvement in graph interpretation: first, the ability to see the graph being produced while the experiment was taking place in real time with the opportunity to make connections between the equipment being using and the actual data being collected; second, the ability to finish the task of graphing more quickly thus allowing more time for reflection, and third, that student seem to be more engaged in the actual science being conducted. However, Adams and Shrum (1990) reported that there was no statistically significant difference between students taught with computer based software and students taught with conventional methods on their graph interpretation abilities, but students taught with conventional methods outperformed students taught with computers on graph construction tasks. Beichner (1990) also concluded that computer based instruction did not have a substantial educational advantage over traditional instruction in improving high school physics students' understanding of graphs. This dissertation project included both conventional graph construction, as well as computer based methods.

There is also research that suggests a difference in learning through graphing depends on whether the students are working individually or in small groups (White, Wallace and Lai, 2012). According to Moschkovich (1996), working collaboratively with peers is one possible context for supporting learning and improving attitudes about subject matter and peers. "Conceptual understanding in this domain involves more than using procedures to manipulate equations or graph lines; it involves understanding the connections between the two representations (algebraic and graphical), knowing which objects are relevant in each representation, and knowing which objects are dependent and independent." (p. 242). Arzarello and colleagues (2009) analyzed the ways students working together in a small group package together resources including words, gestures, and inscriptions into "semiotic bundles" in order to coordinate their efforts in completing a graphing task. Within this instructional unit, students worked initially with small groups, then partners and finally individually on graph construction and analysis activities to help them build their comprehension.

The rationale for using Design Research

The Educational Design Research (EDR) format being implemented in this study is a direct result of a previous pilot study with a group of secondary students and their teacher. As the second iteration of a research study with the same cooperating teacher, this study reflects a unique context for carrying out a teaching unit on Education for Sustainable Development. It is relevant to discuss the concepts of EDR as well as how it can be effective in teaching and learning in models such as this investigation.

"Educational design research is a genre of research in which the iterative development of solutions to practical and complex educational problems provides the setting for scientific inquiry" (McKenney & Reeves, 2013). Principles identified in *Scientific Research in Education* (NRC, 2002) called for research that poses significant questions that can be investigated empirically; links empirical research to relevant theory; uses research designs and methods that permit direct investigation of the question; is guided by a coherent and explicit chain of reasoning; replicates and generalizes across studies; and attends to contextual factors. The National Science Foundation (NSF) aims to improve the quality and amount of science and engineering research in a variety of contexts, has emphasized basic research on STEM learning, cognition, and development of instructional approaches, technologies, and materials in both formal and informal settings (NSF, 2013, p.7). NSF supports educational design research or design-based research approach, referring to it as "Design and Development Research (Research Type #3)", describing its goal related to developing solutions related to education or learning, improving student engagement or mastery of skills. They note these types of projects draw on existing theory and evidence to design and iteratively develop interventions or strategies to achieve specific learning goals (NSF, 2013, p. 9) helping inform the practice of teaching science. The central question from educational design research is not whether something works but how a learning environment works and design research aims to create unique conditions for learning that theory suggests might be productive but are not common or well understood (Design-Based Research Collective, 2003).

There are several distinctions between design research and typical experimental designs. EDR process has to be original ideas with a basis in theory and should try to answer a research question that is going to have application to both instructional methods as well as contributing to the greater understanding about learning processes. Two significant papers were published which are often credited with launching educational design research as a specific genre of scientific inquiry. Brown (1992) discussed tensions between laboratory studies and integrating these innovations into real world classrooms as background to her own design experiments with middle school science students. Collins (1992) published a book chapter arguing that education should be viewed as a design science akin to aeronautics, as opposed to an analytical science similar to physics, emphasizing the fact that laboratory conditions could rarely approximate those in real classrooms. The lack of emphasis on controlling variables and then using the unique observations within the classroom setting to produce further iterations of the design also distinguish EDR. Based on the notion that scientific understanding should be used to solve or at least gain a better understanding of practical problems, the call for scientific inquiry to yield what Lagemann (2002) refers to as 'usable knowledge' is still pervasive. Thus EDR can be thought of as intervention research designed to inform teaching "practice."

Design-based research (DBR), originally developed by Brown (1992), has become more common in the literature and is based on the characteristics described by Wang and Hannafin (2005) and Anderson and Shattuck (2012). These include:

1. It should design and test a significant intervention.
2. It should be practical, where the research refines both theory and practice.
3. It should be grounded in theory to inform the research design.
4. It should be iterative, interactive, and flexible, where designers are involved in the process and work together with participants, and iterative cycles of analysis, design, implementation, and redesign are used.
5. It should be integrative, where mixed method approaches are used in the research.
6. Finally, it should be contextual, where the research results are connected with the design process and have a practical impact on instructional practice within specific settings. (McNeal et al, 2004, p. 561).

Though the terminology and contents vary, three general phases can be characterized in EDR: an analysis/orientation phase; a design/development phase; and an evaluation or retrospective phase all of which are often repeated in the duration of a project. Typically this research involves four components:

- Development of a solution (for example, an instructional approach; design and learning objects, such as museum exhibits or media; or education policy based on a well-specified theory of action appropriate to a well-defined end user

- Creation of measures to assess the implementation of the solution(s)
- Collection of data on the feasibility of implementing the solution(s) in typical delivery settings by intended users
- Conducting a pilot study to examine the promise of generating the intended outcomes (NSF, 2013, pp. 12-13).

Design experiments involve both developing instructional designs to support particular forms of learning and systematically studying those forms of learning within the context defined by the means of supporting them (Cobb, 2003). For example, Doerr (1995) distinguished between expressive design where students are encouraged to invent and test the adequacy of tools like mathematical notations that express their developing understanding, and exploratory approaches to design which involve the development of computer environments in which students can investigate the links between conventional mathematical symbol systems and everyday phenomena. Bannan-Ritland (2003) acknowledged that EDR can result in potentially usable educational innovation (e.g. technology system, curriculum, materials, systemic approach, etc.), generates knowledge about teaching and learning through basic and applied research cycles, is an iterative process of improvement of innovation, is data-driven design and research decision-making, provides rich information about learners, context and instructional strategies to inform empirical studies and embeds different research methods at different phases in design and the research processes.

Cobb, et al. (2003) suggested design experiments entail both “engineering” particular forms of learning to increase understanding of a *learning ecology* which is described as a complex interacting system where the methodology can be conducted in diverse settings such as: one-on-one (teacher-experimenter and student) design experiments in which a research team conducts a series of teaching sessions with a small number of students; classroom experiments in which a research team collaborates with a teacher (who might be a research team member) to assume responsibility for instruction; pre-service teacher development and in-service teacher development studies; and school and school district restructuring experiments. Cobb recommended using different "lenses" to view the research and argues that science and design may focus on the same kind of objects, but to do so from different epistemological positions and describes the elements of a conjecture map which represents the hypothesized learning trajectory embodied within a designed learning environment for a single design study (2003). Bannon-Ritland proposed that these emerging methods call for the articulation of new processes and criteria including factors such as the "usefulness and usability of knowledge, its share-ability, and marketability, how well it disseminates and the extent to which it positively impacts practice" (2006, p. 115). Her Integrative Learning Design (ILD) is a "meta-methodological" view that attempts to integrate the design, research and educational innovations. Clements' Curriculum Research Framework (CRF) emphasized learning trajectories built upon natural developmental progressions identified in empirically based models of children's thinking and learning of mathematics with sets of activities sequenced according to learning trajectories (2007). These design based models involve both qualitative and quantitative data collection.

Current instructional design theories call for analyses of students' learning to be tied to our (i.e., teachers', trainers', or researchers') role in supporting that learning (Cobb, Stephan, McClain, & Gravemeijer, 2001). Stephan (2003) found that review of students' learning within social contexts of the classroom can help to inform designers of the ways in which instructional sequences (or training techniques) can be revised to better support students' learning in this environment. The purpose when experimenting in the classroom is not to try to demonstrate that the initial design formulated in advance of the experiment works, but rather to test and improve the initial design as guided by both ongoing and retrospective analyses of classroom activities and events. Most classroom design experiments are conceptualized as cases of the process of supporting groups of students' learning in a particular content domain. While teachers are primarily concerned with the effectiveness of their practices in their local settings, design researchers also focus on the development of theoretical insights. Design studies involve a pronounced emphasis on the narrative report of the complex interactions and feedback cycles that can significantly blur the roles of researchers, teachers, curriculum developers, instructional designers, and assessment experts (Kelly & Lesh, 2000). Furthermore, Kelly, Lesh, and Baek (2008) stated design researchers are challenging the assumptions about learning, teaching, and knowing that underlie available assessment techniques within and across the stages of design research.

While educational design research (EDR) is not tied to any specific subject area, much of the work published so far has been linked to teaching science or mathematics, perhaps because more funding has been available for research related to STEM (science, technology, engineering, and mathematics) disciplines than for other areas (Kelly et al., 2008). Plomp and Nieveen (2010) provide dozens of examples of EDR projects related to science and mathematics topics in all grade levels and teacher professional development. Suter and Frechtling (2000) identified Design Research as one of the five primary research methodologies in mathematics and science education. Scientific knowledge is valued because it offers reliable, self-correcting, documented, shared knowledge based on research methodology (NRC, 2002). Educational design research uses scientific knowledge and other knowledge such as teaching "craft" understanding to position design work and even produce scientific knowledge while striving to develop both interventions in practice and reusable knowledge. Because scientific advances are achieved ultimately by the standards of a scientific community over time, the goal cannot be to develop a single ideal curriculum but, rather, dynamic problem solving, progress, and advancement beyond the present limits of competence (Clements, 2007). A complete, scientific, curriculum development program should address questions about effects and conditions in three domains: policy, practice, and theory. Methods such as teaching experiments, design experiments, and curriculum evaluation should be synthesized into a coherent, complete curriculum framework (Clements, 2007, p.39).

Ideally, curriculum development is a design science (Brown, 1992) with the goals of engineering a learning process and developing local instructional theories (Cobb et al., 2003). DiSessa & Cobb (2004) stated a series of design experiments can serve as the context for the development of theories or theoretical frameworks that entail new scientific categories which would be embedded in a supporting theoretical framework and use the term "ontological innovation." In contrast to science research, educational design concentrates its investments on developing and testing the effectiveness of well-defined curricula, programs, and practices that could be implemented by schools (NSF, 2013, p.7). The goal of scientific research is the creation of knowledge, whereas the goal of curriculum development is the production of instructional materials. Bannan-Ritland (2003) describes a design research team creates a design to support an envisioned learning process, conducts an experiment to subject the design to certain stresses, and generates data to test and revise theoretical conjectures derived from prior research that are inherent in the design. “Design research is recommended when the problem facing learning or teaching is substantial and daunting how-to-do guidelines available for addressing the problem are unavailable. Further, it is recommended when a solution to the problem would lead to significant advances in learning or at least a significant reduction in malfunction in the educational system” (Kelly, 2006, p. 137).

Science itself is based on a representational view of knowledge, in which educational phenomena are approached as empirical objects with descriptive properties (Sloane, 2006). The descriptive and analytic nature of science helps to explain any existing or emerging educational phenomena, but, generally cannot account for qualitative differences. Finbarr Sloane argued that “science develops knowledge about what already is, whereas design involves human beings using knowledge to create what could be, that is, things that do not yet exist” (Sloane, 2006, p.27). Kelly (2006) suggested it is appropriate to use EDR strategies in a variety of science-related areas including: introducing existing science or mathematics at earlier grade levels, learning new or emerging science content, and teaching reading and inquiry science.

Many EDR examples involve using technology such as Klopfer and Squire (2008) who described a multi-year project to enhance student learning related to environmental science through the development and refinement of learning games that are accessed with handheld devices such as PDAs and smart phones. Brown (1992) based EDR on the procedures of design sciences such as aeronautics and artificial intelligence creating innovative educational environments, while simultaneously conducting experimental studies of those innovations. Lehrer (2009) stated the traditions of research including laboratory, historical, and ethnographic have contributed to securing a prominent role for model-based reasoning as a central knowledge base of science because scientists make, revise, and justify models. His EDR involved using teachers as co-researchers with two years of professional development to enable them to work with physical models and representational models of natural phenomena like plant growth, or the functioning of the human elbow joint. Both forms of modeling provided opportunities for students to experience science as an expressive form of activity, one where their evolving identities and dispositions to participate in disciplinary knowledge are supported (Lehrer, 2009).

Additionally, Lehrer, Schauble, & Lucas (2008) tracked growth in sixth-grade children's understanding of inquiry as they investigated two local pond ecologies and then invented and revised models of the functioning of these ecologies by creating one gallon jar ecosystems. Mastery of the processes of science and knowledge of the content of science develop hand in hand. They acknowledge that scientific reasoning involves the development and coordination of several inter-related phases and entails substantial knowledge building and revision, so studies that track participants for an extended period of time are of particular value. Core ideas such as diversity and structure derive their influence from the models that support them, so students must realize the "big ideas" outlined in national science reform standards *such Next Generation Science Standards* (NGSS Lead States, 2013) and *A Framework for K-12 Science Education* (National Research Council, 2012) are both models and forms of argument (p.514). These documents outline effective science teaching practices such as shifting to student-centered learning, integrating inquiry and argumentation in experiments, field based science, using discourse and questions, and teaching for understanding.

Bannon- Ritland argued that if design researchers can articulate an integrative research and design process, "it may have the potential to significantly improve our understanding of teaching, learning and training in-situ" (2006, p. 117). McNeill, Pimentel, and Strauss (2013) studied multiple characteristics of teaching that are correlated with improved student learning and found significant learning gains when an inquiry based curriculum was put into practice where students spent a larger amount of time in groups, sharing ideas and engaged in argumentation. Capps et al. (2012) suggested that inquiry-based science teaching has the potential to engage all students including underrepresented groups by increasing understanding and helping motivate them to learn science. Lederman (1992) studies suggested that students appear to create more realistic conception of the nature of science, in which collective/group practice and teacher/authority are intertwined with individual ownership. I agree with Brown (1992) and admit that "making the shift from laboratory to classroom studies of design research involves a trade-off between experimental control and richness and reality" (p.152). This design research study integrated different teaching strategies such as inquiry and graphing studies, along with different learning modalities within groups and individually as described above as a goal to facilitate long term student understanding of sustainability and personal ownership of their role in the future of the global environment.

A previously discussed, a review of empirical educational studies of Complex Systems in Science Education (CSSE) from 1995-2015 by Yoon, Goh and Park (2018) highlighted 75 studies that met their parameters focusing on the teaching and learning or understanding of scientific systems that are complex in nature. Of these 75, twelve related at least in part to high school students in subjects covered in this project including ecology and earth science, but only three of these had elements of Design Based Research (DBR) which was used in this project. Most of the studies investigated student learning or understanding of complex systems, but the authors generally felt there was limited comparative research design and recommended more quantitative and scaled-up investigations. They also acknowledged that even though the research has resulted in new digital tools, curricula and theoretical frameworks, there is no consensus on how to best support student learning. Thus, this research design study helped to fill a gap in the literature with designing and testing a series of teaching strategies that emphasized student learner responses. Furthermore, The National Academies (2009) concluded that more educational interventions are needed that examine systems with addressing global issues such as biosphere sustainability. To that end, this investigation moved beyond the typical studies that focused on helping students recognize complex system components, structures and processes (Yoon, et al., 2018) to involving students in activities that stimulated problem solving of environmental sustainability issues and increased self-awareness.

CHAPTER 3

METHODOLOGY

INTRODUCTION

Science education should incorporate curriculum that helps students develop greater understanding about sustainable development, and their role as stewards of the environment both in a local and global context (Bybee, 2010). The purpose of this study was to develop a design research project to investigate the implementation of a two week unit on sustainability. The study incorporated different teaching strategies broadly aligned with the *System Thinking Hierarchical Model* (STHM), an eight step cognitive model outlined by Assaraf and Orion (2005). As described by McKenney and Reeves (2013), "Educational design research is a genre of research in which the iterative development of solutions to practical and complex educational problems provides the setting for scientific inquiry." Design research includes a team who creates a plan to support an envisioned learning process, conducts an experiment to subject the design to certain stresses, and generates data to test and revise theoretical conjectures derived from prior research that are inherent in the design (Bannan-Ritland, 2003).

The iterative aspect of the endeavor was accomplished by the research team conducting an initial three day pilot study eighteen months prior to implementation of this project. Concepts for this study are based on a preliminary investigation which was a case study of one International Baccalaureate Standard Level Environmental Systems and

Societies class of eleventh and twelfth graders in October, 2017. The preliminary pilot study was only four days, and the cooperating teacher and I agreed that the next iteration should be at least two weeks. During the pilot phase several different strategies and activities were included and assessed by the team and thus represented the analysis/orientation phase. This helped to focus the current project both sequentially for content delivery, and in terms of the potential usefulness in improving the initial design/development as guided by both ongoing and retrospective analyses of classroom activities and events. As described by Stephan (2003), review of students' learning within the social contexts of the classroom can help to inform designers of the ways in which instructional sequences (or training techniques) can be revised to better support students' learning in this environment.

Based on literature on the underuse of inquiry strategies, this study included a variety of approaches but student research and experimental inquiry on their choice of paper or plastic manufacture, usage, disposal, and recycling was a central focus. Through the activities students engaged in systems thinking or linking thinking on a broader scale. The unit integrated whole class instruction, brainstorming, research, graphic organizers, experimental design/student inquiry, graphing and analysis of individual and class data, and other teaching strategies. These tools were anticipated to assist high school earth science, environmental science, or biology students make connections between their own paper or plastic consumption and the greater role of this local issue on global environmental issues such as deforestation, soil degradation, water usage, climate change and other concepts such as the hydrologic and atmospheric cycles.

One of my passions as a secondary and university teacher for nearly forty five years has been teaching students about environmental science and stewardship. I wanted my students to learn from Alexander Von Humboldt that nature is a living whole (Wulf, 2015), and from John Muir that when you try to pick out anything by itself you find it connected to everything else in the universe (Muir, 1911). Not only have I taught these subjects but I also have trained teachers for decades and have developed and published many teaching strategies and laboratories in this field. Development of a study in which students design an investigation or experiment, do "hands on" collection and manipulation of data, and then extrapolate and analyze their data in a way that makes them recognize larger environmental trends is definitely in my comfort zone. Additionally I became interested in doing design research over three years ago and wanted to combine this methodology in the study.

STUDY OVERVIEW

The scholarly goal of this study was to learn whether high school students can make connections to global environmental cycles and issues by looking at a single topic through the lens of a systems approach to sustainability. I also wanted to understand how students assimilate their knowledge of a set of quantitative data (paper or plastic usage/recycling) into a broader realm of understanding their impact on the environment. This employed a reflective and qualitative analysis of their data by examining social and economic aspects in addition to the science concepts they learned. The investigation involved mixed methods for gauging student learning. Qualitative methods included observations of students during class discussions and interactions as well as assessments of graphic organizers, reflective essays, surveys, a digital poster for a possible implementation project, a formal laboratory report of their inquiry investigation, and small focus group interviews. Quantitative measurements were more limited but included appraisals of student graphs and required calculations for data analysis, as well as summary evaluation of surveys by students. There were also quantitative data from final essay rubrics, and Mentimeter results at the end of some class periods. A summary of these qualitative and quantitative methods is provided in Data Collection Methods Table 3.2.

Research Design

This project was a classroom-based Educational Design Research (EDR) study with several phases including: preliminary research, participant selection, research team planning meetings, implementation, and research team meetings to assess/evaluate. This educational design project, in contrast to science research, concentrated on developing and testing the effectiveness of a sequence of instructional strategies, and teaching practices that could be implemented by schools as supported by National Science Foundation recommendations (NSF, 2013, p.7).

This project was student-centered, experiential, grounded in Constructivist Theory. While developing the instructional plan these approaches were taken into account so that students were encouraged to develop system thinking by considering the effect of paper/plastic consumption holistically, use knowledge and skills from different disciplines, and be active learners by thinking critically about their data collected. Activities and sequences followed guidelines suggested in *Handbook on Methods Used in Environmental Education and Education for Sustainable Development* (Scoullos & Malotidi, 2004). The design of the project was also loosely based on the eight characteristics of *System Thinking Hierarchical Model* by Assaraf and Orion (2005). The core focus of the instructional activities and learning goals were built on a fundamental understanding of systems thinking and environmental systems and cycles.

Research Questions

The three overarching research questions for this study were as follows:

1. Using Design Research and various instructional tools, how do students develop an understanding of systems thinking and relate it to environmental sustainability?
2. How does analyzing personal and classroom data on paper or plastic usage and recycling influence high school science students' understanding of global environmental sustainability issues through the lens of systems thinking?
3. How do students come to understand the impact of the effects of individual behaviors on broader issues of environmental sustainability?

Many student artifacts from the instructional activities were used to evaluate student understanding for research question 1. Both research questions 2 and 3 involve student reflection on their ownership of the data they collected and their changes in personal behaviors (if any), related to learning about environmental sustainability through systems thinking. Students were given opportunities to discuss and reflect in writing on these topics through global and personal perspectives using summary reflection essays, their lab report summary, and through surveys. There were also daily Observation Checklists, and debriefings with the cooperating teacher, and small focus group interviews at the end of the project to help evaluate the success of the project regarding the research questions.

Learning Goals

The following Learning Goals were identified for this unit, and represent the key component of the daily observation checklist. The project design research addressed each activity in terms of these goals through the cooperating teacher completing a Daily Observation Checklist (DOC) in which activities were assessed based on their correlation to each of the Learning Goals. A sample and all of the daily DOC's submitted by the teacher are included in Appendix B. Learning Goals One and Two are related to Research Question One, Learning Goal Three is associated with Research Goal Two and the final Learning Goal Four connects with Research Goal Three.

1. Students will be able to understand how environmental systems interconnect
2. Students will be able to relate environmental systems to environmental sustainability.
3. Students will be able to analyze the effects of manufacture, production and use of either paper or plastic on environmental systems.
4. Students will be able to evaluate the roles and responsibilities of individuals, groups and societies in general in terms of environmental sustainability.

Setting and Sample

Students in this study were purposely chosen because they were in the cooperating teacher's class. According to Patton (2002) this study was "people based," but since the project takes place over a two week period it could also be considered "time based." Since these categories for case studies are not mutually exclusive (Patton, 2002, p. 231) it could also be considered an "activity based" study, since the time frame is also associated with completion of specific tasks and activities. The specific location for the study was a12th grade International Baccalaureate Higher Level Biology class at a secondary school in a coastal region of the Southeastern United States. The school and subjects were selected because these high school students have already learned basic environmental topics which were necessary for this sustainability education project. The students previously completed an Ecology unit as one of their additional topics for the course several months prior to this project. Selection of potential participants is based on the strategy of Homogeneous Sampling (Patton, 2002) because it used only students in one subject of similar grade levels. The IB Biology students used this design research unit as part of their end of year final assessments by their teacher so there was a motivation by the students to perform the tasks for grades.

It was optimal to have a specific teacher to work with who had an interest in teaching environmental science in general, and who valued emphasizing sustainability and stewardship of the environment. The teacher was selected because of her interest in the subject but also her willingness to participate with her students. The same teacher worked with me in a pilot study in October, 2017. She valued making research, inquiry, graphing, writing, and analysis priorities in her classroom I have a relationship with the teacher who participated in my study as she is a both former high school student of mine, and was hired by me when I was the department chairman. I have been retired from public school teaching for six years so I have no power hierarchy over her and consider her a friend. I believe I was perceived as an older veteran teacher when in the classrooms to conduct my study. The teacher was also full participant in the study and helped determine how the study was implemented in the classrooms. I introduced myself to the class initially and kept a professional distance from them while at the same time being warm and friendly, answering questions and participating if they asked me to.

Although it is expected to have variations on the level of ability, particularly based on possible non-native English speakers and a few Special Education students, it was necessary to investigate the conceptual learning in a group of students who are similar in age and who have been in the same class with the same teacher for several months. In some ways these students could also represent Critical Case Sampling as well since Patton suggests "if it happens here, it could happen anywhere" (2002, p. 236). These students represent model participants for the investigation because even though they have not taken a complete course in environmental science, they have been introduced to the introductory topics of water cycle, water usage and pollution, deforestation, and basic soil chemistry, climate change and biogeochemical cycling. Additionally the teacher claimed these students had been trained to conduct both independent and group inquiry laboratory investigations, and had good computer and research skills. It was anticipated by the teacher that the class could also benefit from improved instruction in graph construction and analysis. There was an expectation that students may have been exposed to systems thinking in a prior International Baccalaureate Programme course, but prior knowledge of systems thinking was addressed by the initial survey and none of the students had an idea of what it meant. After discussions with the teacher it was determined they represented a cross section of the school-wide student population despite the homogeneous nature of the selection process. Class demographics included 2 white males, 1 Hispanic male, 5 white females, and 5 Hispanic females.

The importance of qualitative inquiry can include the search for meaning where a major interest is in how different people make sense of their lives. There is a lot of variation in socioeconomic strata within this small geographic area of the Southeastern United States. There are children of wealth and privilege who drive expensive European cars who go to school with many students of poverty, some are even homeless. Some of the students may not have much if any printed material in their homes which could impact their data collection. This school district has the highest percentage of Hispanic and non-English speaking students in the state, and there is also a population of other immigrants from Eastern Europe and Asia, as well as approximately 15-20% African American so there is a lot of ethnic diversity in the school.

Positionality

In terms of implications of my positioning on the study process, I realized since I am not a secondary classroom teacher anymore, and I was taking on the mantle of researcher and university professor I thought I might initially be considered an "outsider" to teachers and students. I positioned myself so that the teacher considered herself as part of the research team, as an equal with me much like Cobb and Jackson proposed (2015). Direct communication with the teacher about her own student population and how best to achieve the research goals helped develop a higher level of trust and moved me more into being an "insider." I was an observer and my direct participation with the students was minimal. I introduced myself to the class initially and kept a professional distance from them while at the same time being warm and friendly, answering questions and participating if they asked me to. Although I maintained my distance and did not directly participate with the class activities, the students were aware of my presence in the classroom and laboratory and sometimes asked me questions about what I was doing. They seemed to be very interested in both me personally and the study in general. Since I got to know them indirectly while conducting the research, I provided the students with gift sets of recyclable bamboo utensils and metal straws at the end of the study when all instruction was finished and they were excited to receive them.

With design research it is important to discuss the progress of each aspect of each day with the teacher and if appropriate with others on the team each day. I realized this was a big investment in time for the classroom teacher so I needed to develop a good rapport and achieve “buy-in” about the project. Also, as the observer-researcher, I needed to give the teacher my full support during the class period and withhold judgment about performance of both the teacher and the students. I did not want my presence to influence the behavior of the teacher and students, so it was important not to be an obvious disruptive force in the normal classroom routine. To that end, an initial classroom visit was made before the research study began so the students could meet me and learn about the project. The classroom teacher collaborated completely on developing the design research.

LEARNING TRAJECTORIES

Simon (1995) suggested that a hypothetical learning trajectory should include the learning goal, the learning or instructional activities, and the thinking and learning in which students might engage. Learning trajectories typically include a sequence of instructional activities and resources with instructional theory that constitutes the rationale for the instructional sequence within specific fields (Cobb & Jackson, 2005). Clements et al. (2004) noted there is evidence that successful teachers help children move through learning trajectories and not through a curriculum per se. The initial design is a conjecture, a prospective notion of what and how students will learn but as a design study is conducted more specialized conjectures are usually framed and tested in other iterations (Cobb et.al, 2003). Hypothetical learning trajectories were developed for each of the four Learning Goals in this study by incorporating a group of instructional activities into a learning progression. The activities were sequenced to build on prior student learning.

The structure of the unit reflects modifications and additions to the learning strategies and instructional activities after the initial pilot study findings. The instructional sequence generally reflects a constructivist learning theory, modelled after *System thinking hierarchical model (STHM)* (Assaraf & Orion, 2005). The progression of activities began by ensuring students understood foundational knowledge about systems thinking in general, specific environmental systems and cycles, and issues of global sustainability. The lessons then had students explore through various metacognitive applications such as constructing a graphic organizer, followed by graphing/modelling and inquiry activities. There were crossovers between the instructional activities and sequences for each of the hypothetical learning trajectories as one activity was involved in addressing more than one learning goal. Students built on understandings from Learning Goals and made connections to systems thinking, environmental sustainability and evaluated their own impacts as they completed the assignments. Table 3.1 represents the instructional activities sequenced for hypothetical learning trajectories.

Table 3.1: Instructional activities sequenced for hypothetical learning trajectories relative to each Learning Goal.

Learning goal	Instructional activities sequenced for hypothetical learning trajectory	Tools to attend to learning goal
1. Students will be able to understand how environmental systems interconnect.	Foundational knowledge about systems thinking, environmental systems and sustainability issues was given first. This included whole class instruction using WWF website on systems, teacher-made materials on biogeochemical cycles, and active discussion on global sustainability issues. Internet research and construction of graphic organizer included production, manufacture, use and disposal of either paper or plastic chosen by student. The teacher explained students should include impacts on many different environmental systems.	Teacher power point, Internet website Student computer access, graphic organizers
2. Students will be able to relate environmental systems to environmental sustainability.	Activities listed above were followed by students creating bar and line graphs from environmental data provided by internet websites related to paper and plastic production, use and disposal. Students shared their environmental impact graphs and discussed sustainability issues brought forth from these graphs with the whole class. Students learned how to create a trend analysis for 50-100 years in the future using global temperature data provided by http://data.giss.nasa.gov/. Whole	Environmental data sets from Internet, student access to Excel spreadsheet or other graphing program or graph paper Global temperature data, student access to Excel spreadsheet

	class discussion about possible consequences of this trend followed. Students collected data on their own paper or plastic use and disposal as an inquiry investigation for three days and create expected/projected use for one year and 50 years or more using the same type of trend analysis. They reflected on consequences of their consumption and use in the conclusion/discussion of their lab reports.	or other graphing program for Trend analysis Student data collection methods for inquiry investigation, access to scales/balances, student access to Excel or other software for Trend analysis
3. Students will be able to analyze the effects of manufacture, production and use of either paper or plastic on environmental systems.	The activities listed for Learning Goals 1 and 2 supported this, particularly the graphic organizer which represents a flow chart of effects of manufacture, production and use, and also the environmental data set graphs. Construction of a digital poster which represents a possible implementation project involving Reduce-Reuse-Recycle (RRR) ideas involved more research on possible environmental systems impacts.	Student access to Internet for research, digital method for RRR project or poster board
4. Students will be able to evaluate the roles and responsibilities of individuals, groups and societies in general in terms of environmental sustainability.	Throughout the activities for Learning Goals 1, 2 and 3 students were encouraged to make real world connections about consequences of continuing to manufacture, use and dispose of paper or plastic the way we do today. Conclusion/Discussion of student lab reports based on their trend analyses also related to Learning	

	Goal 4, as did the RRR project. The final reflection essay prompted them to think about their own behaviors and those of others to help them predict how personal and societal changes can impact sustainability.	 Student access to computers to write up lab reports and reflection essays or use notebooks

DATA COLLECTION

Different qualitative and quantitative data were obtained each day as well as videotapes of classroom activities and interactions which were reviewed. A complete outline of the two week project with activities, student assessments, documentation, survey questions and proposed data collection points is located in Appendix A, 2 Week Instructional Activities and Sequence. There were many data collection methods and data analyses used; see Data Collection and Analysis Methods Table 1 which links them to the Learning Goals. Each day before the classes began the teacher was consulted about the plan for the day, and the teacher debriefed with me after school about what worked and did not work. All teacher preparation and debriefing conferences were audio recorded and transcribed. All class sessions were video-recorded by using a SWIVL camera and observation field notes were made during all of the class periods.

The design research took place over a two week span and included eight class periods ranging from 45 minutes to 3 hours of contact time with participants, with the typical sessions lasting for a 90 minute block schedule. The project was conducted from May 13-17, and May 20-24, 2019, and a preview classroom visit and introduction occurred on May 10, 2019. Given permission by students and parents, all classes were videoed using a SWIVL camera and microphones. Field notes of every class were written, and I maintained an electronic notebook throughout the class periods, writing down what the teacher said and did and as much of the students' comments and interactions as could be heard. The notes also included "memos to self" to remind me of specific events and questions to ask the classroom teacher. This provided a running narrative of the classroom observations and was used to augment the class videos. Videos and observation notes were used to assist in evaluating student understanding especially when they were making whole class presentations of their research and explanations of some of their activities.

Student artifacts

This study provided both qualitative and quantitative data collection. Student samples of brainstorming as a whole class, and graphic organizers were evaluated to determine the degree of system wide approaches the students detailed, and the results were quantified. Daily student work samples were assembled sequentially and included: Graphic organizers/research; Simple bar graphs; Sustainability data bar graphs; Trend analysis graphs; Digital posters/Reduce Reuse Recycle implementation projects; Reflection essays and final laboratory reports. Pre and post survey answers of students' understanding of systems thinking were quantitatively examined. Student experimental design reports and data analysis, and graphic representations were quantified when reporting the findings on how well they understand systems thinking. Surveys by students were presented to represent their own perspectives and their changes in understanding related to systems thinking and environmental sustainability. General evaluations on student learning were more qualitative in nature when reviewing their reflective writing, but this was also quantitative when using a scoring rubric. Laboratory reports were assessed for completion and scored using a rubric as well. Student comments on surveys, observations from videos, as well as discussions and interviews with students were qualitative. Daily Observation Checklists by the cooperating teacher were used to evaluate the connections students were making to Learning Goals.

Several pre and post class questions which served as brief warm ups and exit slips for the lessons were conducted using two-question Mentimeter online surveys. These gave the class immediate feedback to the answers of the group and were shown to students on the smart board. Additionally an initial survey, a mid-point survey and a final summary survey were also conducted using Survey Monkey online survey software and the results provided further insight into student learning, and attitudes. After students answered the initial Survey Monkey before the project started, the teacher briefly introduced the researcher and student consent forms were collected**.** The researcher obtained human subject approval and consent forms from students and parents, and the teacher and was approved for the project by the university Institutional Review Board (IRB).

The classroom teacher provided a Power Point of the information she taught students each day, with instructions for completing all activities. She also provided her laboratory report format which is based on the International Baccalaureate Internal Assessment template and the criteria rubric she uses to evaluate these laboratory investigation formal write ups. Daily observation checklists were submitted by the cooperating teacher after each class period to reflect on ways the activity support or do not support the four learning goals which are described later.

Focus group interviews

Small focus group interviews were conducted with the students on the last two days of the week where they were asked to make interpretations of their data and relate their experiences with systems thinking to the over-arching question of environmental sustainability. Two small focus groups of three students each were conducted during the last two days of the two week study. There were no white males represented in the small focus groups as these students were not in class during the times allotted for the interviews. The first group contained students A, B and C and the second group contained students D, E and F as identified below:

- Student A: Hispanic male
- Student B: Hispanic female
- Student C: White female
- Student D: Hispanic female
- Student E: White female
- Student F: Hispanic female

Table 3.2: Data Collection and Analysis Methods

		DATA SOURCES			
		Participant Group 1: *STUDENTS*	Participant Group 2: *TEACHER*	Documents/ Artifacts:	Document/ Data Analysis
RESEARCH QUESTIONS	RQ 1	Videotape classroom, surveys, observations, Mentimeter questions, small focus group interviews, Observation Checklist, field notes Brainstorming,	Videotape classroom, observations, field notes, informal and formal evaluation of student work and class discussions. Pre and post surveys, conferences and interviews.	Qualitative: Videotape, observation, and video review notes of classes. Student work, surveys, graphing activities, investigation design, raw data	Videos transcribed using Speechnotes; student/teacher conversation/ discussions coded using grounded theory Focus group questions evaluated

	research, preparation of graphic organizer with partner Individual inquiry/ experimental design activity pre-lab and final report Individual and group graphing instruction and analysis of data Final reflective essay, RRR project	Observation Checklist	collection, data analysis, group brainstorming graphic organizers, RRR poster, summary research <u>Quantitative:</u> Evaluation of student graphing and data analysis	based on learning goals Student surveys, Mentimeter answers (pre-, during, post-project) analyzed and quantified Observation Checklists from teacher and researcher reviewed each day/each activity and related to learning goals Review student activities for correctness of application and evaluation of data Review student pre-laboratory and final laboratory reports using a rubric/ evaluate connections to learning goals Final reflective essay scored using rubric to

				assess connection to learning goals RRR project evaluated to connect to learning goals
RQ 2	Videotape classroom, observation, field notes, Observation Checklists, small focus group interviews Inquiry laboratory report data analysis and conclusions RRR project Final reflection Essays Surveys	Videotape classroom, observations, and field notes. Informal and formal evaluation of student work and class discussions. Pre and post instruction conferences and interviews with students and teacher, Observation checklist	<u>Qualitative:</u> Videotape, observation, and video review notes of classes, and Observation Checklists. Evaluation of student work: graphic organizers, data analysis and conclusions in inquiry laboratory reports, RRR project, final reflection essays <u>Quantitative:</u> Scoring of reflection essay, evaluation of survey answers	Videos transcribed using Speechnotes; student/teacher conversations and discussions coded using grounded theory Observation Checklists from teacher reviewed each day/ activity and related to learning goals Review student graphing activities for correctness of application and evaluation of data Evaluate student pre-labs and final laboratory reports using

				rubric and connections to learning goals RRR project for connections to learning goals Student surveys and Mentimeter answers (pre, during, post project) analyzed and reviewed
RQ 3	Videotape classroom, observation, field notes, small focus group interviews Inquiry laboratory report data analysis and conclusions Final reflection essays Surveys	Videotape classroom, observations, Observation Checklists, field notes. Informal and formal evaluation of student work and class discussions. Pre and post instruction conferences and interviews with students and teacher	<u>Qualitative:</u> Videotape, observation, field notes of classes. Evaluation of student work: data analysis and conclusions in inquiry lab reports, RRR project, final essay <u>Quantitative:</u> Evaluation of survey answers, scoring of reflective essay	same as above

Daily data collection summaries

Day 1

The first day began with an online initial Survey Monkey survey to assess students' understanding of sustainability and systems thinking, followed by a whole class introduction to systems thinking and a short video on circular economy or clothing industry. This was followed by small group brainstorming on different kinds of paper and plastic.

Day 2

The students asked to have more time to finish brainstorming paper and plastic since not all students had time to give examples before the end of class. Students then selected either paper or plastic as their focus for the project and began internet research and construction and presentation of a graphic organizer/concept map. Students were supposed to complete a brief Mentimeter survey as a class exit slip but were called to a school wide assembly.

Day 3

Students completed the two- question Mentimeter as a warm up. To use this technique students logged into www.mentimeter.com using either their cellphones or tablets, and they were given a specific code for accessing the questions. The purpose of these questions was to get an initial sense of what student interest was related to environmental sustainability and what terms they associated with this topic. None of the students had previously used Mentimeter surveys and they were engaged and excited to complete the questions and see the immediate responses to both questions on the classroom smart board.

The teacher next reviewed the idea of concept mapping, and graphic organizers and showed an example. She showed how they should begin with an essential theme that then branches off. She told them they could use Kami app on their tablets or another method of drawing. Some students used Prezi. She directed them to a Google Dropbox on their class website for them to submit their electronic versions, and also told them they would be presenting their concept map/graphic organizer to the class. Directions for this activity on the smart board were as follows:

- pick partner
- decide on paper or plastic as topic for the unit
- begin to research on how paper/plastic is made and how this contributes to usage of resources: trees, fresh water, fossil fuels for production, transportation fuels, other environmental systems
- brainstorm about global consequences of paper or plastic production
- use research to prepare a graphic organizer/concept map of what you find relative to manufacture of paper/plastic and the effects on the environment

Students pulled their desks together worked with partners, and one group of 3 girls. While students worked, the teacher walked around and checked resources and told the class she wanted them to make a hyperlink to each reference source they used. Two of the groups made presentations of their electronic versions of the graphic organizers at the end of the class. Students critiqued each other's concept maps/graphic organizers and also discussed the links to environmental systems. The students completed a Mentimeter which asked them to assess to what degree the research and graphic organizer on production /use of paper/plastic helped them understand environmental systems, and also to evaluate "How would you describe your skill at data collection and graphing?" as a benchmark for their skills.

Day 3

The teacher permitted the remaining students to finish presenting their graphic organizers at the beginning of class and students continued to discuss environmental systems related to paper and plastic manufacture and use. The teacher began whole class instruction of graphing. Her notes for this lesson were in her Power Point for the two weeks. She reviewed Pie charts, Line graphs, Scatter plots and Bar graphs and discussed when they should be used for specific kinds of data. She discussed proper labeling of graph axes, making appropriate titles and set up using dependent and independent variables. Her list for making "good graphs" included using the right type of graph for the data, include a title, label and use correct units for each axis, distribute the data evenly on the graph and provide a key if necessary. She related those topics to good hypothesis writing and how they should write these as "if, then" statements emphasizing "If 'independent variable' then 'dependent variable'." After she went through her presentation on good graphing techniques, the students were assigned to six small groups and went back into the laboratory and stood in their group at one of the laboratory tables. At each laboratory table was a data table with a simple survey and the choices as follows:

1. What type of pet do you have? Cat, dog, fish, rodent, other, none
2. What is your birth month? All twelve months listed
3. Mode of transport to school? Car, bus, bicycle, walk, other
4. Number of siblings? Zero, one, two, three, four, five or more
5. Favorite pizza topping (choose one)? Just cheese, pepperoni, sausage, veggie, other
6. Favorite color? Red, orange, yellow, green, blue, indigo, violet, black, other

The students were directed to go around the laboratory tables and fill out each of the data tables by using a hash mark to indicate their answers in the appropriate box so that a complete set of class data could be compiled for each survey question. After they finished answering the questions, the student group assigned initially to each laboratory table was required to create a “good graph” of the class data. The teacher also briefly mentioned they would be starting a 3 day inquiry investigation/experimental design project from home in which they would collect data on paper or plastic usage but she did not go into details.

Day 4

Students began reviewing and actively producing different kinds of graphs with the idea that students must understand how to both collect and interpret data. Different groups were assigned to produce bar graphs, and line graphs from different environmental science Internet websites that contained information related to either paper or plastic such as loss of forests, or plastic leachate in water. She directed them to access the data provided from Statistics Brain or World Watch, U.S. Department of Agriculture, World Health Organization, World Watch and other websites which was in her Google Class Dropbox. Each pair of students was assigned one of the data sets with the specific graphing directions associated with them. In addition to finding the URLs in Google classroom, the teacher also gave students a small strip of paper with the website and instructions. The data sets were identified and selected by the researcher because they contained relevant information about paper product manufacture, per capita use, deforestation, soil degradation, global water availability and water use in paper production and other related topics to environmental systems impacted from the paper industry. The complete list of websites provided to the students is located in Appendix A.

Students worked with a partner using these sustainability data sets to prepare their own bar graphs using Excel spreadsheets. The teacher gave them “Basic instructions” for using Excel to make bar graph using a slide from her Power Point. She then went through a process for making a graph from Excel. She also reminded students to be sure to make title, label axes, and give units as they had done the day before with the simple graphing activity. After they produced their graphs, students were instructed to write a brief summary paragraph of what the data represents, and were told they would make a short presentation of their graph and what it means in terms of environmental systems and sustainability. Students were instructed to upload final graphs to the teacher's Google classroom folder.

Additionally students began to formulate their experimental design in order to facilitate collection of data on paper usage for three days and homework involved preliminary design of this inquiry activity. The teacher introduced students to the plan for the next three days in which they would design a three-day inquiry investigation to collect data on their personal and family use of paper or plastic. She used a Power Point to review how to write up parts of an experimental design and how to begin collecting data, and formulating hypotheses. Students finished the class by answering two Mentimeter questions as an exit slip for the day. The first question was related to the experimental design "How many categories of paper of plastic did you come up with for your data collection project?" The second question asked them to "Predict what kind of paper or plastic item you and your family will have most during the three day study."

Day 5

The cooperating teacher and researcher decided to have students begin two activities which they would finish the following day, allowing them to complete a part of each on day 5. First she briefly reviewed her "good graph rules" again using the same

Power Point she had used in class for the past two days. The next thing the students were asked to do was to input data on average global temperatures from 1866 through 1975 into an Excel spreadsheet using their Chromebooks. The data was provided from NASA Data and Images (2019) and was placed in the class Google Dropbox for student access. All students completed the line graph and saved it for the next day to work on making a trend analysis.

As students were finishing their line graphs of the temperature data, the teacher referred them back to their laboratory report format in Google classroom so they could follow the steps on how to write up their investigation. She re-posted both her IA (Internal Assessments) Laboratory Report Template and IA Criteria Rubric for the students to use to begin writing up their three day study. These documents are located in Appendix C: IA Laboratory Report Template and Rubric. They had experience doing these reports before as part of their International Baccalaureate Biology course during which they did several independent research experiments. She explained to the students they are doing their own write up but could have the same hypothesis or research question or a different one from their classmates.

At the end of class students were surveyed as using Mentimeter Questions to briefly identify “What is your method of collecting paper or plastic over three days?” and to “Give a word or short phrase to describe how you feel about the amount of paper or plastic being used worldwide.”

Day 6

Students took the data they saved in Excel spreadsheet for global temperature change and learned how to create a model trend analysis of data over another one hundred year period of time. This was performed so they would be able to do a similar trend analysis of their own paper or plastic data for three days which they would extrapolate for a month, a year and eventually fifty or more years in the future. Additionally, they continued to collect their data as homework and further delineate their experimental designs as required by the laboratory report format the teacher provided. This included hypothesis, materials, stepwise procedure and creation of data tables to this point. She provided directions for conducting the investigation on her Power Point teacher notes

The teacher reminded them about examples of qualitative and quantitative data collection and also suggested it is better to have more categories for collection of paper or plastic. They discussed whether to just measure things that were being disposed of and not what was being purchased, and they made a class decision to do it that way. They discussed whether to collect data from each person in their home, were then asked what unit they would use, and most students agreed to use kg. The teacher also suggested that if they are using a bathroom scale may need to convert from pounds, and to remember there is a possible source of error. One girl brought up use of plastic drinking straws and remarked about controversy because they are often associated with impacts on marine animals. The teacher suggested that starting today they should monitor straw use, and one boy asked if plastic straws are recyclable and there was a discussion in class about alternatives like metal or paper straws and the sustainable use of those.

Students had the last part of class to work on their formal write ups of the inquiry laboratory investigation, and also completed the two-question Mid-point Survey on Survey Monkey online. The first question asked student "Which of the graphing activities completed were most effective in helping you review graphing techniques?" The second survey question asked "Which of the graphing activities were new methods or skills for you?"

Day 7

Students collaborated with a partner to create reduce, reuse, and recycle (RRR) digital poster implementation project ideas. They presented their poster to the class and prompted discussion about sustainability and personal behaviors. There was little time left for students to work on their formal laboratory report. The researcher conducted one small focus group interview session while some classmates were finishing their RRR posters and uploading them.

Day 8

Students were given time on the last day to write their final reflection essay and also to submit their final laboratory report by uploading both to the Google classroom. The rubric for the reflection essay is in Appendix D and the laboratory report rubric is in Appendix C. The teacher evaluated students using these scoring rubrics. Students were given a gift of bamboo utensils and steel straws set by the researcher, as well as cupcakes as a thank you for participating in the project. The final day also included a number of wrap up activities including discussions, reflective essay and final survey questions, small focus group interviews.

DATA ANALYSIS

Classroom observations

Videotaped classroom observations, and sessions with the classroom teacher, as well as small focus group informal interviews with the students provided qualitative data. When watching the video recordings, the researcher took notes and re-watched classroom incidents that included possible student misconceptions or barriers to student learning. Video recordings of each class were transcribed using Speechnotes online an online text to automatic transcription software. These transcripts were coded to provide evidence from the observations. All of the classroom videos were analyzed using principles of video analysis suggested by Derry, Pea, Barron, Engle, and Erickson (2010). I watched the classroom video recordings with the guidance of field notes and described general features of each session such as class topic, types of learning activities, patterns in classroom discussions and behaviors. Each classroom activity was evaluated by the teacher using the Observation Checklist in relation to the overall Learning Goals for the unit.

Coding

Although Cresswell (1998) outlined five different qualitative methods, one method, Grounded Theory is most applicable to this study in which data were collected by field observations and interviews which were then subject to coding. Initial or open coding categorizes data into broad groups, and axial or secondary coding aims to further subdivide the codes into similar or common categories. The broad categories for coding were evidence of systems thinking, specific environmental systems, and connections of systems thinking or environmental systems to specific activities, and to sustainability and finally connections to behavior related to sustainability. The broad categories were subdivided based on who was giving the information, either the teacher or students. The categories helped identify trends and misconceptions and there was substantial data that was iterative and process oriented. Coding categories were also used to assist in clarifying the notes for relevant observation points. Another colleague assisted with reviewing and coding of two days of observations to validate the researcher's interpretations. I originally planned to use a reductionist coding approach as often seen in Grounded Theory (Strauss and Corbin, 1998). This approach involves multiple coding of students' open-ended responses, and separating out codes according to emerging themes. However, I found by reviewing transcripts of the classes that my initial codes represented commonly used concepts the students and teacher expressed in discussions and while completing activities. Tracking the classroom observations and activities using codes listed below assisted in evaluation of student understanding, frustrations or misconceptions. The initial six categories were related to whether students or the teacher made any mention of the topics of systems thinking, environmental thinking or environmental sustainability, while the second set of six categories noted deeper connections to the topics.

Field notes were particularly helpful related to student comments and their personal interactions that were not clearly picked up by the audio. Categories for coding of the lesson observations, transcripts and student focus groups included the following:

- Teacher discusses systems thinking
- Student discusses systems thinking
- Teacher discusses environmental systems
- Student discusses environmental systems
- Teacher discusses environmental sustainability
- Student discusses environmental sustainability
- Teacher makes connection of activity to environmental systems
- Teacher makes connection of activity to systems thinking
- Teacher makes connection of activity to environmental sustainability
- Student makes connection of activity to environmental systems
- Student makes connection of activity to systems thinking
- Student makes connection of activity to environmental sustainability
- Student addresses his/her behavior related to environmental sustainability

Student Artifact Analysis

Grounded theory supported the collection of data in the form of student work artifacts (Strauss & Corbin, 1998). Some of the specific student-produced documents collected and examined included an initial survey questions on environmental sustainability, and system thinking. Graphic organizers from research on paper or plastic manufacture and usage were collected. Then students reviewed and made simple bar graphs, followed by an Excel spreadsheet produced graphs of related environmental systems data sets and summary paragraphs. Students extrapolated a trend analysis of a data on global temperature change using Excel spreadsheets to see the possible extension of the data over one hundred years in the future. Experimental designs for paper/plastic collection, raw data for paper/plastic collection, graphs created from raw data, individual and small group calculations of extrapolated paper data for a year were all included in the formal laboratory report write up. Reviewing the level of graphing ability of the students was important to the project to understand if they could take raw data, graphically express it, and make associations from it. Small group digital posters on a possible reduce-reuse-recycle implementation project were created as well as a final reflection essay Students completed daily exit slip type questions using Mentimeter, or survey questions using Survey Monkey. Throughout the two week unit, each activity was evaluated through the lens of the four learning goals using the daily Observation Checklist. Many of the Mentimeter and Survey Monkey questions likewise related to the learning goals. In addition, the final reflective essay rubric also linked to the learning goals.

Examining and analyzing the students' work and survey questions along with reviewing classroom observations during the sessions helped make it possible to assess how effective the paper/plastic usage study was at helping the students understand the impact of usage on their systems thinking. For example, as the students make associations between cutting down trees for paper pulp and deforestation, can they also connect that understanding to water runoff, erosion, water contamination, loss of soil fertility and so forth? Also it was important to see how students understand the implications of their own consumption on a global scale. An important aspect of this project was to understand how graphing and analysis of data about one topic (paper or plastic usage) could possibly jump start conversations and students' comprehension of systems thinking and sustainability. Having students conduct the trend analysis of these data were designed to help them prepare to extrapolate their own paper/plastic consumption data from a two day total to one month and eventually one year. In my previous study in October, 2017 the students took longer than anticipated to complete this activity so the teacher and I decided that they would require more time and actually some students needed to take this work home to finish. All graphs were uploaded into the class Google Dropbox and reviewed by the researcher and teacher. Links to systems thinking were made by the teacher who also encouraged student interaction and discussion as time permitted. The teacher created a rubric for evaluating the students' inquiry experimental design lab reports, and the research team created a scoring rubric for the reflection essay. A general evaluation of student understanding through their graphs, and RRR projects was made by the team.

Validity Evidence/Trustworthiness

Lincoln and Guba (1985) suggest that trustworthiness of a research study involves establishing four parameters: credibility or confidence in the truth of the findings; transferability which demonstrates the findings may be applicable in other settings; dependability which shows the results are consistent and replicable; and confirmable which represents neutrality or lack of bias by the researcher and her subjects. They describe a number of techniques for establishing credibility that were employed in this study including prolonged engagement, persistent observation, triangulation, peer debriefing, and member checking. To ensure transferability Lincoln and Guba suggest "thick description" as a way to provide external validity. This is accomplished by describing a phenomenon in sufficient detail one can begin to evaluate the extent to which the conclusions drawn are transferable to situations. As far as dependability of the data, daily reviews and input by the cooperating teacher and evaluation of coding of two classroom video transcripts with another colleague constituted a type external audit and for confirmation of neutrality. Triangulation of the various kinds of data collected on the same topics also provided validity evidence. Reflexivity was enhanced by having a cooperating teacher as a co-researcher and field notes were a springboard for reflexive journaling.

In order to monitor and mitigate the impact of researcher subjectivity and positionality multiple data collection strategies were employed. Classroom activities and teacher roles were planned before the study began so that the cooperating teacher became a true teacher-researcher. This helped establish a strong contribution resulting in greater "buy in" as well as trustworthiness. The researcher acted as an observer with limited interaction with the students. Field notes and transcribed videotapes of the actual class observations as well as daily Observation Checklist by the classroom teacher added to daily debriefing and planning sessions with the classroom teacher. Researcher appearance, behavior, discretion, sensitivity, patience, friendliness, and attentiveness were addressed by the researcher. Research and review of literature helped employ strategies to consider experiences from the students' perspectives. Rigorous data collection while keeping subjectivity to a minimum was accomplished by reflective thinking, journaling and memos to self, discussions with colleagues, and input from the cooperating teacher.

Validity evidence included the many types student generated work, responses to surveys, observations and small focus group interviews. The teacher completed a daily Observation Checklist which will helped evaluate the activities in terms of their relationship with what they have learned compared with the Learning Goals. The teacher and researcher also evaluated the formal laboratory reports using a standard rubric in Appendix C, and graded the reflection essays using the rubric in Appendix D.

CONCLUSION

An educational approach that emphasizes life situations and global issues has emerged as a primary concern in order for students order to understand and address global environmental challenges (Bybee, 2010). The development of systems thinking in the context of the earth and environmental systems consists of several sequential stages arranged in a hierarchical structure (Assaraf and Orion, 2005, 2010; Hmelo, Holton, and Kolodner, 2000). The cognitive skills that are developed in each stage serve as the basis for the development of the next higher-order thinking skills. While developing the instructional plan in this design study, these approaches were considered so that students were encouraged to develop systems thinking by considering the effect of paper or plastic manufacture, consumption and disposal in a holistic manner. Through their knowledge and skills from different disciplines, they can be active learners who think critically about their data collected, and begin to take ownership of their impact on environmental systems. In selecting and sequencing the activities, guidelines suggested in the literature were taken into account and multiple methods were used to achieve learning objectives and to help all students respond equally (Scoullos & Malotidi, 2004). The fundamental characteristic of system thinking is thinking as a whole so I argue that teaching about complex issues of environmental sustainability can be taught through this template for learning.

CHAPTER 4

FINDINGS

PART ONE: INTRODUCTION

This dissertation study used a design research experimental framework to investigate different instructional strategies and their impact on student understanding of environmental systems thinking and sustainability education. Design experiments involve both developing instructional designs to support particular forms of learning and systematically studying those forms of learning taking place (Cobb, 2003). Educational Design Research (EDR) can be thought of as intervention research designed to inform teaching "practice". Three general phases can be characterized in EDR: an analysis/orientation phase; a design/development phase; and an evaluation or retrospective phase all of which are often repeated throughout the duration of a project. EDR can result in potentially usable educational innovations (e.g. technology system, curriculum, materials, systemic approach, etc.) and generate knowledge about teaching and learning through basic and applied research cycles. Design research is data-driven and provides rich information about learners, context and instructional strategies to inform empirical studies (Bannan-Ritland, 2003).

A pilot test study was conducted eighteen months earlier and helped determine the aspects of this research as a design/development phase. Cobb, et al. suggested these educational design experiments entail "engineering" particular forms of learning to increase understanding of a *learning ecology* which is described as a complex interacting system, (2003, p.9). One such setting involves experiments in which a research team collaborates with a teacher (who might be a research team member) to assume responsibility for instruction where the methodology can be conducted in diverse classroom settings. This Educational Design Research (EDR) project embraced the phases and precepts outlined above. The setting involved collaboration with a secondary classroom teacher during all stages of the research, who served as an equal member of the research team and who conducted the classroom instruction. Educational design projects, in contrast to typical science research, concentrate on developing and testing the effectiveness of the kind of curricula, programs, and practices that could be implemented by schools as supported by National Science Foundation recommendations (NSF, 2013). As reviewed earlier in Chapter 2, NSF supports educational design research describing its goal related to developing solutions for education or learning, improving student engagement or mastery of skills. They note these types of projects draw on existing theory and evidence to design and iteratively develop interventions or strategies to achieve specific learning goals (NSF, 2013, p. 9) helping inform the practice of teaching science. The research team looked for learning goals built upon natural developmental progressions or trajectories of the thinking and learning of high school science students, similar to those described by Clements' Curriculum Research Framework (CRF) (2007). Originally Clements emphasized learning trajectories identified in empirically based models of children's thinking and learning of mathematics. The CRF included sets of activities that were sequenced according to learning trajectories (2007).

To help identify a sequence of learning in this project, four Learning Goals were established as follows:

1. Students will be able to understand how environmental systems interconnect.

2. Students will be able to relate environmental systems to environmental sustainability.

3. Students will be able to analyze the effects of manufacture, production and use of either paper or plastic on environmental systems.

4. Students will be able to evaluate the roles and responsibilities of individuals, groups and societies in general in terms of environmental sustainability.

Each teaching strategy and activity employed during the project was evaluated through the lens of these Learning Goals by the collaborating teacher each day using Observation Checklists. The Learning Goals were reflective of overarching research questions of this EDR which were used to develop a learning process which focused on sustainability education with emphasis on systems thinking. The first two Learning Goals were focused on Research Question One. Learning Goal Three centered on Research Question Two, and Learning Goal Four related to Research Question Three. The research questions for this study were:

1. Using Design Research and various instructional tools, how do students develop an understanding of systems thinking and relate it to environmental sustainability?
2. How does analyzing personal and classroom data on paper or plastic usage and recycling influence high school science students' understanding of global environmental sustainability issues through the lens of systems thinking?
3. How do students come to understand the impact of the effects of individual behaviors on broader issues of environmental sustainability?

In order to achieve data saturation, samples of all student work were collected from each different activity and were reviewed by the research team for patterns in terms of student responses, and student strengths and weaknesses related to the Learning Goals and the Research Questions. These work samples were assembled sequentially and included: Graphic organizers/research; Simple bar graphs; Sustainability data bar graphs; Trend analysis graphs; Digital posters/implementation projects; Reflection essays and Final laboratory reports of an Inquiry Investigation. Several pre and post project questions served as brief warm ups and exit slips for the lessons and were conducted using Mentimeter online surveys. These gave the class immediate feedback to the answers of the group and were shown to students on the smart board. Additionally an initial survey, a mid-point survey and a final summary survey were also conducted using Survey Monkey online survey software and the results provided further insight into student learning, and attitudes. Finally, two small focus group interviews of three students in each group were conducted to gain more insight into student perceptions of the activities in the project. The proposed two week instructional sequence with all activities is located in Appendix A.

The following Table 4.1 summarizes the four Learning Goals with daily activities during the two week research project. Short Mentimeter questions helped focus students on topics for the day or reflect on the activities they completed. Initial, Mid-point and Final surveys using Survey Monkey are also included because they were used to set benchmarks initially for preliminary understanding, and later for reflection on environmental systems and sustainability and how they were engaging in the project. The two small focus group interviews were conducted during class on the last two days while other students worked on the other activities. Daily Observations Checklists were submitted by the cooperating teacher which allowed her to reflect on the activities conducted during the class period to evaluate ways they supported the four Learning Goals which were described earlier. These data and samples of student work are provided for each instructional activity. Teacher reflections and conversations with the researcher were helpful in understanding whether the given activities helped address not only the Learning Goals but how they supported the Research Questions. A complete set of all Daily Observation Checklists is located in Appendix B.

Table 4.1: Daily activities correlated with Learning Goals

Day	Learning Goal 1: Students will be able to understand how environmental systems interconnect.	Learning Goal 2: Students will be able to relate environmental systems to environmental sustainability.	Learning Goal 3: Students will be able to analyze the effects of manufacture, production and use of either paper or plastic on environmental systems.	Learning Goal 4: Students will be able to evaluate the roles and responsibilities of individuals, groups and societies in general in terms of environmental sustainability.
Day 1	Initial survey on sustainability and systems thinking Whole class instruction on environmental systems and sustainability Video on fashion industry/circular economy Whole class brainstorming on things made of	Initial survey on sustainability and systems thinking Whole class instruction on environmental systems and sustainability Video on fashion industry/circular economy Whole class brainstorming on		Video on fashion industry/circular economy

	paper and plastic	things made of paper and plastic		
Day 2	Mentimeter on Environmental systems Research/Graphic organizer/ presentation on paper/plastic manufacture and usage	Research/Graphi c organizer/ presentation on paper/plastic manufacture and usage	Research/Graphic organizer/ presentation on paper/plastic manufacture and usage	Mentimeter on Environmental systems Research/graphic organizer /presentation on paper/plastic manufacture and usage
Day 3	Mentimeter on graphic organizer, graphing/data collecting skills	Mentimeter on graphic organizer, graphing/data collecting skills	Mentimeter on graphic organizer, graphing/data collecting skills Simple data collecting/bar graphing	Mentimeter on graphic organizer, graphing/data collecting skills Simple data collecting/bar graphing
Day 4	Sustainability bar graphs of worldwide data, summary paragraphs, presentations	Sustainability bar graphs of worldwide data, summary paragraphs, presentations	Sustainability bar graphs of worldwide data, summary paragraphs, presentations	
			Design data table for inquiry investigation, begin data collection	Design data table for inquiry investigation, begin data collection
			Mentimeter on categories for data collection and prediction of paper and plastics usage	Mentimeter on categories for data collection and prediction of paper and plastics usage
Day 5	Line graphs of global temperature data/prep for			Line graphs of global temperature data/prep for

	trend analysis		Design procedure/methodology for collecting paper/plastic data and extrapolation for inquiry investigation Mentimeter on inquiry methods, and perception about worldwide paper/plastic use	trend analysis Design procedure/methodology for collecting paper/plastic data and extrapolation for inquiry investigation Mentimeter on inquiry methods, and perception about worldwide paper/plastic use
Day 6	Trend analysis using Excel spreadsheet of global temperature data Continued data collection and research for inquiry investigation	Trend analysis using Excel spreadsheet of global temperature data Continued data collection and research for inquiry investigation	Continued data collection and research for inquiry investigation	Trend analysis using Excel spreadsheet of global temperature data Continued data collection and research for inquiry investigation Mid-point survey on graphing skills
Day 7	Data analysis/trend extrapolation and research for inquiry investigation Digital posters/ implementation (Reduce Reuse Recycle) projects	Data analysis/trend extrapolation and research for inquiry investigation Digital posters/ implementation (Reduce Reuse Recycle) projects	Data analysis/trend extrapolation and research for inquiry investigation Digital posters/ implementation (Reduce Reuse Recycle) projects Small focus group	Data analysis/trend extrapolation and research for inquiry investigation Digital posters/ implementation (Reduce Reuse Recycle) projects

Day 8	Small focus group interview #1 Final Reflection Essay Formal Write up of Inquiry Investigation Final Survey on systems thinking, environmental sustainability and engagement in project Small focus group interview #2	Small focus group interview #1 Final Reflection Essay Formal Write up of Inquiry Investigation Final Survey on systems thinking, environmental sustainability and engagement in project Small focus group interview #2	interview #1 Final Reflection Essay Formal Write up of Inquiry Investigation Final Survey on systems thinking, environmental sustainability and engagement in project Small focus group interview #2	Small focus group interview #1 Final Reflection Essay Formal Write up of Inquiry Investigation Final Survey on systems thinking, environmental sustainability and engagement in project Small focus group interview #2

PART TWO: INTITIAL PRE-PROJECT SURVEY RESULTS

Student's initial thinking was assessed before starting this two week design research project. The thirteen students were asked to answer a series of four online Survey Monkey questions before class to establish baseline information about their exposure to and understanding of Systems Thinking, and Environmental Sustainability. Students were not able to see the class answers. For Question 1: "Have you ever heard of environmental sustainability?" 10 out of 13 students or 77% indicated "yes," and 3 of 13 or 23% indicated "no." Question 2 was open ended and asked "Give a brief definition of what you think environmental sustainability means." Students in general gave vague answers to this question and often used the words "sustain" or "sustainability" as part of the definition. Five indicated it had something to do with the health of the environment, one indicated the need to provide for the earth's population, and one suggested maintaining resources for future generations. Four students described keeping ideal conditions was important. Student responses are presented below in Table 4.2.

Table 4.2: Initial Survey Question 2- Give a brief definition of what you think environmental sustainability means.

Student Initial Survey Responses
"Using the non-renewable resources we have on Earth in a rationed manner so that future generations will still have those resources."
"How to sustain the environment in a healthy and efficient way"
"Taking care of the environment."
"Watching consumption/usage of nonrenewable resources and utilizing the renewable resources available in the environment"
"Environmental sustainability is maintaining the environment in good conditions such as by assessing the health of the environment."
"Individual ecosystems that are capable of sustaining the life within it"
"Environmental sustainability is when the environment has enough resources to support the population"
"the ability of the environment to sustain itself"
"Retaining Earth's natural resources."
"Taking care and being able to sustain the environment"
"The ways in which we can keep our environment in an ideal condition where it is safe to live on"
"Ability to maintain the environment"
"Providing services that keep the environment healthy at a reasonable cost."

Initial Survey Question 3: "Have you ever heard of systems thinking?" was included as a benchmark to see what, if any exposure students had to the idea of systems thinking, which was an important aspect of the project. Based on the answers, none of the students in the class had ever heard of systems thinking. This was unexpected as all students had a prior International Baccalaureate course called Theory of Knowledge as juniors that did address systems thinking in a general way.

Initial Survey Question 4 was also open-ended: "Give a brief definition of what you think systems thinking means." As with responses to question 2, many of the students answered vaguely and used the word "system" in their answer. In general the characterizations the students gave were not accurate. An accurate definition would include an understanding of how components regarded as interrelated systems influence one another within a larger whole. Five of the responses made a connection to the environment or ecology, even though the question did not indicate that was part of the definition. Students may have made assumptions about including environment in the definition because they had a previous question about environmental sustainability and that concept was still in their focus. Additionally they may have considered merely how systems thinking could be applied to environmental issues and not thought about the concept in a broader sense. Only one of the students gave a definition that was a good representation of what systems thinking means in a general way, "Thinking in terms of the whole instead of the parts." Another student likened the definition to mind maps, which is possibly something they have done in classes before writing, "It could be the ways that the mind thinks such as how our thoughts are like mind maps in a sense and how certain aspects such as how one approaches the way of learning knowledge." Student responses are presented below in Table 4.3.

Table 4.3: Initial Survey: Question 4- Give a brief definition of what you think systems thinking means

Student Initial Survey Responses
"Thinking about systems"
"Thinking in terms of the whole instead of the parts"
"It could be the ways that the mind thinks such as how our thoughts are like mind maps in a sense and how certain aspects such as how one approaches the way of learning knowledge."
"Thought processes involving the interconnection of environmental systems"
"I think it refers to the way ecological systems work"
"I don't know"
"How certain processes work."
"Thinking in different systems"

“To come up with solutions to help fix the problems in a way in which you are thinking about the biotic and abiotic factors around it.”
“Thinking that is methodological”
“Trying to figure out a way to reduce the cost of certain services that are towards an overall goal.”
“Thinking about the life cycles of the non-degradable materials we use.
“How to plan out systems of the environment”

In summary, the initial survey suggested that while 77% of the class answered that they had heard of Environmental Sustainability before starting the unit, they wrote a wide variety of inaccurate definitions or descriptions for this term. The research team was looking for descriptions that would indicate the students understood that Environmental Sustainability involves conservation of resources, alternate energy sources and energy saving practices, and overall reduction in pollution in the future to decrease negative human impacts while providing for coming generations. The survey answers also indicated that the students had not heard of the idea of Systems Thinking prior to the project and their definitions were basically guesses since they were unfamiliar with the term. The research team was seeking answers that would suggest students know that systems are cohesive, interrelated parts of a whole and that Systems Thinking is the process of understanding how the parts influence one another. Within the context of environmental systems this could include air, water, soil, plants and animals and how they work together or contribute to unintended consequences. Overall the initial survey provided reference points that showed the students were beginning the project with minimal background regarding the research topics, nor preconceived ideas about systems thinking or environmental sustainability.

PART THREE: RESEARCH QUESTION FINDINGS

This section focuses on looking for evidence that the design research methods had an impact on student learning in a way that addressed the three research questions. Several examples of recurrent teaching and learning actions were observed. First, the cooperating classroom teacher gave whole class instruction to introduce new concepts throughout the unit, followed by regular engagement with students individually and as partners while they were working on tasks in order to answer questions and reinforce the concepts. Additionally, she reviewed prior learning at the start of each new class, and reinforced the concepts of Systems Thinking and Environmental Sustainability at every possible point, trying to bring students to a more complete understanding. She also encouraged students to participate in discussion and ask questions frequently. Secondly, students were employed in numerous activities that were designed by the research team to build on their understanding of content but also to be engaging and increase in complexity throughout the unit. The students were asked to explain their work to their classmates so that they were not only producing physical products but also making sense of the products verbally. The student work samples provided evidence of participation, connections to the research questions, and evaluation of their degree of understanding. Finally, students were asked to self-reflect on their learning before, during and after the project using daily Mentimeter or Survey Monkey questions. These daily reflections provided supporting evidence of students' increased comprehension as well as their discernment about their personal beliefs about their roles regarding sustainability issues.

Research Question One

The first Research Question focused on how students were able to come to understand Systems Thinking, specifically environmental systems and then relate this perspective to environmental sustainability. The stated research question was: Using Design Research and various instructional tools, how do students develop an understanding of systems thinking and relate it to environmental sustainability? The sections discussed below describe the instructional activities that were conducted sequentially during the study. Student responses and interactions are discussed and give evidence to support their understanding of systems thinking and environmental sustainability which reflects the expectations for research question one. The results described include: whole class/ discussion based instruction, system representations; graphic organizers, graphing activities, RRR implementation project, reflection essay, inquiry/experimental design, post-project survey and small focus group responses.

1. **Teacher whole class/discussion based instruction**

Throughout the unit, the teacher gave whole class instruction at times but also encouraged a lot of back and forth dialogue with the students to informally assess their understanding. The teacher introduced the concept of environmental systems at the beginning of the first class period of the unit. This was helpful for students to begin to understand content as well as to model examples of environmental systems. She expected them to have some understanding of these from prior learning in the course during a unit on ecology. The teacher reviewed biogeochemical cycles such as carbon, sulfur, phosphorous, water and nitrogen cycles which they had learned about previously in the class. She reminded them that they should remember prior learning “You know the acronym CHONPS: carbon, hydrogen, oxygen, nitrogen, phosphorus and sulfur helps you remember the cycles.” She specifically went through the water/hydrologic cycle and also briefly discussed global climate change including both natural and anthropogenic causes. She also pointed out things to include when looking at environmental systems such as erosion and soil degradation and emphasized “I want you to just be thinking about systems that could be impacted by what you're doing and researching this week.” This introduction and review of biogeochemical cycles and environmental systems in general appeared adequate, however when reviewing student reflection essays at the end of the unit, they did not always make substantive connections. When assessing the essays using the rubric in Appendix D, most students were not able to connect more than three or four specific systems.

The teacher continued to discuss the kinds of environmental systems that are impacted by human activities throughout the unit, introducing them the first day but reinforcing these ideas regularly. Across the unit the teacher made repeated references to systems in her presentations of content which allowed students to make connections to interactions between systems. For example, the teacher discussed the cutting of forests and used the detailed example of reduction of tropical rainforests in Puerto Rico and planting of sugar cane during the colonial period to connect to modern environmental systems impacts. These included effects of erosion and soil degradation, reduction in rainfall resulting in desertification and runoff were highlighted. This discussion about deforestation also introduced the idea of environmental sustainability for the first time and she gave students specific examples of interfaces of environmental systems:

> So once they cut down all the trees what happened to the climate of Puerto Rico is it became much more arid; they didn't have as much rain… areas of the world by removing trees creates little vestiges of microclimates…These islands used to be full of trees that provided shade and then of course the roots of the trees hold soil when you cut those down you start seeing depletion of nutrients which reduces production in the future.

After reviewing environmental systems and cycles, the teacher first introduced a broad definition of systems thinking and used other terms such as linking thinking, and holistic thinking which are interchangeable. She emphasized the importance of integrating different environmental cycles and human activities in a non-linear way. Another specific link was made between systems thinking and sustainability when she discussed issues related to corn ethanol production on Day One:

> So when we think about a stalk of corn and consuming that form or using it for alcohol/ethanol to put into gas fuel and all those different uses it's more than just the stalk and the corn itself, right? There's the water, there's the soil, there's the carbon cycle, there's the nitrogen cycle, etc. So we want to build on that framework and talk about sustainability by using systems.

She continued describing the impact of producing corn ethanol for automobile fuel:

> So instead of just saying oh we get the corn from the seed. We grow it we get it out of the ground; think of all those impacts on the soil. Then we mush it all up and we turn it into biofuels and then we have an effect of growing the corn on the soils and fertilizer run-off into the Mississippi River …and then we make the oil we put it in, you know, if alcohol we put it in our cars. That's kind of what started

as a linear process. We're going but we have to be more circular, like what happens with all the systems that we're going to impact when we grow that corn. Or if we take corn out of the food chain, what are those effects?

This discussion about soil runoff into the Mississippi River encouraged students to consider the idea that although using corn ethanol is considered a viable type of alternate energy source, there are multiple negative consequences in environmental systems from loss of food resources, erosion, reduction of soil nutrients, and eutrophication of the river.

2. System Representations

The teacher not only discussed examples of environmental systems she helped students to build visual system representations. For example the teacher made the connection of an introductory activity to systems thinking on the first day. The teacher used the simple diagram of a spider web versus a box to first illustrate Systems Thinking. This helped students conceptualize that Systems Thinking requires that they look at different parts of a whole. She then used another diagram of a tree with roots, trunk, branches and leaves as another example of different parts of a whole, which work together (World Wildlife Federation, 2016). She then allowed time for students to suggest different uses of the tree, and impacts of the tree allowing them to make connections of this activity to environmental systems. Students offered uses such as food, homes for animals, timber/lumber, roots for holding soil/preventing erosion, and when prompted for more impacts of trees they mentioned shade/cooling of ground, carbon sequestration, and even as a source for artistic or spiritual meanings. In another query to students to support their learning about systems thinking the teacher asked them to think about "how much water does it really take to fry an egg?" Students were encouraged to think about all the ways water is involved in the process and make connections. Some student responses included water to grow the grain to feed the chickens, water to clean the chickens, and for them to drink, transportation of the eggs to market and even water to wash the trucks and the pans to cook them in. The teacher encouraged students to think of the effects of using so much water on other environmental systems.

A summary table of the teacher's responses is given in Table 4.4. This is given as a sample, but as previously mentioned all Daily Observation Checklists are located in Appendix B. When referring to the introduction to systems thinking/linking thinking activity using the World Wildlife Federation site the teacher noted that for Learning Goal 1, "This introduction was perfect to demonstrate the interconnectedness of environmental systems." She felt this was a very useful activity overall, but it did not address any of the other three Learning Goals. Her response to Learning Goal 1 related to the Circular Economy video on the garment industry the teacher indicated that "This video demonstrated the importance of interconnections in fashion, and since everyone chooses what to wear, each person shared interest in the topic from this perspective." For Learning Goal 2 using the video, the teacher shared "Students were able to consider the system thinking skills and their clothing." She also emphasized that for Learning Goal 3 and 4 "This was the most focused goal of this activity. It made students consider the importance of their choices and responsibilities."

The teacher continued to develop students understanding of systems thinking in relation to environmental sustainability through the use of a reflective warm-up. To begin to further introduce the concept of Environmental Sustainability, the teacher used a warm up Mentimeter questions on Day 2. Based on results from question 1: "How important is learning about Environmental Sustainability (ES) to you?" it was determined 77% of the students had a favorable response to the question.

Table 4.4: Daily Observation Checklist summary of activities by cooperating teacher, Day One-Connection to Learning Goals

	Systems/Linking thinking introduction; using WWF	Circular Economy video
Learning Goal 1: Students will be able to understand how environmental systems interconnect.	This introduction was perfect to demonstrate the interconnectedness of environmental systems.	This video demonstrated the importance of interconnections in fashion, and since everyone chooses what to wear, each person shared interest in the topic from this perspective.
Learning Goal 2: Students will be able to relate environmental systems to environmental sustainability.	This was not specifically addressed.	Students were able to consider the system thinking skills and their clothing.
Learning Goal 3: Students will be able to analyze the effects of manufacture, production and use of either paper or plastic on environmental systems.	This was not addressed.	This was the most focused goal of this activity. It made students consider the importance of their choices and responsibilities.
Learning Goal 4: Students will be able to evaluate the roles and responsibilities of individuals, groups and societies in general	This was not addressed.	This was also the most focused goal of this activity. It made students consider the importance of their choices and responsibilities.

46% of the students in the class responded that they were very interested in learning more about environmental sustainability, and 31% indicated they think it is one of the most important things for us to understand. Only 8% indicated they had no interest and 15% expressed minimal interest in learning about ES. The purpose of this question was to get an idea of how engaged students were at the beginning of the study related to environmental sustainability. It does not directly impact their learning of systems and environmental sustainability but represents a benchmark that can be considered at the end of the study. In question 2 students were asked to "Give a word or short phrase they would associate with Environmental Sustainability.' This allowed open-ended responses that could serve as a point of reference as to what students thought the term meant. This activity produced a "Wordle" which all of the students could view on the smart board. Student answers indicated a wide range of ideas with terms including possible concerns like " pressing," "preserve," "vital," "future," and other suggestions like "non-renewable resources," " carbon dioxide," and "survival." The warm-up Mentimeter questions and responses are given in Figures 4.1 and 4.2 below. Regarding Mentimeter questions with reference to Learning Goal 1, students will be able to understand how environmental systems interconnect, the teacher stated: "The Wordle created showed all of the responses to the prompt. Since so many terms were duplicates, some were larger and interconnected." For Learning Goal 2, students will be able to relate environmental systems to environmental sustainability, the teacher noted: "Since this was still an introduction this was just terms, not substance yet."

Throughout the unit the teacher brought up the connections of environmental systems and sustainability. For example, the teacher showed students a photograph of a plastic bag that was found at the bottom of the Challenger Deep of the Mariana's Trench to prompt a discussion about the prevalence of plastic in the environment. She used this as an interest hook for the day and the teacher brought up the issue of single use plastic bags and a recent ban on these by the town and county. The students appeared to be quite aware of this issue and several offered that their families were now using reusable grocery bags. The teacher reviewed systems thinking and environmental systems which she introduced the day before, specifically mentioning carbon cycle, water usage for paper production, fossil fuels for plastic production and transportation, and biodegradability. She also asked students if they were aware of alternative plastics. Some students mentioned corn and potato based plastics and asked them to think about “are all plastics created equal?” in terms of environmental impacts. Another day the teacher said to the class “think about what is the beginning of the story.” She re-emphasized nonlinear, interconnected aspects and reminded them of the video on garment manufacture and circular economy they watched on Day One as a way of reminding them of systems thinking approach. Overall, the teacher gave many examples of environmental systems and helped students visualize how they interconnected.

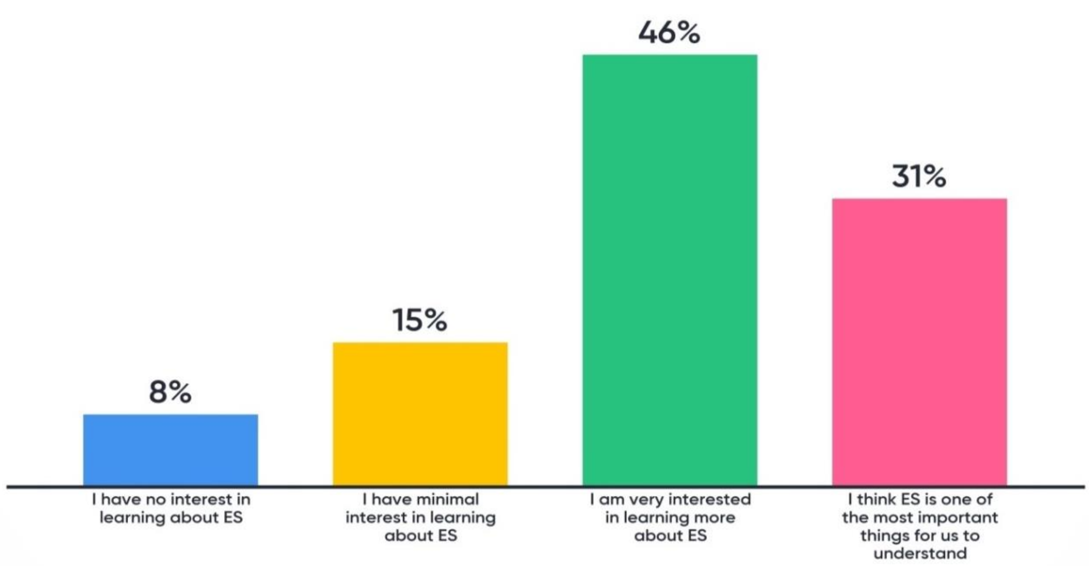

Figure 4.1: Mentimeter Question 1, Day Two- How important is learning about Environmental Sustainability (ES) to you?

Figure 4.2: Mentimeter Question 2 (Wordle), Day Two- Give a word or short phrase that you associate with environmental sustainability.

3. Graphic organizers

On Day Two, the teacher emphasized the value of a graphic organizer to demonstrate interconnectedness of the ideas they had found about paper or plastic manufacture and use. Of note, the pilot study group for the first iteration of this design research eighteen months earlier seemed to be more able to make the connections to soil erosion, water runoff, soil contamination, and other environmental cycles or systems, and they also constructed graphic organizers. Pairs of students in this study created graphic organizers that were less well developed in terms of the environmental systems they presented compared with the pilot study group. For example they often only looked at carbon cycling or deforestation instead of incorporating other biogeochemical cycles and environmental systems such as hydrology, soil chemistry, erosion and runoff. At one point the teacher asked the class if they had linked their internet research for the graphic organizer to the carbon and other cycles she had discussed with them the day before. They appeared to emphasize environmental pollution more than environmental sustainability of resources. In this iteration the teacher showed a sample graphic organizer ahead of time and thoughtfully explained what they were supposed to do however some students did not follow the directions. For example one group created a Power Point instead of a one-page graphic organizer and they had to re-do their work. Examples of student graphic organizers are illustrated in Figures 4.3, 4.4 and 4.5. Students uploaded their graphics into the class Google Drive and used them during presentations to their class. The formats were diverse using Kami application, Microsoft Word, Power Point slides or Prezi as students felt comfortable with different methods. In Figure 4.3 the students copied a sample graphic organizer provided by the teacher in the class Google Dropbox, and made minimal changes to the basic format. There were a number of lines showing interconnectedness but these were not explained during the presentation. Some of the connections were made clear as in Figure 4.4 which includes short explanations. In Figure 4.5 interactions were not distinct by looking at the graphics themselves, and it appears the group did not spend as much time looking at use and manufacture. When students stood in front of classmates, they generally were better able to orally interpret the meaning of their graphics and diagrams.

A pair of girls discussed production and use of plastics in Figure 4.3. They focused on fossil fuels consumed and environmental impacts production and plastic waste:

> The amount of fuel used to make single plastic bag could power a car for 30 feet. So yeah, global consequences of plastic pieces is (sic) that increase manufacturing uses fossil fuels which leads to the increase of oil based industries. There are various environmental impacts such as toxic waste and CO_2 emissions. Chemicals used in plastic can be absorbed by human bodies, which can have

many toxic effects on health. Boats pass plastic waste into oceans and can be a transportation device for invasive species, which bring side effects. Recycling them takes up to 15 percent more energy than producing the first place and it's mostly not biodegradable. So to stay in our landfills for centuries, which means that like the plastic buried in the landfill is can release harmful chemicals into the groundwater supply. If every household recycled like ten bottles we would save up 200 million bottles from landfills. In the U.S. in 2010 around 31 million tons of plastic waste was generated and only 8% was recycled… more than a 180 species of animals have been documented to adjust to plastic debris and there are diseased transferred to other animals by invasion.

Their graphic organizer was very complex and incorporated many different aspects of plastic manufacture, use and disposal. The students appear to have a good understanding of how to make connections between the interrelated topics.

When presenting their graphic organizers about paper or plastic manufacture, production, usage and global consequences to their classmates, a few of the groups of students did link environmental systems and the issues of sustainability. For example, in Figure 4.5 a pair of boys started the process of paper production by describing the cutting of trees which leads to deforestation. Then the students got into describing processing the wood:

They need to grind the wood chips. And then this is using non-renewable resources to feed these machines. And then also there's (sic) high levels of air pollution because of the chemicals that are released from the factories. Other types of plant fibers are used to make the paper such as cotton flax bamboo and

> hemp and then the cotton fibers are used to make paper for money…So for Global consequences, we kind of focus on like two categories because the effects on the environment and then the effect on the community or like the workers. So on the environment the paper industry has been a major source of accumulated toxins in several rivers; the way it gets that is because the solvents have chlorine compounds that is (sic) used to bleach and to prevent bacterial growth in the pulp and finish paper products. That's how come the toxins then get in the rivers because the paper how it gets everywhere. Delignification is taking off like that lignin glue from the little wood fibers….trucks are used to transport and a lot more like greenhouse gases get admitted (sic) into the environment.

This group mentioned pollution and toxins but they did not identify anything specific other than chlorine compounds like bleach. They also did not make links to specific kinds of greenhouse gases that would be emitted from transportation.

In Figure 4.5 another group of students presented a different type of graphic organizer on plastic production. In this account, the students made a connection to groundwater supplies but the emphasis on harmful chemicals, toxic effects and potential disease transmission was very general. For example during their presentation the students stated "harmful chemicals" can be released into the groundwater but did not mention anything specific or how plastic decomposes and leachate occurs to get into the groundwater supply, and none of this was represented in their graphic organizer. Although students were missing some details, they were getting the concepts of interconnectedness of systems and potential negative environmental consequences, especially related to climate change.

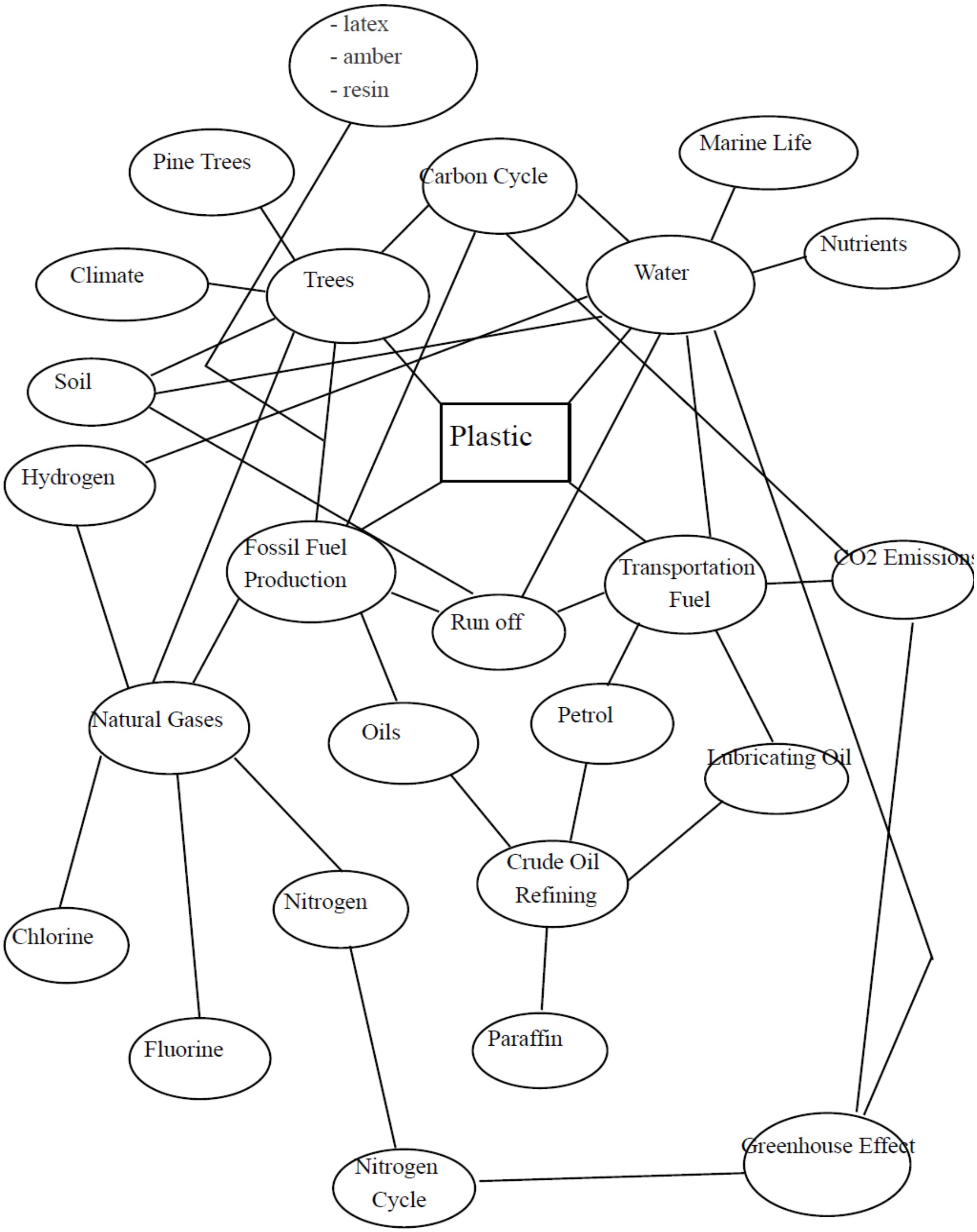

Figure 4.3: Student graphic organizer for plastic production and use #1

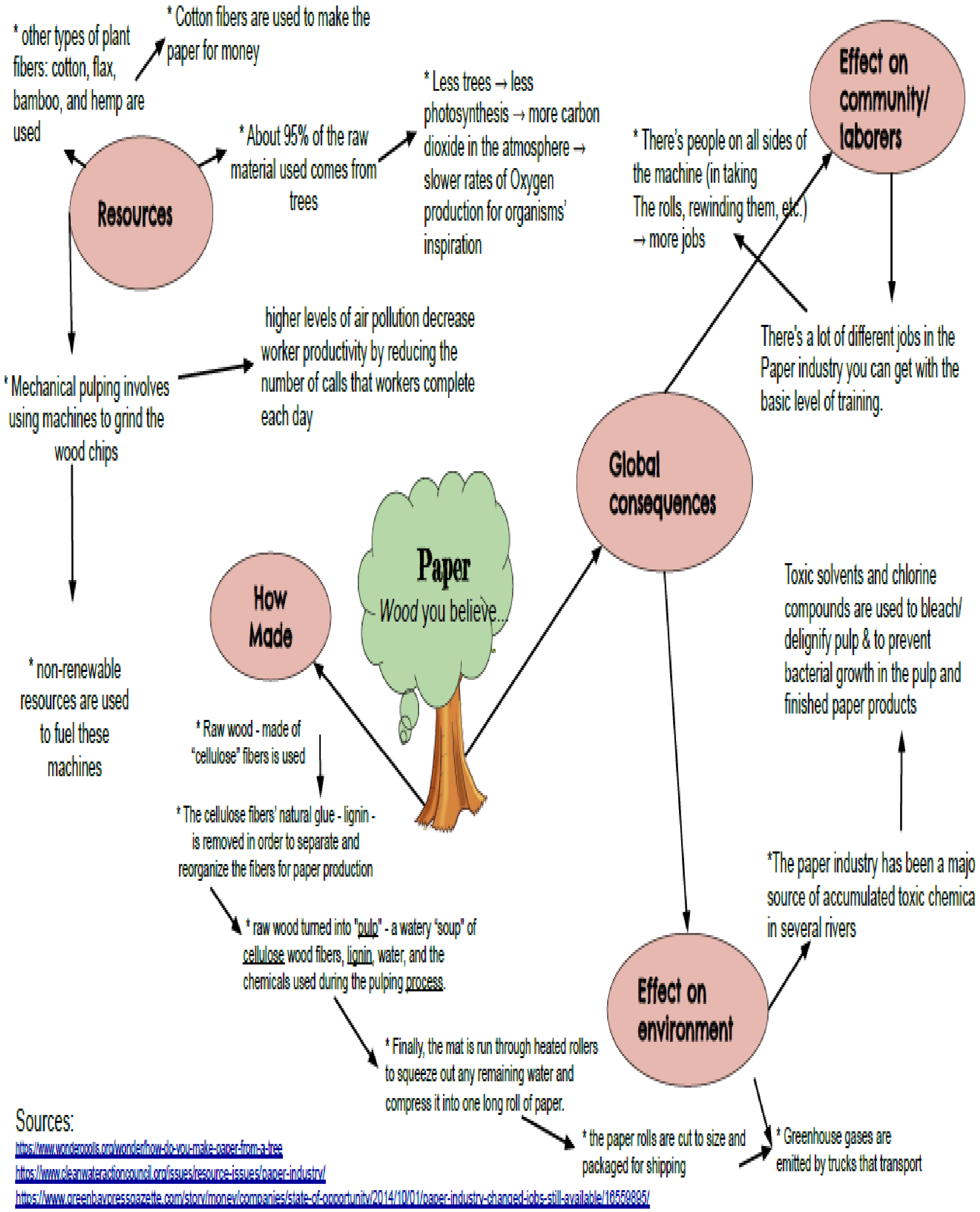

Figure 4.4: Student graphic organizer for paper production and use #2

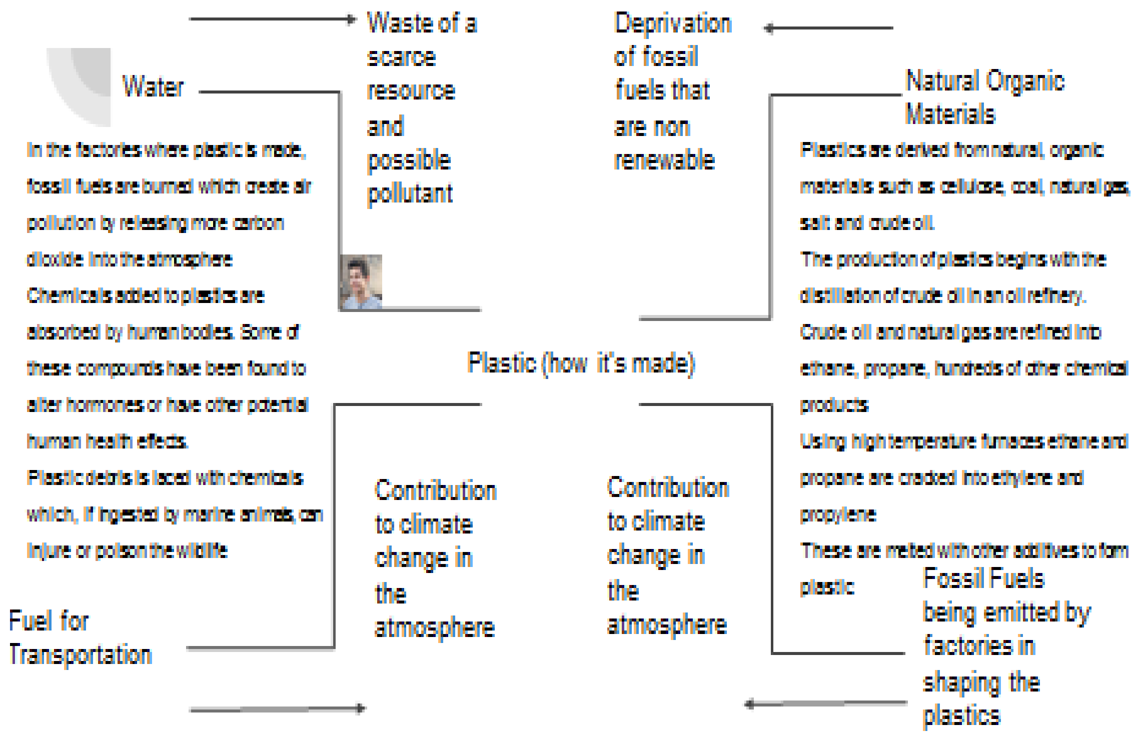

Figure 4.5: Student graphic organizer for plastic production and use #3

The cooperating classroom teacher was very pleased with the activity for the day and made several positive comments relating to the Learning Goals in the Daily Observation Checklist which are summarized in Appendix B. She acknowledged that the students could have used more time for the activity and most felt they wanted to continue to add more information, finding the research acted like a domino or ripple effect. Regarding the graphic organizers students completed on Day Two, the teacher observed that the students who chose to research paper seemed better able to relate environmental systems and sustainability as indicated by Learning Goal 2. She suggested this was perhaps because the origin of paper is trees and they could connect with deforestation, soil degradation and hydrology more easily because of earlier classroom discussion about those topics.

Students completed a Mentimeter before class on Day Three. The first question reflected what they learned about environmental systems and sustainability while researching for, preparing and presenting their graphic organizers on paper or plastic use. The teacher noted Question 1 allowed students to reflect on what they learned about environmental sustainability. Based on the student responses to Question 1 which asked them how the research for and creation of a graphic organizer on production /use of paper/plastic impacted their understanding of environmental systems and sustainability, 75% of the students responded in a positive way to the question. 25% indicated the activity helped them understand some environmental systems, 17% said the activity made them much more aware of environmental systems, and 33% answered the activity made them more aware of systems and more concerned about sustainability. The remaining 25% of the students selected the option that the activity did not help them understand environmental systems. The overall positive responses about the graphic organizer activity, the last answer choice represents a link to Research Question 3 reflecting an increasing awareness and concern about environmental sustainability. Results are presented in Figure 4.6.

4. Graphing

The use of graphs to teach systems thinking is a logical method to integrate data collection, prediction, analysis and interpretation on a broader scale. Graphing also corresponds with Science Practice 4: “Analyzing and interpreting data” from *National Research Council* which noted that “scientific investigations produce data that must be analyzed in order to derive meaning and scientists use a range of tool including tabulation, graphical interpretation, visualization, and statistical analysis to identify the significant features and patterns in the data" (2012, p. 51).

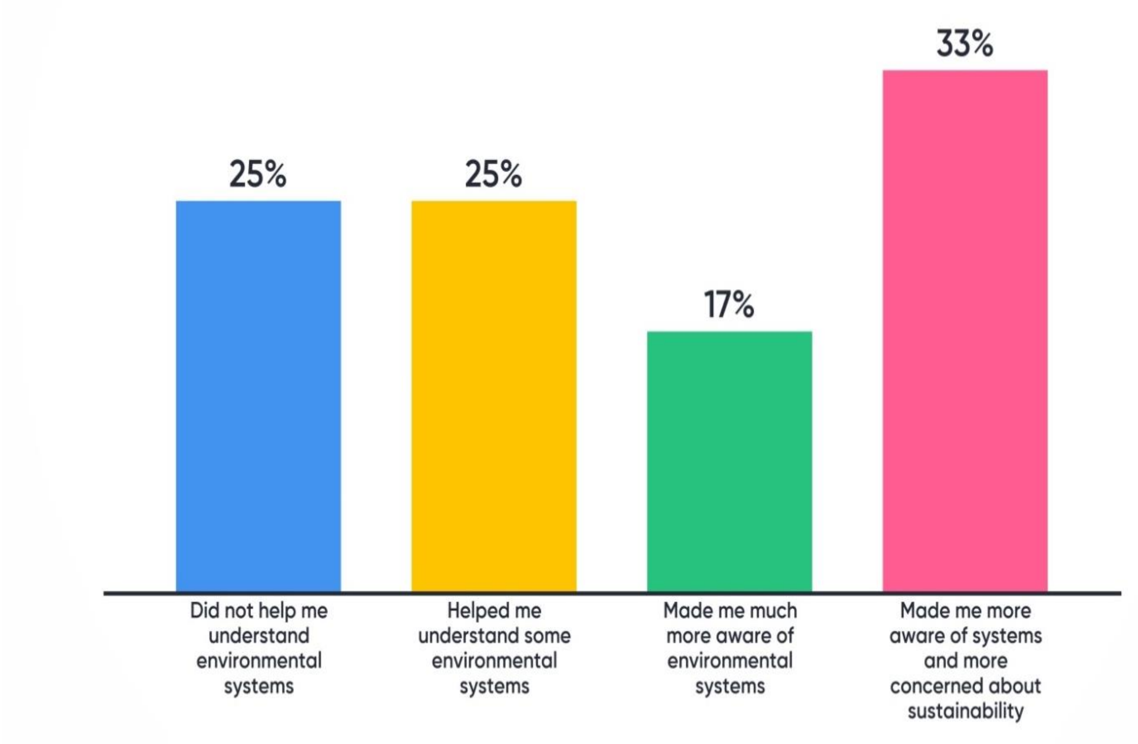

Figure 4.6: Mentimeter Question 1, Day Three- Research and graphic organizer on production/use of paper/plastic

Within this unit, students worked initially with small groups, then as partners and finally individually on graph construction and analysis activities to help them build their comprehension of environmental systems impacts for Research Question 1, but also in developing and deciphering their own inquiry project related to Research Question 2. The teacher started each class by reminding the students what they had learned about paper and plastic manufacture and use, environmental systems and interconnectedness, and environmental sustainability. She made links to prior learning and associated themes to what they were going to do next in the unit.

Internet environmental data set graphs

After students did some basic graphing and reviewed best practices for different types of graphs, students were assigned to use Excel spreadsheets and construct bar graphs of environmental data sets provided from online websites. While practice with bar graphs, line graphs and making trend analyses are not directly related to systems thinking and environmental sustainability, in the context of this design research these activities were selected to help facilitate students' understanding of both "big picture" components of environmental systems and become more aware of future problems. When students finished uploading their graphs and summary paragraphs, they were called on to do a brief presentation. This activity involved students being assigned to specific environmental data sets from Statistics Brain, World Watch, U.S. Department of Agriculture, World Health Organization, World Watch and other websites with directions for graphing the data. The teacher said "So the first thing we're going to do is talk about this idea of sustainability and how we can integrate our graphing and math skills to the data." After students created their spreadsheets and constructed graphs, they wrote a brief summary paragraph and made group presentations of the data to the class, and examples are provided in class observations for Day Four. Some group presentations about their specific environmental data set graphs are summarized in Table 4.5 and illustrate how the students were able to make connections to environmental sustainability (ES). When students finished their presentations the teacher emphasized how they could improve their graphs but also how they could expand their perspectives on environmental systems and sustainability.

Table 4.5: Student summaries of environmental data set graphs

Group #	Student summaries	ES connections
Group 3:	Two girls gave estimates of all degraded lands in million km^2 in dry areas, given all continents. They did the percent of degraded over total area showing North America highest and Australia lowest. They did not connect directly to water use and paper production but teacher suggested how could be connected.	Global land degradation
Group 4:	Two girls showed water availability by region in m^3 per person. Noted North America includes Mexico. Described how this is used to measure water available for each population region and linked to manufacture as well as personal water use.	Global water resource depletion
Group 5:	Two girls displayed deforestation hectares in a five year period 2000-2005 showing Brazil highest, Nigeria least. These girls really delved into why deforestation was happening, made a link to systems thinking. Described a "domino effect" to deforestation, including habitat loss, negative feedback, water cycle, soil stability, turbidity in the rivers. One girl asked if Brazil is really high in paper production. The teacher suggested deforestation is not just about cutting down trees for paper products but also for agriculture, mining and other uses. Lively discussion about "What is going to happen in the future?"	Global deforestation, Habitat loss, water cycle. soils

The cooperating teacher indicated in the Daily Observation Checklist that having students do these graphs of environmental data was a good way for them to connect with Learning Goal 1, students will be able to understand how environmental systems interconnect and Learning Goal 2, students will be able to relate environmental systems to environmental sustainability, which supported Research Question One. The data sets that students graphed and discussed provided students with concrete information about topics such as deforestation, destruction of habitat and reduction in groundwater supplies. The area of weakness for students was linking their specific data set to the larger scheme of environmental systems. They were able to discuss their own graph and impacts but did not always connect with alternate systems.

Two samples of student graphs from the website data they were given are illustrated in Figure 4.7 and Figure 4.8. In Figure 4.7 the students showed degraded lands by continents in million km^2. The students did not use superscripts for the unit of measurements, and also incorrectly stated this graph was for "6 different countries" when in fact it represented continents and this was stated correctly on the graph label. The group appeared to understand that the impact of this data because in the summary paragraph they stated that the "term 'degradation' or 'desertification' refers to irreversible decline in the 'biological potential' of the land." This represents a good understanding of an important issue in sustainability however they did not make any other connection to other environmental systems or general concepts of environmental sustainability. The group who designed the Figure 4.8 graph on availability of water by regions indicated in their summary paragraph that the data were presented in cubic feet/person but the actual data on the graph represents cubic meters/person. The students made clear they understood that over one fifth of the world's population lives in areas with scarcity of water however they did not make any connections to other environmental systems or sustainability in their summary. This group of students noted "this bar graph is a visual for how severe the water scarcity problem is around the world" which addresses the impact of the information while also stating "The author also reports that she predicts the situation will only get worse as climate change and population grows" which suggests they were aware of more global consequences of water scarcity.

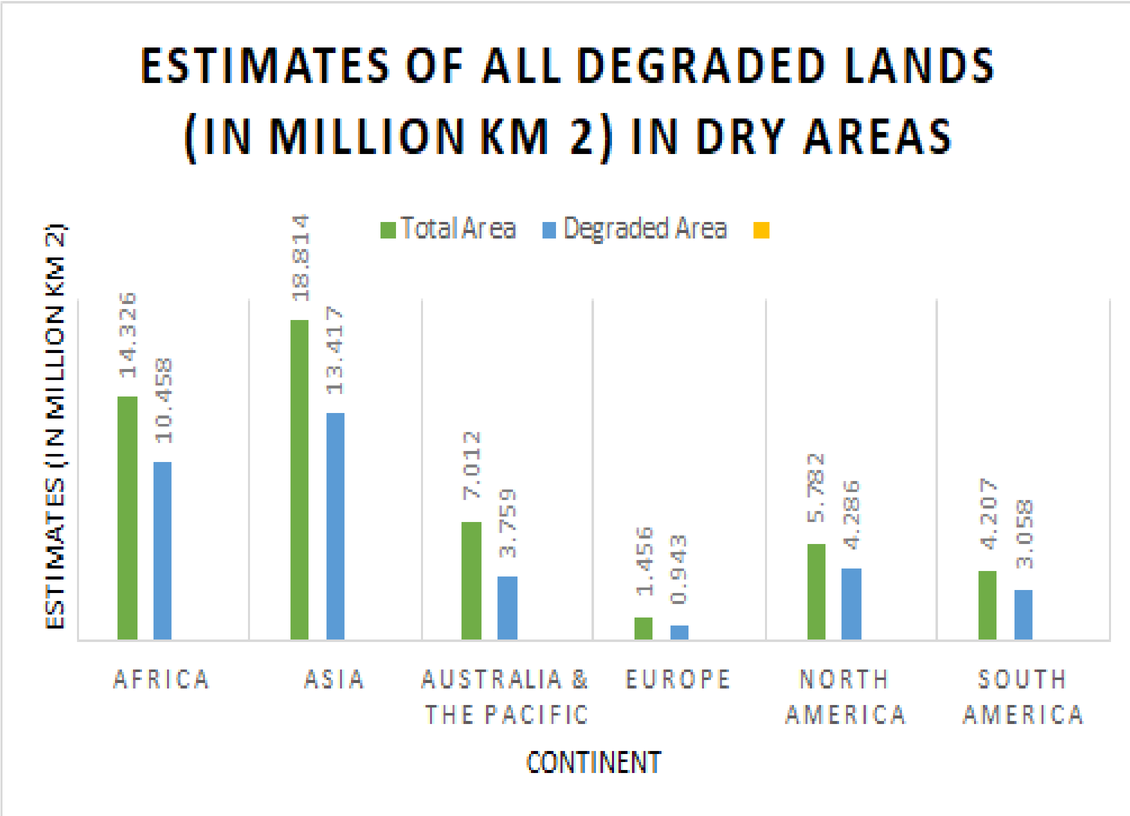

Figure 4.7: Student sample of sustainability graph of degraded land

Student paragraph description of sustainability graph of degraded land:

> This graph shows the estimate of all degraded lands in dry areas in million km2 for 6 different countries; Africa, Asia, Australia/The Pacific, Europe, North America, and South America. The term 'degradation' or 'desertification' refers to irreversible decline in the 'biological potential' of the land. According to this data, Asia had the largest total of degraded land, however, North America has the largest percentage of degraded land; it had a 74 % degraded land ratio.

Additionally, Australia and the Pacific had the lowest % degraded because it only had 54 %.

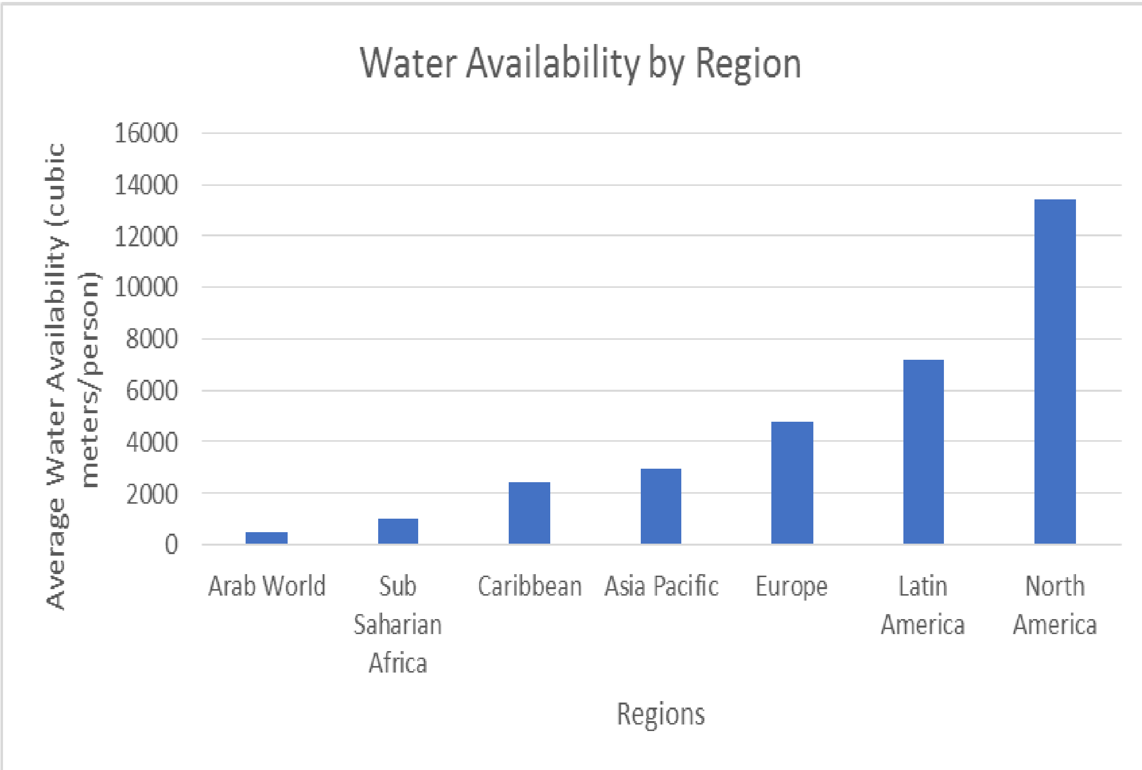

Figure 4.8: Student sample of sustainability graph of water availability

Student paragraph description of sustainability graph of water availability:

The sustainability bar graph we chose to create comes from the article "The Looming Threat of Water Scarcity" by Supirya Kumar. In this article, the author reports that about one fifth of the world's population lives in an area with water scarcity. The author also reports that she predicts the situation will only get worse as climate change and population grows. This article had data that appealed to a bar graph format because it listed regions with estimated water (in cubic feet / person). For the bar graph, we recorded the regions that Kumar listed on the x-axis, while we put the amount of water available on the y-axis. Overall, this bar graph is a visual for how severe the water scarcity problem is around the world.

Trend analysis graphs

The next graph the students were asked to do was to input data on average global temperatures from 1866 through 1975 into an Excel spreadsheet using their Chromebooks. The data were provided from NASA Data and Images (2019) and placed in the class Google Dropbox for student access. The teacher asked "So when do we use line graphs?" and a student responded "Change over time?" to which she said "Excellent!" The she asked them "When do we use bar graphs?" and a student offered "Comparing two things." Some students struggled with how to create the trend for the next 100 years and how to re-title. One boy asked about using "projected in the future" in his title. This reflects the student understood the importance of the data and activity in terms of Learning Goal 2 associating with sustainability and possibly Learning Goal 4 in which he connected to human actions. The teacher helped other students set up their Excel spreadsheet and create the extrapolated cells for another one hundred years so they could produce a model of what might happen to global temperatures into the future. The trend graph activity was incorporated to help students see the effects of global climate change as part of systems sustainability but also to teach the skill so they could incorporate it into extrapolating their own paper or plastic use into the future.

Three examples of student graphs of Trend Analysis of Global Temperatures are illustrated in Figures 4.9, 4.10 and 4.11. One student completed the initial graphing of the data set from Excel but did not attempt to complete the trend analysis. The actual production of the graphs varied slightly. For example Figure 4.9: Student sample 1 shows a student who created a line graph from data and clearly added 100 years in the future. This example also shows the years on x-axis in 5 year increments from 1906. Figure 4.10: Student sample 2 used 50 year increments and provided points on the line graph for the initial data set. The students both generated the same trend line for another 100 years correctly as did 10/13 or 77% of the students. The third example, Figure 4.11: Student sample 3 shows a student who created more of a scatter plot of the original data instead of a line graph, however the student did create a correct trend line and showed both an extrapolated trend and an interpolated best fit line of the data. This student also projected beyond the 100 years which were expected. This type of scatter graph with trend line was also submitted by another student, representing 2/13 or 15.4%.

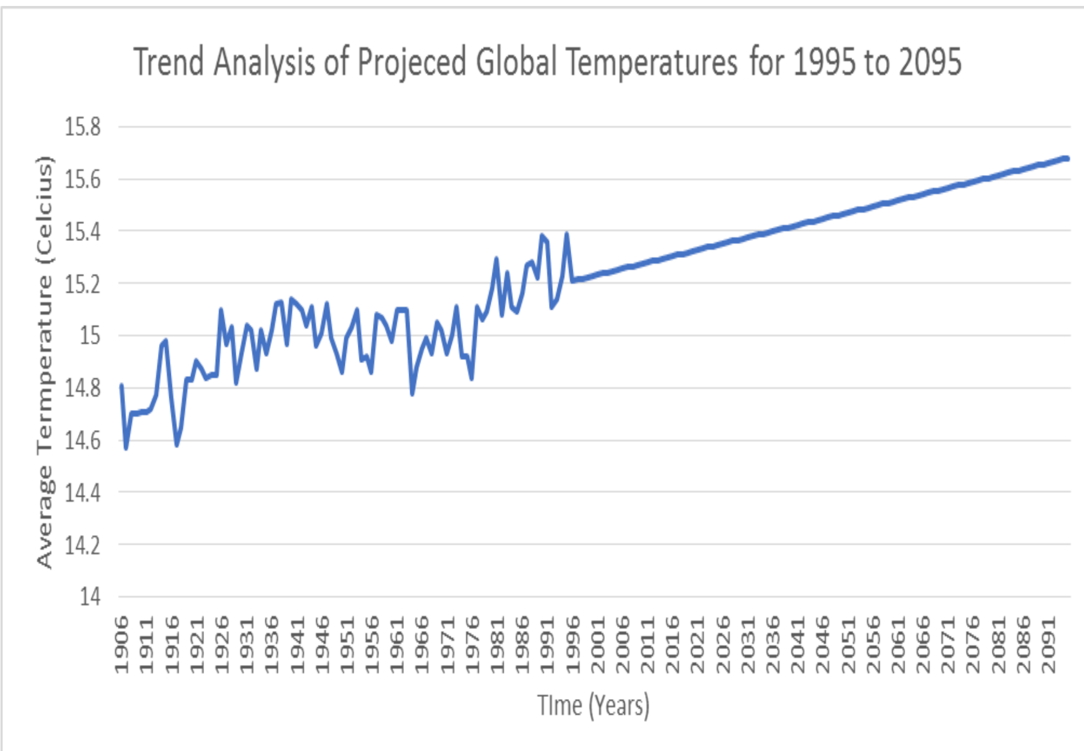

Figure 4.9: Student sample 1- Trend Analysis of Global Temperatures

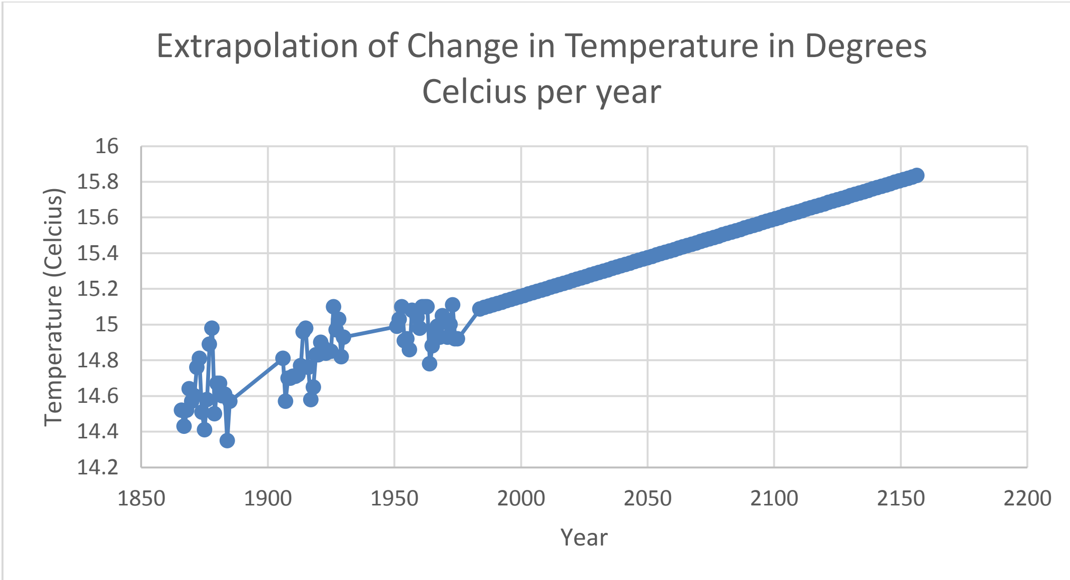

Figure 4.10: Student sample 2- Trend Analysis of Global Temperatures

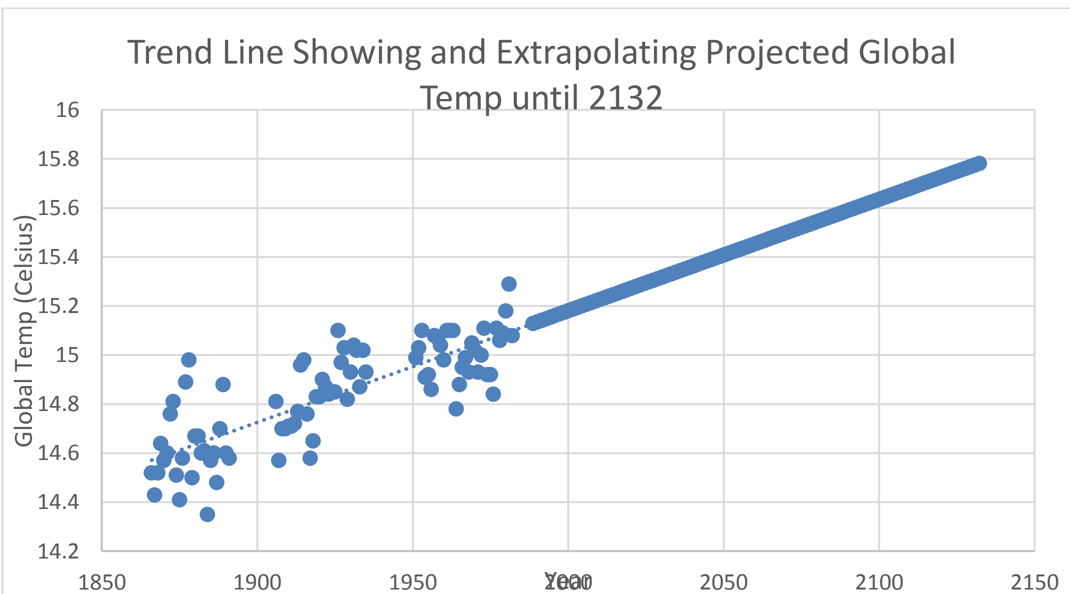

Figure 4.11: Student sample 3- Trend Analysis of Global Temperatures

After this class period, the teacher reflected on the Trend Analysis graphing activity relative to the Learning Goals, noting the first three were not directly supported by the activity. She did provide the caveat “This graphing lesson was critical as a foundation that students would build skills and use later in the project. Many improved their understanding of using Excel.

Based on student responses to the Midpoint Survey Monkey Question 1 “Which of the graphing activities completed were most effective in helping you review graphing techniques?” overall the highest percentage of respondents indicated that all of the graphing activities were equally helpful (38.46%) and working individually on the environmental data sets from internet websites described above was the second highest percentage of answers (30.77 %). Figure 4.12 gives the results. 15.38% of the students selected working in a group on basic graphs, and working individually on trend analysis graphs. No students selected that none of the graphing techniques was useful in helping them review graphing which supports the inclusion of the various methods used. The cooperating teacher felt that Learning Goal 1 “Students will be able to understand how environmental systems interconnect” was represented in the sustainability graphs and summary paragraphs once they could interpret the data in graphic form. She also felt students made good connections between environmental systems and environmental sustainability of Learning Goal 2 using the sustainability graphs because they had to interpret the graphs and explain them.

The second question from the Midpoint Survey Monkey asked “Which of the graphing activities were new methods or skills for you?” Overall more than half of the students indicated that none of the graphing activities were novel to them, but the nearly one third indicated that doing trend analysis was a new skill for them while 7.7% indicated working individually on the environmental data sets (internet websites) was new to them. The answer choices were selected as follows: None of the graphing activities were new to me 7/13 or 53.9%; All of the graphing activities were new to me 1/13 or 7.7%; Working as a group on basic bar graphs was new to me 0.0%; Working individually on the environmental data sets (internet websites) was new to me 1/13 or 7.7%; Working individually on the data sets provided with trend analysis (global temperature and carbon dioxide) was new to me 4/13 or 30.8%. Results from this survey question are provided in Figure 4.13. It was interesting that although the students indicated the basic bar graph techniques were not new to them they noted in the previous survey question 15.38% did find this activity a useful review.

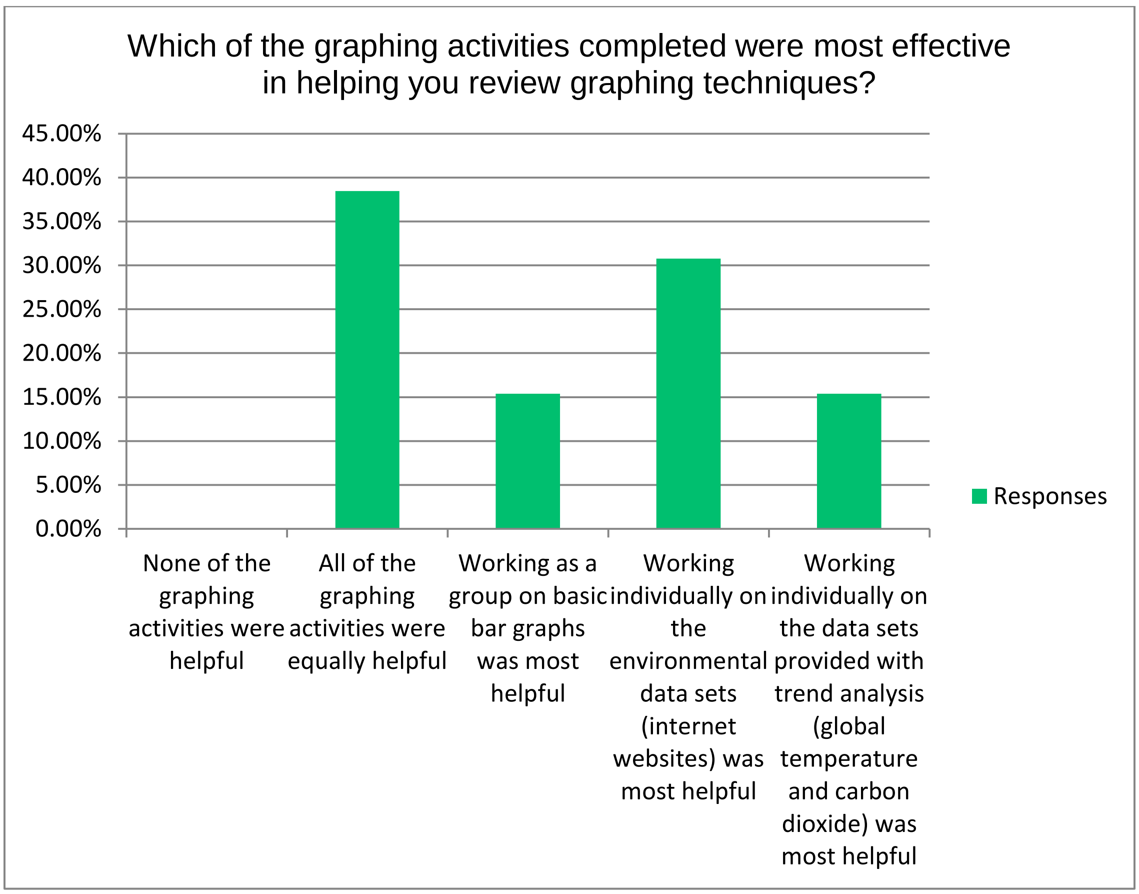

Figure 4.12: Mid-point Survey student responses to graphing question 1

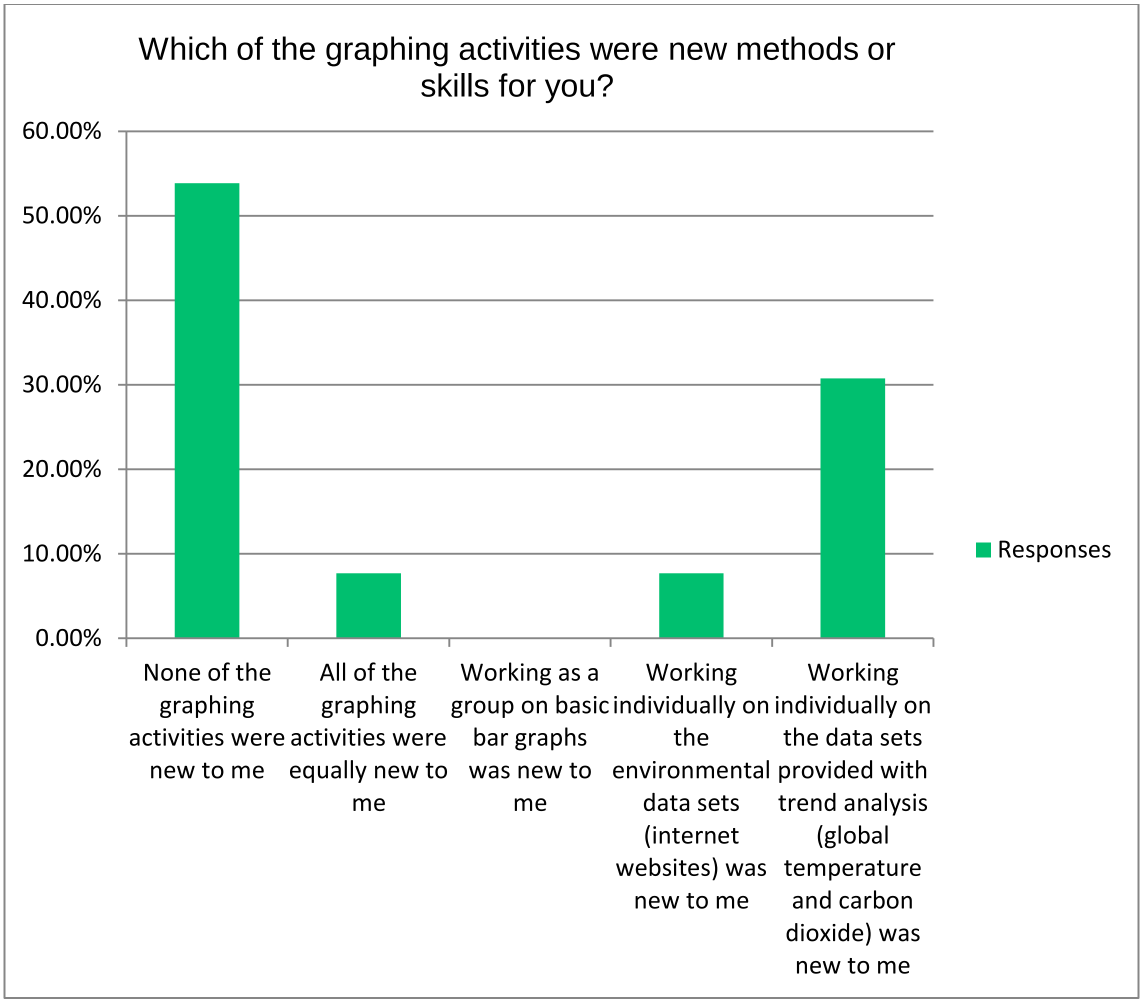

Figure 4.13: Mid-point Survey student responses to graphing question 2

5. **Reduce-Reuse-Recycle Implementation Project**

In another instructional activity on Day Seven students created digital Reduce, Reuse, Recycle or RRR “posters” with a partner. Students collaborated with a partner to generate a possible implementation project idea. In the explanation of Student RRR Poster sample 1 in Figure 4.14 the students discussed the prevalence of single use plastic bags throughout the environment and explained that their poster was supposed to dramatically show the impacts of these bags on wildlife particularly aquatic organisms like fish, birds and sea turtles. This is a particularly relevant sustainability issue in the town where they live and the local government banned the practice of single use plastic bags. In Figure 4.15: Student RRR Poster- sample 2 this group of students made a proposal for implementing a specific action in the community, namely to place recycle bins in local businesses. Figure 4.16: Student RRR Poster- sample 3 was another graphic about plastic use and disposal and students made the connection to wildlife who ingest or become entangled in plastics. The cooperating teacher evaluated the Reduce-Reduce-Reuse digital poster and student presentations related to the Learning Goals. They made a general connection to Learning Goal 1 by describing the effects on animals and their life cycles but did not address environmental systems other than to describe pollution. Overall, the activity reflected some student realization of all four of the Learning Goals.

Figure 4.14: Student RRR Poster- sample 1

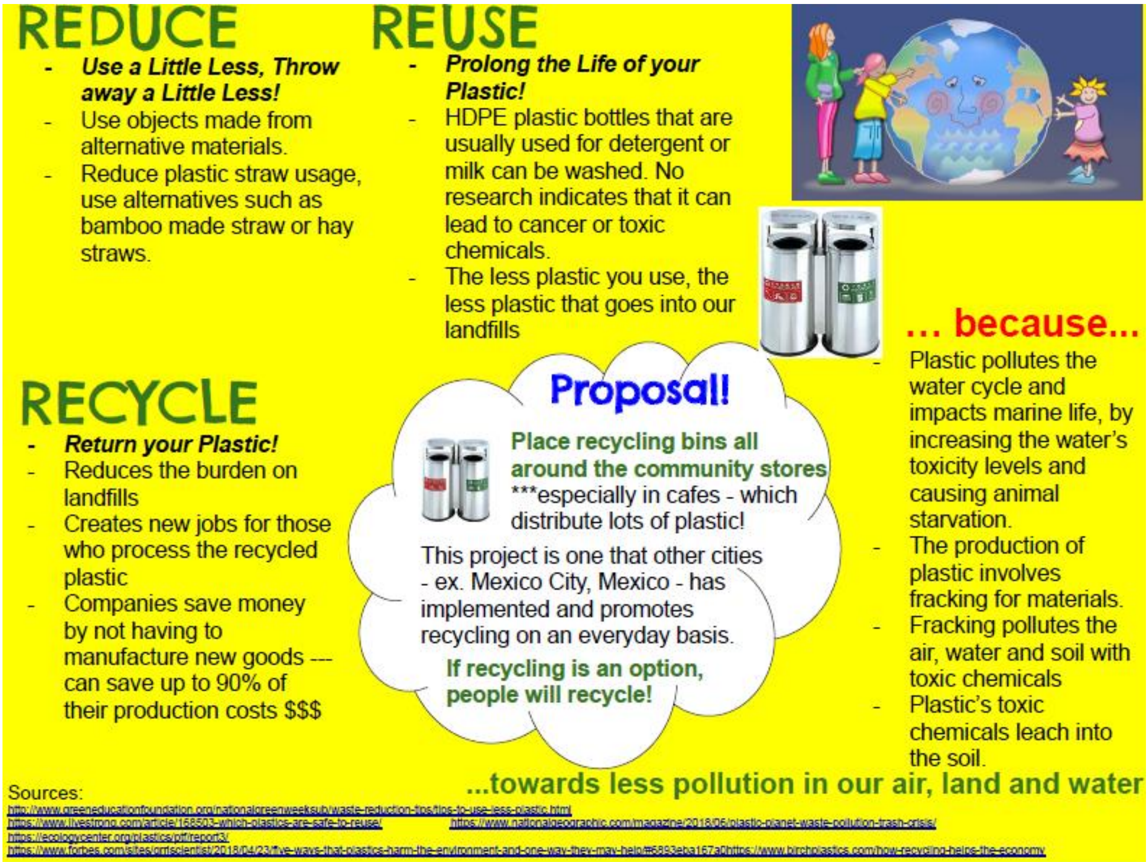

Figure 4.15: Student RRR Poster- sample 2

Figure 4.16: Student RRR Poster- sample 3

The students RRR Posters were able to make the point of the importance of reducing, reusing and recycling of paper or plastic but the connections to environmental systems were not always clearly provided. Some made links to effects on animals and food chains from plastic pollution and potential toxins released into soil or water. She said "Many of the photos and descriptions for reasons we should RRR were powerful and reinforced the interconnected-ness" when discussing Learning Goal 1 that students will be able to understand how environmental systems interconnect. She also noted that many of the descriptors the students used in their posters were related to environmental sustainability of Learning Goal 2.

6. Reflection Essay

The final reflection essay on Day 8 encompassed several parts for students to write about including those pertaining to Research Question One. The entire prompt for the final reflection essay was "Discuss the environmental consequences of paper/plastic production and usage on a global scale. Include as many systems as you can think of that are impacted. What does environmental sustainability mean and how does it connect to systems you identified? What can you do personally, and what do you suggest for humans to do to in general to affect a change?" Three student reflection essay examples are represented in Figures 4.17, 4.18, and 4.19.

It is unfortunate that over the past century, plastic has been in demand for society but has been destroying many environment systems. According to the National Geographic website page, plastic was invented in the late 19th century and became popular during the 1950's. Plastics are made of very complex compounds and the main source is crude oil; these components may be toxic under various conditions such as heat ("How Plastics Are Made.") Surveys and tests are a great way to estimate and count the possibilities of plastic disposal and plastic recycling. All plastic production and disposals adds to the global pollution and environmental disturbance. The water cycle is affected such that many toxins from plastics are inside the water, that water is flowing in a cycle and contaminates many environments. Environmental sustainability refers to how all environments interconnect and the ways living organisms demand resources but there is only so much of resources in the environment, therefore, there should be limited resource usage to sustain the environment. It also refers to the ways in which one can prevent further environment damages. It is important to act as an entire community to get the best results. However, it might seem difficult, but if each person acts, then there will be an influence in the community and more individuals will participate to reuse, reduce, and recycle. How Plastics Are Made." *PlasticsEurope*. www.plasticseurope.org/en/about-plastics/what-are-plastics/how-plastics-are-made. Treat, Jason, and Ryan Williams. "We Depend On Plastic. Now, We're Drowning in It." *We Depend on Plastic. Now We're Drowning in It.*, 16 May 2018, www.nationalgeographic.com/magazine/2018/06/plastic-planet-waste-pollution-trash

Figure 4.17: Student reflection essay- sample 1

Plastic production has many different environmental consequences which affect different environmental systems. The production and several uses of plastic which are thrown away and not recycled has a negative effect on environmental sustainability. Environmental Sustainability refers to a state in which the demands placed on the environment can be met without reducing its capacity to allow all people to live well, now and in the future. However, the sustainability of the environment can be put in jeopardy due to the mass production of plastic. For example, when plastic is produced, many fossil fuels are used as means for production. When the fossil fuels are "cracked" it releases more carbon dioxide into the atmosphere. This increase in carbon emissions affects climate change causing the Greenhouse Effect. It blocks the reflection of heat back out into space, causing more to be absorbed into the earth's terrain. A stronger greenhouse effect will warm the oceans and partially melt glaciers and other ice, increasing sea level.

Adding to this, pollution from plastic, such as plastic bags, also harm the environment. When plastic bags are thrown on the ground and littered, if it lands in soil, it can cause it to become less fertile. The plastic does not dissolve, but rather it breaks into small pieces which can last thousands of years, contaminating soil waterways and oceans. Plastic can slowly release toxic chemicals which seep into the ocean, and ultimately disrupt the water cycle.

Not only does plastic waste contaminate the ocean and waterways, but it can also directly harm animals and humans. Chemicals added to plastics are absorbed by human bodies. Some of these compounds have been found to alter hormones or have other potential human health effects. Also, plastic debris is laced with chemicals which, if ingested by marine animals, can injure or poison the wildlife. These plastics are ingested by marine animals often times, because it is being mistaken for other sources of food such as jellyfish. Different types of plastics can also cause the animals to be trapped or entangled, ultimately killing them.

A lot of the problems regarding the effect of plastic on environmental sustainability is caused by humans. First, many don't recycle their plastic when they are done using it. Second, littering is a big problem, and that can cause disruptions and contamination in the soil and in our oceans and other water sources. However, there are many different ways which people can help reduce the amount of plastic that is in our environment. For example, you can reduce the amount of single use plastics that are used. Single-use plastics include plastic bags, water bottles, straws, cups, utensils, dry cleaning bags, take-out containers, and any other plastic items that are used once and then discarded. The best way to do this is by refusing any single-use plastics that you do not need and purchasing, and carrying with you, reusable versions of those products. Also, recycling any single-use plastics is a good way at reducing plastic waste. Recycling helps keep plastics out of the ocean and reduces the amount of "new" plastic in circulation. By making efforts to reduce the use of plastics that aren't re-usable, then plastic waste and contamination can decrease drastically, and help with environmental sustainability.

Figure 4.18: Student reflection essay- sample 2

Plastic and paper can end up in ecosystems where animals either mistake plastic for food and eat it, or unknowingly eat it. The toxic chemicals used to create plastic can also seep into the earth or water and be harmful to the environment. Since it takes a very long time to break down, those changes will remain in that ecosystem for a very long time just because we have single use plastics or papers that have consequences of a lifetime. Even in process of making or refining oil to make plastic and paper is harmful for the environment. Oil refineries pollute water and the processing plants to shape the paper and plastic release carbon dioxide into the atmosphere speeding up the greenhouse gas effect. Deforestation is also a big result of creating paper because it is the resource that is used to make paper. Soil degradation as mentioned before is also a result because of the landfills with plastic and the chemicals that seep into the ground. The water cycle is affected because of the polluted water in the oil refineries and all the waste that ends up in waterways. Environmental sustainability is the ability to maintain a healthy balance between production of goods while not harming the environment and scarring it for centuries in the future. They find clean ecological alternatives that do not leave a footprint that halts the balance of life in an ecosystem. When I use plastic or paper, I can leave it next to my trash can instead of throwing it away and at some point that day, sort into recyclable and non-recyclable waste so I'm not just throwing everything away and keeping track of how much I can save. I will also become more conscious about how much I am using.

Everyone should take part in an activity of the sort to be more conscious of the environment and their impact on it.

Figure 4.19: Student reflection essay- sample 3

In one response the student connects the water cycle to toxins from plastics, but uses vague language like "global pollution" and "environmental disturbance" rather than giving specific consequences. This student also attempts to define environmental sustainability saying it “refers to how all environments interconnect and the ways living organisms demand resources but there is only so much of resources in the environment, therefore, there should be limited resource usage to sustain the environment.” This is not a clear definition, although the student does state that “there should be limited resource usage to sustain the environment.” This essay also notes that if each person acts to reduce, reuse, and recycle then they will “influence the community” but it does not explain how this will be an impact. This type of writing was seen in other examples as well in which little specific linking to environmental systems was given, the notion of sustainability was poorly described but changes in human behavior could have an impact for the greater good of the environment.

Another student essay expresses similar vague descriptions of sustainability but the student did make more direct connections with “cracking” of fossil fuels used in plastic production and the production of carbon emissions into the atmosphere exacerbating climate change. The student gave a very clear explanation of how greenhouse gases block heat radiation to space and therefore warm the planet, potentially creating sea level rise. This student also discussed how plastic does not degrade but produces particles that get into both soil and water, slowly releasing toxic chemicals, and made a good connection to the hydrologic cycle. This essay also contained the connection to environmental systems related to plastic effects in food chains and finally made the association to environmental sustainability and how humans need to modify behavior. In the third essay example this student made similar elusive comments about how paper and plastic use and disposal can “harm” the environment but the student was able to give more distinct examples of environmental systems that are impacted such as deforestation, soil degradation, landfill leachate into groundwater and soil, greenhouse gas emissions from using fossil fuels. The student stated these kinds of potential effects but did not give impacts, for example she/he did not explain what the problem with more greenhouse gases represents. In another example the student did not express what were the actual consequences of deforestation on environmental systems in a more specific way such as leading to erosion, loss of nutrients, runoff, increased flooding and so forth. Based on evaluation of the final reflection essays using a 12 point rubric located in Appendix D, it was found that the average score for the essays was 8.4 out of possible 12 or 70 percent. This reflects some areas of weakness in student understanding of different environmental systems if we consider 80 percent as mastery of the information. Most students only incorporated three or four different environmental systems in their discussion and did not elaborate on their interconnectedness. It is also possible that some students did not take the activity seriously because it had a low point value.

7. Independent Inquiry/Experimental Design

Students designed a three day experiment collecting paper or plastic at home. The teacher asserted that Learning Goal 1 was achieved somewhat by the Formal laboratory write-up in that "Much of this learning goal is referred to in the background information." However, the students did not appear to make strong connections to environmental systems beyond global warming, soil degradation or water use. Formal laboratory reports of students' experiments were evaluated by the teacher for a summative class grade using IA Criteria Rubric. Both of these were provided by the teacher in Appendix C. Two student samples are presented in Appendix F. Some components of the formal laboratory report for their investigation relate back to Research

Question One. For example the research question, hypotheses and data collections methods relate to predicting outcomes of the project and possible impacts on sustainability. Data processing which included bar graphs of categories for three day and data analysis which contained line graphs extrapolated from three days to a month to a year, and then a trend analysis graph for the next fifty years related back to the graphing activities. The trend analysis of their own data specifically provided students with impacts of their consumption of paper or plastic which is interrelated to all three research questions. The conclusion and evaluation sections of the laboratory report provided strengths and weaknesses of their design. The application section which suggests real world value for the investigation was most impactful for students in terms of making connections between their investigation, systems and sustainability but also in terms of their own behavior related to Research Question Three.

8. Student Post Project Survey

All post survey results and graphs of student answers are compiled in Part 4 of this chapter. Based on student responses to the final Post Project Survey Question 1: "How well did you understand systems or linking thinking for environmental science before this project began" 27.27% responded "Not at all, never heard of it" to this; and 72.73% responded "Understood somewhat." In the initial Pre-Project Survey none of the students indicated they had ever heard of Systems Thinking. Final survey question 2 asked "How well do you understand systems thinking for environmental science now that you have completed the project?" None of the students answered "I do not understand what systems thinking is at all;" 1/11 or 9.09% answered "I understand some of what systems thinking involves;" but 10/11 or 90.91% selected "I have a good understanding of systems thinking related to environmental science issues." This self-assessment is in stark contrast to the original student responses from the initial survey as referred to above in Initial Survey: Question 3- "Have you ever heard of systems thinking?" to which none of them responded they had ever heard of systems thinking. This self-evaluation question represents a strong realization on the part of the class that they had developed a new understanding of Systems thinking at the end of the two week unit.

Final Post Survey question 3 allowed students to reflect on the activities implemented in the study asking "Select the most helpful strategy that helped you develop your own systems thinking." The most commonly selected responses were: Introduction to systems thinking with tree diagram; Brainstorming session about effect of paper manufacture and making a graphic organizer; Research on consequences of paper/plastic manufacture in the environment and linking to environmental sustainability for essay after completion of the project; Final reflective essay. These answers reflect similar choices given by the students in the pilot study. Question 9 from Post Project Survey allowed students to write comments and one student said "This helped me understand more clearly how different systems are linked and how paper/plastic pollution can affect them in an interconnected way."

9. Small Focus Group Responses

Transcripts of student responses from small focus groups are found in Appendix E. These two focus groups were interviewed the last two days of the study however when the small groups were asked to define environmental systems in the initial question, the students did not have clearly thought out ideas, and were not able to express a definition or give an example without prompting from the researcher. When asked to give a specific example of an environmental system, the students appeared to have difficulty and thought mainly of biogeochemical cycles responding “like the so-called carbon cycle?”; “The phosphorous cycle. The water cycle”; “CHONPS”; “Nutrient Cycles, water cycle for sure and carbon cycle”; “I mean there's soil chemistry, the soil of roads and you know it loses nutrients.” These students seemed to have a better understanding of environmental sustainability than either environmental systems or systems thinking, and were also able to relate how their understanding of sustainability has changed. One stated “Just making sure like doing certain I guess like things to make the environment stay healthy and like not a control on too much negative stuff like plastic or global warming … just keeping it so that you can keep living here for a good long time… so just for us and our future generations.”

In response to how their understanding of environmental systems changed during the two week project, students had more well developed answers. For example, one student stated, “I had never thought about how they all interconnect and for example, even with the topic of paper and plastic they (the systems) all interconnect back to paper and plastic and the processes of how it's made and how we use it and how it decomposes and the environment. Like matter is not created nor destroyed is just passed on from cycle to another cycle.” Another student said “… also adding on to that (circular idea) these two weeks like because I don't think I look into these things on like my free time but these two weeks has definitely like opened my eyes and kind of like made me go out there and search more… and it's interesting how like I read a lot about the crude oil and the processes of making plastic that compounds, the complex compounds that go into like the mixing to make plastic and that's just very like shocking. You know that I really think of other systems are in the plastic like oil, and these other materials and you never think about it like that. You just think plastic."

When students were asked what activities were helpful in their understanding of environmental sustainability they were able to relate specific examples they completed without any prompting by the researcher and stated "The trend analysis with short term and long term effects was really impactful"; "Collecting your own stuff for just measuring how much plastic is used in the day was kind of eye-opening"; "I really like the mind maps (graphic organizers)…because once again you are able to see the interconnectedness of everything." Another student said "Yeah, and even though in my mind map I was missing some arrows I could have connected more boxes…" When asked if any of the graphing activities specifically helped them understand sustainability, the responses were positive. Once student commented "I think so because it made us more easily be able to like make comparisons and like relationships with what we were studying and also like I'm a visual person so like being able to see the like trend line go up and stuff has really helped." Another noted

> For me it was when we did …graph projects when we were kind of like the ones that we were like a little pairs, I think it was. And we all were getting like a new partner. I really like that personally just because I felt that I was able to see something different. Like everyone got like a different section of data…I like what one person's looks like, I wasn't really aware of it. I just wasn't really like conscious of it is the best way to put it; like subconsciously I knew about it, but it wasn't something I really looked into so when I actually saw like, I guess qualitative data on it, it just made me realize like the greater effect.

In summary, the different instructional activities in this unit provided students with opportunities to make connections between different environmental systems. This was especially evident in research and construction of graphic organizers, graphing of Internet data sets, trend analysis, RRR proposal, background information and application sections of their laboratory reports and reflection essays. They were able to associate these systems with issues of global environmental sustainability especially during class discussions and student presentations.

Research Question Two

Research Question Two posed: How does analyzing personal and classroom data on paper or plastic usage and recycling influence high school science students' understanding of global environmental sustainability issues through the lens of systems thinking? To answer Research Question Two, similar features of the curriculum will be highlighted as seen in Research Question One. For example, the importance of the teachers' whole class instruction, students use of graphic organizers to understand paper or plastic manufacture and use, student graphing activities, RRR project, and reflection essay. The main instructional strategy that supports Research Question Two is the inquiry/experimental design component because this is directly related to collecting personal data on paper or plastic consumption and reflecting on that impact on environmental systems and sustainability.

1. **Teacher whole class/discussion based instruction**

In the final activity of the first class period, the teacher instructed the students to consider the importance of paper and plastic in daily usage and then asked each of them to suggest one use of paper and plastic. This was an introduction to the individual inquiry projects/experimental designs the students would be conducting as well as other activities they would be involved in during the following two weeks. She wrote their answers and ideas on the smart board and told them they could not duplicate anything that had been offered by another student. Throughout the brainstorming session, the teacher asked students to think about these items they suggested, such as plastic bags and straws, and how they impact sustainability through their disposal.

2. Graphic Organizers

Regarding the graphic organizers students completed on Day two, the teacher noted for Learning Goal 3 graphic organizer activity was directly related to and supported the goal. This Learning Goal states that "Students will be able to analyze the effects of manufacture, production and use of either paper or plastic on environmental systems." Since the inquiry investigation deals with use of paper or plastic, the graphic organizer helped students understand the ideas of use, re-use and disposal.

3. Graphing

In order to make all students have a degree of comfort with doing basic graphing before they engaged in their independent data analysis project, the teacher planned a whole class review of graphing and a short activity. Before this graphing lesson, students completed the second Mentimeter question on Day Three which was given as a benchmark for students to evaluate their data collecting and graphing skills which would relate to the remaining activities for Day 3 and subsequent graphing endeavors during the project. Results of this question "How would you describe your skill at data collection and graphing?" are displayed as Figure 4.20: Mentimeter Question 2, Day 3. 75% of the students responded that they are confident about data collecting and graphing, 17% said they did not understand how to represent data as a graph, and 8% indicated they are comfortable collecting data but not sure about graphing.

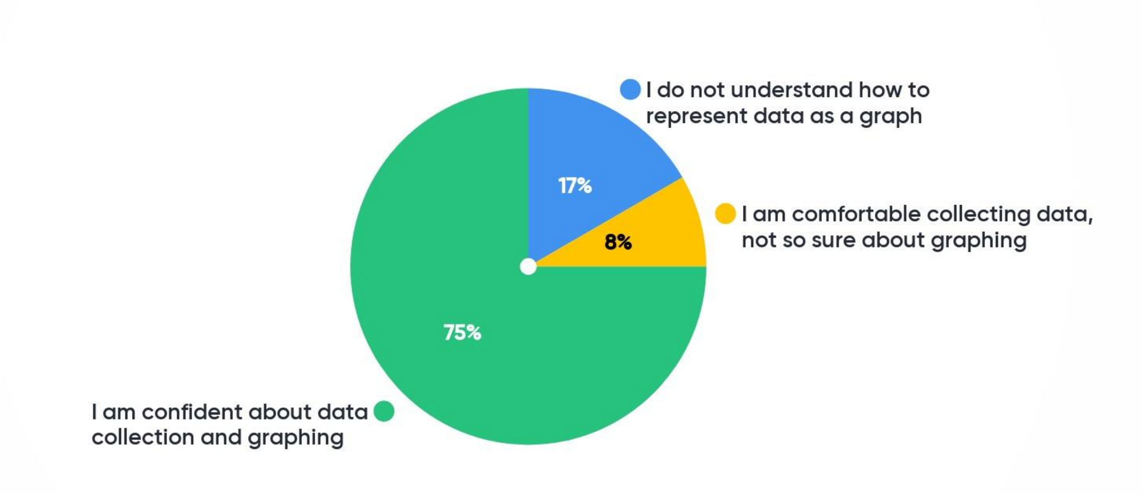

Figure 4.20: Mentimeter Question 2, Day Three- How would you describe your skill at data collection and graphing?

All students demonstrated that they used the “good graph” techniques which were highlighted by the teacher to include the title, correct labels and units for the axes. The class performed well on the data collecting and graphing aspects of this initial task which was to prepare them for data collecting and analysis of their own inquiry project. An example of the bar graphs produced by the students in illustrated below as Figure 4.21 Sample student practice bar graph, which referred to the data collected on favorite pizza toppings and was constructed by hand on graph paper by one group. This example is indicative of all the graphs produced by the six groups of students and demonstrates that they used the “good graph” techniques highlighted by the teacher to include the title, correct labels and units for the axes. The class performed well on the data collecting and graphing aspects of this task. The teacher indicated that the simple graphing activity while not specifically related to the learning goals was significant in that it would help the students prepare for other graphing activities planned for the unit.

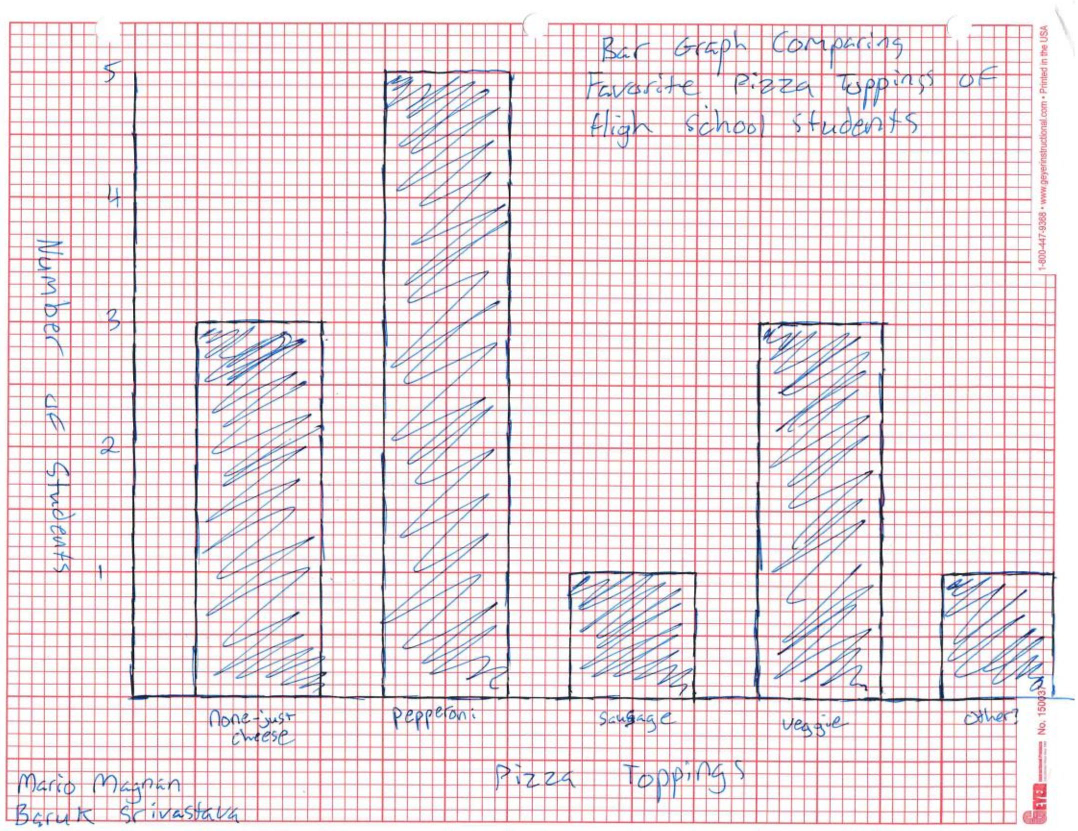

Figure 4.21: Sample student practice bar graph.

The next graphing activity of environmental data sets and using Excel spreadsheets was also part of the preparation for students to analyze personal and classroom data on paper or plastic usage and recycling, while at the same time re-emphasizing environmental systems and sustainability concepts. After each group had presented their graphs and summaries the teacher introduced the next activity which was going to be a three day independent science inquiry into paper or plastic use by the students' families. She began by linking to prior learning:

> Do you remember earlier this week when we started brainstorming all the different kinds of paper and all the different kinds of plastic and then we kind of put that down for a second and started thinking about graphing. What we're going to do now is bring those two lines of thought back together. And I'm going to be

> asking you to develop a method for categorizing your own family's paper or plastic use. You will create a data table for a three-day period. You are encouraged to brainstorm and work together so that you can designate different kinds of paper or plastic products. I can even go back to the slide where we took all of those notes and try to remind you all the things that you said. Do you remember when we said things like cardboard boxes, paper towels toilet paper, cash, wrapping paper. Or plastic book bags, storage bins, water bottles.

This linked to prior learning from the first and second day of the study when the students brainstormed different kinds of paper and plastic products which they could now incorporate as data sets for their own inquiry investigation.

4. **Reduce-Reuse-Recycle Implementation Project**

When evaluating the way students presented their Reduce-Reuse-Recycle digital posters, the teacher was pleased with the association students made to Learning Goal 3 "Students will be able to analyze the effects of manufacture, production and use of either paper or plastic on environmental systems." In these activities students addressed the manufacture of paper and plastic and effects on environmental systems based on the nature of their idea for RRR.

5. **Independent Inquiry/Experimental Design**

The teacher provided initial directions for conducting the investigation on her Power Point teacher notes. She explained:

> So if we have been practicing graphs, right, here is what your next thing is. For the paper or plastic project at home, you are going to need to develop a method of categorizing your own paper or plastic for three days. You're encouraged to

brainstorm and work together to designate different kinds of paper or plastic products you use including but not limited to similar types of brainstorming which we already did. Here's the thing: you're going to be collecting real data from the people in your home. You need to also figure out how you're going to transport it to school or do you have a reliable scale at home if you don't plan to bring it in.

The teacher introduced students to the plan for the next three days in which they would design a three-day inquiry investigation to collect data on their personal and family use of paper or plastic. She used a Power Point to review how to write up parts of an experimental design and how to begin collecting data, and formulating hypotheses. Students finished the class by answering two Mentimeter questions as an exit slip for the day. For Mentimeter question 1, Day Four, students were asked "How many categories of paper of plastic did you come up with for your data collection project?" the number of categories students came up with for paper/plastic project collection 8 of 13 students or 61.5% created one to three categories, 4 of 13 or 30.8% imagined four to six categories and only 1 of 13 students or 0.08% thought of more than six categories of paper or plastic to collect during the three day assignment. The results of these surveys are given in Figure 4.22. For the second Mentimeter survey question the students were asked to "Predict what kind of paper or plastic item you and your family will have most during the three day study." Only nine of the students responded to this question. 4 of 9 or 44.4% who responded indicated they and their families would likely have more plastic water bottles, 2 of 9 or 22.2% said office paper, 1 of 9 said money and the other two students gave erroneous answers and appeared to not take the survey seriously.

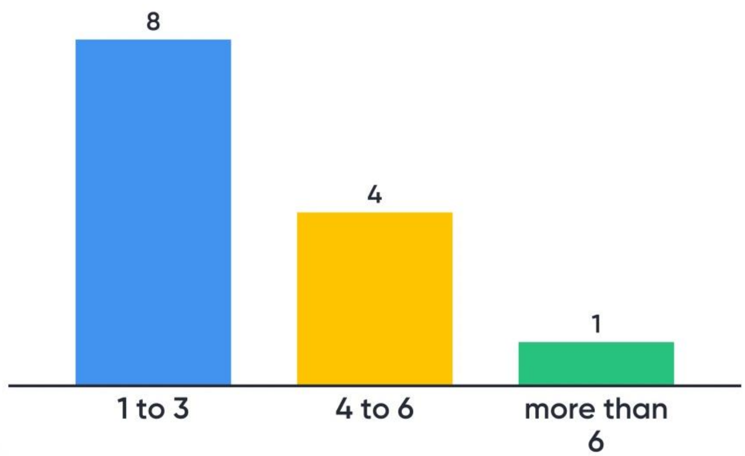

Figure 4.22: Mentimeter question 1, Day Four- How many categories of paper of plastic did you come up with for your data collection project?

After this class period the teacher and researcher discussed the two activities that were completed including sustainability graphs and summaries and prepping their data tables for their experiment which included the responses to the Mentimeter questions. She also noted the graphing addressed parts of both Learning Goals 3 and 4 because students could connect raw materials and manufacturing, and students were made more aware of responsibilities and options. Learning Goal 4 was also addressed in the second activity by students preparing their data tables for their three day investigation. This was because collecting their own and their family's paper or plastic helped focus attention on their roles and responsibilities in terms of sustainability. Learning Goal 3 was also indirectly addressed by students creating their data tables by helping them consider the different sources of paper and plastic although they did not directly describe the effects of these on environmental systems.

As students were finishing their line graphs of the temperature data, the teacher referred them back to their laboratory report format in Google classroom so they could follow the steps on how to write up their investigation. She re-posted both her IA

(Internal Assessments) Laboratory Report Template and IA Criteria Rubric for the students to use to begin writing up their three day study. These documents are located in Appendix C- IA Laboratory Report Template and Rubric. They have had experience doing this before as part of their International Baccalaureate Biology course during which they did several independent research experiments. She explained to the students they are doing their own write up but could have the same hypothesis or research question or a different one from their classmates.

At the end of class on Day Five students were surveyed as using Mentimeter Question One to briefly identify "What is your method of collecting paper or plastic over three days." The students gave the following methods which are indicated in Table 4.7.

Table 4.6: Mentimeter Question 1, Day Five- What is your method of collecting paper or plastic over three days?

Student responses
I weigh the paper using a scale I have at home, then I am converting those pounds to kilograms.
Have three boxes labeled plastic bottles, plastic bags and plastic food containers. Empty the three boxes each night for three nights.
Adding up the kilograms of the plastic used in the data table. I created a data table per day.
Eyesight
Weighing each category and putting the weight in the data table.
Weigh the amount of plastic used in each category every day.
I will count the amount of items in each category and multiply it by the average weight of the item.
Using my scale at home to measure.
Dividing the paper into five categories and weighing it using a scale.

Setting used plastic aside for weighing.

Collect the plastic I use and weigh it daily.

Having separate bins for each of the three days.

Every plastic I use over a day, instead of placing it in the trash bin I will but (sic) on the counter next to the trash can and at the end of the day sort into recyclable and non-recyclable then weigh for each.

The teacher thoroughly related the background research they previously did using a graphic organizer and presented to the class telling them it will be helpful to connect to the project, and also to make connections to environmental systems. All of the classroom instruction she gave to help students prepare to implement their inquiry/experimental design was helpful for students to understand the goal of the activity which was to not only collect their paper or plastic but to be able to see the significance of consumption in the context of environmental systems and sustainability. She reminded them they have a start on the research from the bibliography they submitted with the graphic organizer which they can use as part of their formal laboratory report. She teacher explained that they needed to write up their procedure or methodology for collecting paper or plastic in their homes for the three day investigation. The teacher explained how to put their predictions and methods into their investigation. She also reminded them about qualitative and quantitative data collection. For qualitative data some students said take a photo of it, and another suggested making notes. She explained that she wanted to see their empty data table before they left class so they know what they are going to be sorting and collecting and also reminded them of the whole class brainstorming about different kinds of papers and plastics they had done in order to get ideas of categories.

A student suggested they compare data with their partner and the teacher really like this idea and suggested they collaborate on categories going forward with this. The teacher reminded them it is better to have more categories "I want you to tell me what categories and how you are going to measure over 3 days." They discussed whether to just measure things that were being disposed of and not what was being purchased, and they made a class decision to do it that way. Teacher commented that she liked one group's idea of keeping track of each person in the house and what they were using. She asked what unit they would use, and most students agreed to use kg. The teacher also suggested that if they are using a bathroom scale may need to convert from pounds, and to remember there is a possible source of error. One girl brought up use of plastic drinking straws and remarked about controversy because they are often associated with impacts on marine animals. The teacher said starting today they should monitor straw use, and one boy asked if plastic straws are recyclable and there was a discussion in class about alternatives like metal or paper straws and the sustainable use of those.

The teacher reviewed what they were going to need to do to convert from their bar graphs of data collected on paper and plastic at home into a line graph over the three days, noting that this would then need to be extrapolated into a trend of their own use. She noted they needed to add up categories of the bar graphs to get total usage by weight, then predict usage over a month by multiplying the total by 10 (10 x 3 days = 30 days). To then convert the data to a year, they would multiply the monthly usage by 12 months, and then they would produce a trend analysis for another 50 years with directions for this process provided to the students in the Power Point. She stated "This takes that 3-day snapshot and converts into a trend for the future" and she suggested they start setting up their own data into graphs if they have time so they will be ready the next day.

Initial descriptions of their methods of collecting three days of paper or plastic were reported to the teacher via the Mentimeter question on Day 5 above, but were generally vague. They did not write more than a short phrase or sentence and either did not say how they would separate into categories or paper or plastic, or how they would mass the quantities. More review of their procedures is seen in their final experimental reports which are evaluated based on the IA Laboratory Template and Rubric in Appendix C, and two student samples of students' formal laboratory reports are found in Appendix F.

All students were successful in completing the laboratory report template for their inquiry/experimental design collecting paper or plastic for three days, but there were considerable differences in terms of how much information students gave in the Background section. For example in Student sample 1 (See Appendix F for Student samples) the student wrote

> Just to create plastic takes enough effort and environmental damage already, but if that plastic turns into something that is used once then disregarded and thrown away, then it truly is hurting the environment. Plastics are derived from natural organic materials like coal, natural gas and crude oil. To refine the oil, it goes to an oil refinery where much water is used and wasted. Crude oil and natural gas are refined into ethane propane and other chemical products. These are then used in factories to shape the plastics into things we use everyday (sic) and the carbon emission caused by this is great. All of this going into the environment just for us

> to use the plastic once and throw it away to then cause more environmental problems is just an awful waste especially if we can prevent it.

This student made note of water use and waste in manufacture of plastic, carbon emissions but made no real connection to environmental systems. The student used vague language to describe what goes on in plastic manufacture and use such as “environmental damage” and “hurting the environment.” The production of carbon emissions and water use were not connected to specific environmental consequences or systems such as greenhouse gas production and hydrologic cycle. Another vague statement related to throwing plastic away after just one use was “…cause more environmental problems is just an awful waste….” but no specific problems were stated or connected to the waste. Another student sample contains this background on paper:

> Paper is made from raw wood - made of “cellulose” fibers. The cellulose fibers’ natural glue - lignin - is removed in order to separate and reorganize the fibers for paper production. Then, the raw wood turns into "pulp" which is a watery “soup" of cellulose wood fibers, lignin, water, and the chemicals used during the pulping process. Finally, the mat is run through heated rollers to squeeze out any remaining water and compress it into one long roll of paper. This, combined with the trucks needed to transport the goods, emit so many greenhouse gases into the atmosphere. By knowing the origin of the paper production and the negative effects that just one single paper could do, it is most likely there will be more thought process into the next time a paper is about to be used or thrown away.

This student indirectly linked the processing of paper and its’ transport to the production of greenhouse gases in the atmosphere but did not mention fossil fuels as the part of the process involved, nor did she/he provide any specific greenhouse gases that would be produced. Additionally there was no mention in the background about deforestation, and effects to systems such as hydrology, soil composition, erosion and potential runoff. Overall, the students did a weak job in writing their background information in terms connecting to environmental systems, and often just used inexact phrases to comment on the consequences of global production and use of paper and plastic.

One general observation of the overall class performance on this assignment was that they often made hypotheses that did not seem appropriate for the investigation, or not founded on correct assumptions. For example in Student sample 1- *Extrapolating Amount of Plastic Waste Over 3 Days,* found in Appendix F, the hypothesis is "If more than 60% of the plastic waste in kg is non-recyclable, then it is too much and there must be a change in how much non-recyclable plastic is used." It is unclear where this student and others who wrote similar experimental hypotheses came up with such percentages, however it is possible the student conducted the investigation first and back-ended the hypothesis based on what was observed. The significance of this kind of writing suggests that the student is thinking about not only consumption of plastic in her project, but also about eventual waste disposal which relates to their understanding about the effects on sustainability. In Student sample 2 of Appendix F - *Extrapolation of Daily Plastic Use and its Effect on the environment*, the student hypothesized "The highest weighted type of plastic will be the water bottle, since that is used more daily and in larger numbers" which reflects an assumption by the student, but may not be supported by research. Another student wrote "If a household's plastic usage is high, then it will increase in the future" which is similar to several of the other laboratory reports in terms of their vague assumptions. Another student who studied paper consumption hypothesized in her/his "The type of paper that will most be used in the household will be office paper because humans use an excessive amount of office paper everyday (sic) in many types of situations. For example: at school, at work, and in the house."

It was observed that Methods were written as stepwise procedures and these were much better and more thorough than what the students had offered as their protocols when surveyed the day before and provided in Table 4.7: Mentimeter Question 1, Day 5- "What is your method of collecting paper or plastic over three days?" Although the procedures were better than the surveyed answers, there were some steps that were not clearly stated as seen in Student sample 1 who gave only four steps: "1. Organize all plastics into categories; 2. Weigh all plastics about to be thrown away with the digital scale in kilograms; 3. Organize weights into either recyclables or non-recyclables; 4. Repeat 1 time each day for a total of 3 days. (3 trials total)." There is no indication of how this student would gather plastics in the home, how the data would be collected and displayed or how the student would analyze their data. Materials section was also brief and incomplete for most of the laboratory reports. Safety, ethical and environmental issues were addressed by all of the students and mostly involved finding a way to recycle any paper of plastic.

When reviewing the formal laboratory investigations, the class did a good job of collecting data quantitatively as shown with data tables and qualitatively through photos and drawings. Many students separated their collected plastic or paper into recyclable and non-recyclable categories and recorded mass for each day. Some students used grams but most used kilograms as the mass unit. All of the students included photographs of what they collected and incorporated that into a qualitative data set. In the Evaluation section of their reports, several students gave the "number of days" for data collection as strength while a few stated this was actually a weakness. Other weaknesses several students included were the kind of scale used, and the lack of different categories. When recalling Mentimeter question 1 on day 4 "How many categories of paper of plastic did you come up with for your data collection project?" (Figure 4.22) it was noted that most students in the class selected only one to three categories for their investigation. Students did reflect on this and mentioned other improvements and how they would change the project in the future. As mentioned, some said they would use a better scale, others indicated they would include re-usable plastics and not just what they disposed of to get a more accurate accounting of how much plastic they used in total. Two students suggested an improvement would be to compare their data to other households and two suggested comparing the data to consumption in other countries or global comparison.

Most of the students merely wrote a short paragraph for their background information The research team expected more than this since they already had some bibliography and research from their graphic organizers at the beginning of the implementation of the project, but the cooperating teacher noted that she usually did not require them to write extensively for their Background section during their other assignments. Additionally, the class did a very good job related to the Analysis section of their data which supports Learning Goal 3 which stated students would be able to analyze effects of manufacture, production and use of either paper or plastic on environmental systems. Each student report contained bar graphs of daily paper or plastic use which was expressed in appropriate categories they had selected. The students all included line graphs for the overall mass of paper or plastic use over three days, and graphs which demonstrated extrapolation from three days to one month and others showing one month to one year. All of the student reports also had trend analysis graphs of the one year line into the future for fifty years. The graphic analysis was usually accompanied by a short paragraph of interpretation but not in all cases. Another student (Student sample 4) stressed “awareness” to help the problem of over use of paper and stated

> Paper waste is a serious problem that affects the environment in a negative way. To put paper waste into perspective, the waste of each individual was compared to the waste of the household. This way, each individual is made more aware of their waste. This can be expanded on a global scale by making each world country more aware of how paper waste is harmful to the environment, and how much they are contributing to the global totals. Then, steps can be taken to reduce paper waste. Awareness is key, however, to reducing the amount of paper being discarded on a global scale.

This student again used imprecise statements such as “affects the environment in a negative way” without making any connections to specific environmental systems. The student did make the association with “awareness’ for people from individuals to households to expanding globally making “each world country” more aware of paper waste. This is a good link to Learning Goal 4 as well. Imprecise references to environmental consequences of paper and plastic use without specific examples of systems linkage was fairly consistent in the student laboratory reports. Overall the class average for the laboratory reports was 86% based on the scoring rubric found in Appendix C. These were graded by the cooperating teacher.

6. Post Project Survey

Final Post Project Survey question 4 provided students the opportunity to reflect on the project activities asking them to "Select the most helpful strategy that helped you develop your data analysis and conclusions when writing your inquiry/experimental laboratory report." The most commonly selected choices were Small group bar graphing activity with non-environmental topics and Design of method for at-home data collection of paper/plastic with 27.27% selected; while 18.18% picked Extrapolation of at-home paper collection for future consumption. Finally, one student or 9.09% selected three of the choices as most helpful in developing data analysis and conclusions when writing the inquiry/experimental laboratory report which included: Brainstorming session about effect of paper/plastic manufacture and making a graphic organizer; Brainstorming session about different kinds of paper/plastic; Research on reduce-reuse-recycle of paper/plastic products. The other six answer choices were not selected. Complete information from the Post Project Survey is located in Part Four. Post Project Survey Question 9 allowed students to write comments, and one student gave two suggestions which included spending more time doing the paper or plastic collection at home and also to expand the focus to include individual countries and how they differ in paper and plastic use.

7. Small Focus Group Responses

In the small focus groups students were asked whether doing the experimental design/inquiry activity was impactful for them learning about systems or environmental sustainability. They were more descriptive about environmental sustainability than systems, and noted greater awareness about sustainability which was directly related to Research Question Two. For example one student offered:

> For me yes, because my mom kind of help me keep it organized because I wasn't home. We were together three nights, but she did help me and we collected the like I said like the plastic water bottles, where I told my dad to going to bring them. But wow that was nice of him and it's a lot like it's a full box of like just plastic water bottles. It kind of made me aware how much like it's a daily need from him and like if we were to change and then it'd be like a hard process, but I think we can do something about it. It'll just be hard to get them to.

Students also made connections to the graphing of their own data which also directly correlated to Research Question Two and the importance of analyzing personal and classroom data on paper or plastic usage and recycling in influencing students' understanding of global environmental sustainability issues. Many students noted the impact of graphing activities from the project in helping them visualize the importance of paper or plastic consumption. For example, one student said that making bar graphs of their collected data which were separated it into categories were helpful. Another stated, "… that let me show like which kinds of plastic are in my life." Another realized "When I was creating my trend graphs there was like three days of data and I feel like it would have been a lot more accurate if there was like seven days but like it still worked." Another stated "So I saw like how much I was doing to contribute to like the global average…" The conversation continued with one student noting their individual graphing helped them understand sustainability noting, "Yeah, I think it did because it makes you more aware of like how relevant it is to your life. I feel a lot of people like promote recycling, but don't do it themselves. So what are you really doing? So I feel like more of a need to like water recycle, especially seeing how many water bottles. I used a lot." This student's comment also was impactful related to Research Question Three because she reflected on the behavior of herself and others. Another said, "Yeah, it showed me that I should definitely limit like certain types of plastic, too because it showed like which ones I use more; which categories of plastic…I don't use any plastic bottles, but for me it was trash bags…to think on plastic bags." These student comments suggest that the instructional activities, especially the inquiry investigation on paper or plastic were meaningful to students' developing a better understanding of environmental sustainability. Students were also able to integrate ideas about environmental systems into their background information and final aspects of the laboratory report.

Research Question Three

Research Question Three asked: How do students come to understand the impact of the effects of individual behaviors on broader issues of environmental sustainability? The instructional activities of this unit provided numerous opportunities for students to examine human behavior towards the environment and to self-reflect on their own conduct related to sustainability issues. The teacher effectively challenged students to consider the impacts of human actions especially while having whole class instruction, and during student presentations of the products of their learning such as their graphic organizers, graphs, and RRR projects. As in reviewing the first two Research Questions the different teaching strategies each contributed to supporting the last Research Question Three.

1. **Teacher whole class/discussion based instruction**

Throughout the unit the teacher emphasized the ideas of origin or inputs for paper and plastic, the impacts on environmental systems when deriving and processing raw materials, and effects of discarding and dumping items. In an activity on day one, the teacher discussed how the fashion industry can have a huge impact on environmental systems and environmental sustainability and she connected the production of a single T shirt to the amount of water an individual would consume in a year. A video about circular economy was shown involving the garment industry (WorldDynamics, 2017) and a follow up discussion between the teacher and students ensued. This activity allowed for robust debate about interconnectedness of economics and personal choices in addition to the issues of environmental sustainability and systems. Students addressed their behavior related to environmental sustainability in terms of how important buying new clothes is to them, and what choices they can make related to the global issue of trash as a consequence of purchases and usage. In her reflections on the Daily Observation Checklist, the teacher noted how well Learning Goal 3: Students will be able to analyze the effects of manufacture, production and use of either paper or plastic on environmental systems and Learning Goal 4: Students will be able to evaluate the roles and responsibilities of individuals, groups and societies in general in terms of environmental sustainability were addressed by this activity.

The teacher also asked students to reflect on a video they watched the day before the unit began: "Trash, Inc.: The Secret Life of Garbage" from CNBC. She reminded them that we all need clothes but asked them "So do you think you could do or at least being mindful about the choices that you make to make this process maybe a little bit more sustainable?" Some students mentioned that wearing school uniforms has cut down on clothing purchases. The teacher said Learning Goal Four was also the most focused goal of this activity. It made students consider the importance of their behavior and responsibilities in relation to the content.

2. Graphic Organizers

Students also responded to a Mentimeter question on Day Two that indicated a third of the class answered the graphic organizer activity made them more aware of systems and more concerned about sustainability. For learning Goal 4 related to the graphic organizers, the teacher noted the students began to focus on community and laborers in terms of roles and responsibilities. For the Mentimeter Wordle from Day 2, the teacher noted for Learning Goal 4 "This activity briefly addressed this goal when asked how important it is to learn about Environmental Sustainability. However, this activity was a hook; not necessary to the substance of the lesson."

Throughout the unit, the teacher asked students to reflect and consider their own actions but also to note their interest in the subject as a possible motivator for personal behavior. For example students answered Mentimeter Question 1, Day Two- "How important is learning about Environmental Sustainability (ES) to you?" 77% of the students had a positive view of the topic, with 46% of the students answering they were very interested in learning more about environmental sustainability and 31% answered they think environmental sustainability is one of the most important things for us to understand. She also suggested students focus on how paper or plastic is made and how the consequences of production are affecting the environment; not just the looking at final products as litter as a way of reminding them about environmental systems and sustainability. When students were working on their graphic organizers about paper or plastic manufacture and use, the teacher reminded the class to talk about "How does this relate to our responsibilities as consumers and our options as you know, responsible citizens and so on. So what we're going to think about today is trying to kind of add on to this background and follow through with a little bit of processing." Some groups of students talked with each other about global consequences as they worked. For example one girl made good connections to environmental systems when preparing their organizer about paper usage "…but then the resources used during all of this about 95% of the raw materials used come from trees. And then this equals less trees which equals less photosynthesis which equals more carbon dioxide in the atmosphere and slower rates of oxygen production for organisms inspiration (sic)." It was interesting that one group brought issues related to working conditions or availability of jobs into their presentation as this perspective was more humanistic approach but also viewed the process in an even broader vein on human impacts.

3. Graphing

The teacher talked with the students about extrapolating the world temperature data they had graphed into a model of one hundred years into the future. She then explained that later during the project they are going to set up their data tables for their own collected information on paper or plastic use, then analyze the data and create a trend line to help them visualize their own impacts. The teacher noted in her Daily Observation Checklist that students did appear to make good connections and concern with climate change models and possible sea level rise upon completion of the trend analysis of global temperature data. They also connected to individual and shared responsibilities which are reflected in Learning Goal 4.

4. Reduce-Reuse-Recycle Implementation project

Another activity completed was the RRR "Poster" which was a digital product to raise awareness and Reduce, Reuse, recycle (RRR) and was an activity suggested by the cooperating teacher to encourage students to connect to the concepts of paper and plastic use. Students were allowed to choose a partner and they created a digital "poster" to suggest a possible program they could actually implement. The teacher explained this was to represent a way for them to get other people involved in reduce, reuse, and recycling which should have a strong visual appeal. She explained "First select paper or plastic. Then decide if you are going to do an awareness piece or implementing policy change." She showed a poster from the school Interact club as an example of what you cannot do and said they were making a digital poste and could use Power Point as one slide or more. Once the students uploaded their projects into the Google classroom, the cooperating teacher gave each group a few minutes to present their idea to their classmates. One example poster was not only a good way to express the problem of single use plastic bags and educate in a simple manner, it also appealed to the class because it also used humor and irony. Students were appealing to classmates and others to make them more aware, but they also addressed an environmental system in terms of the aquatic food chain thereby addressing all of the Learning Goals in a simple but impactful way. They made an association to Learning Goal 4 by detailing how each person can prevent 330 plastic bags from entering the ocean by using reusable grocery bags while shopping.

Another group made a poster about implementing recycling bins in businesses and the students talked about how this is done in other cities like Mexico City. They suggested that by having the bins in cafes and stores that people would take advantage of recycling opportunities when they are readily available. The students demonstrated how the effects of plastic disposal into landfills can create toxins that leach into the soil and water. They also discussed how making recycling more easily available would encourage people to be more responsible and change their behavior. The teacher commented that relative to Learning Goal 4: "Students will be able to evaluate the roles and responsibilities of individuals, groups and societies in terms of environmental sustainability," was that most of the digital poster projects focused on individuals' roles and responsibilities but they also described the long term effects when groups of people are involved. Many of these students made connections to all four of the Learning Goals through this project.

5. Reflection Essay

On the last day of the unit, students were asked to write a final reflection essay, their penultimate activity. Part of the essay asked "What can you do personally, and what do you suggest for humans to do to in general to affect a change?" All of the essays did address the role of individuals in helping to reduce, reuse and recycle and most of them included that if more people were aware and changed behavior in this manner, there would be improvements in global sustainability. The teacher made a strong positive assessment of the Reflection essay related to Learning Goal 4 stating "This was by far the best activity to address this goal. The students settled nicely and wrote from many different perspectives about the roles of individuals, societies, nations and global citizens.

Great activity encouraging introspection. This also included research and bibliography. Very powerful reading."

6. **Independent Inquiry/Experimental Design**

As the students began to design their inquiry project on collecting their own and their family's paper or plastic, creating data collecting tables and a method for analyzing use focused attention on their roles and responsibilities in terms of sustainability. She explained to the students they would be constructing line graphs next, with global climate change data using Excel and that they would construct trend analysis models using the data they imported today. She asked "Where do you think this is going in light of what we are doing with the project?" One student said "Application to trend over time…yourself, your class, your community." Another student said "Could end up being a bigger issue with sustainability." These comments indicate at least some of the students were thinking ahead as to possible relationship with environmental sustainability and both their own individual roles and those of others. The teacher said:

> We could go bigger and bigger. We're going to do this first and after we figure tomorrow how to extrapolate with our Trend data. You're collecting real data about paper or plastic from your home. You're going to be plotting that and then you are going to be using this kind of process to extrapolate. And when we think about the applications of this you're going to be thinking of your own home, your own setting and that's going to change over time. But also think of that interconnectedness… of not just you but your class, your community, your city. It could kind of have an effect and end up being a bigger issue with sustainability because how many Earths do we have after all?

The teacher followed up with “What do you think the kind of purpose of this whole project is going to be?” One student answered “To see what we are using.” This exchange illustrates the teacher and students making connections to their own usage related to environmental sustainability. She also suggested “To what extent do different people use paper or plastic?” is a possible research question for their inquiry project, which would also focus on individual and group behaviors.

Answers to a Mentimeter Question Two on Day Five “Give a word or short phrase to describe how you feel about the amount of paper or plastic being used worldwide” illustrate students are generally engaged and aware of consequences of human behavior. This created a Wordle in Figure 4.23. Several students said they were “concerned,” while others indicated “angry” and “infuriated.” Words like “not cool,” “overwhelmed” and “disappointed” demonstrated an overall tendency for students to acknowledge paper and plastic usage was problematic and they had negative connotations to associate with the question. One student wrote “apathetic” and another said “oblivious.” It could be they are describing their own attitudes or those of the world in general but it cannot be determined by the format of the responses given. Overall the students seem to have a sense of the possible serious consequences of global paper and plastic use and appear to at least care about it or be concerned on a personal level.

The teacher commented about the student links to Learning Goal 4 in the Formal Write- up which students completed on the last day of the unit stating “In the conclusion and evaluation, students reflected significantly on their own responsibility with regard to their paper (or plastic) consumption. Many also extrapolated to the community and nation.” In terms of Application in the laboratory report, or real world value students made some connections to disruption of environmental systems like carbon and water cycle but did not make clear explanations. For example Student sample 1 states “This experiment is related to the real world because we can see what percent of our plastic is being used once then wasted and how much that contributes to changes in the environment. It keeps us conscious of how much we are wasting and forces us to make an effort to change our habits to be more ecofriendly.” This statement generalizes that the waste “contributes to changes in the environment” but there is no direct link to specific environmental systems. The comment “…forces us to make an effort to change our habits to be more ecofriendly” does indicate a reference to Learning Goal 4.

Figure 4.23: Mentimeter Question 2, Day Five- Give a word or short phrase to describe how you feel about the amount of paper or plastic being used worldwide

7. Post Project Survey

Final Post Project Survey question 8 asked “Which sentence best describes how conducting this project influenced your opinions and behaviors about environmental sustainability?" Results of this inquiry reflects 90.91% of the students surveyed as being either somewhat or definitely influenced in terms of their behavior in the future regarding environmental sustainability, and relates positively to the individual responsibility aspect of Learning Goal 4, and Research Question One. None of the student responded that The project did not influence me to change my behavior; 9.09% answered I have a better understanding about environmental sustainability but the project will not influence my behavior in the future; 36.36% answered I have a better understanding about environmental sustainability and the project will somewhat influence my behavior in the future; and the remaining 6/11 or 54.55% answered I have a better understanding about environmental sustainability and the project will definitely influence my behavior in the future. Post Project Survey Question 9 allowed for students to write additional, optional comments. One student expressed enjoyment related to the project that collected plastic at home and noted that she/he was able to get her family to join in on her learning at school.

8. Small Focus Group Responses

During small focus group questioning regarding whether their understanding of environmental sustainability has changed after completing the unit, students spoke in general about their views on sustainability and somewhat indicated how the project activities had changed their understanding. One stated:

> …it's kind of like stayed about the same but I realize now how much more difficult it is to keep it sustainable and how much we're going the opposite direction with plastic use and like using and carbon emissions, that kind of thing and doing the like the activities with the drawings and all that stuff… you realize

> like how quickly it happens…and like it's finally like the consequences of it can come out…so it makes me like think this much more relevant than we think. That it is a problem for like the future but it's probably gonna' happen soon if we don't do something about it.

Another student said "Like before I knew the plastic and paper was a big issue. But now I'm kind of like realizing every time I throw away piece of plastic or paper, I'm like this isn't good, right? And it would maybe, how would it, well, be a problem."

When asked whether their understanding about sustainability had changed while doing the project, students made some personal connections about how they view sustainability now. For example a student said: "Yes, and it has… once again like looking back at how everything is interconnected and I think it's made me more aware of my choices. Now when I use a plastic bottle it's like, oh man like to reuse it a little longer and it's… I hesitate when I want to open a wrapper because it's plastic and I hadn't thought about that as much as now, yeah."

Another student commented:

> I'm aware more of it now. I have a large family. So I think of plastic disposal. It's like a large amount every day. My dad probably goes through 10 plastic water bottles because he works in construction, even though I'm not even telling him not to anymore because it's so hot outside. And you know, like I tried this weekend, not this weekend, like the last three days. I was like, okay, what if we buy those big bottles or jugs and then just like take it with you because you know- learning about this-and then big coolers then I don't know. I think it's because he told me

> that it's easier. So I really think that sometimes we kind of look at the easier way than rather than the correct way to do thing.

In terms of activities during the unit that were impactful in changing their understanding of sustainability one student noted

> Also something that really helped me was the activity we did with the graphs and like the trend line she gave us in the Dropbox. Yeah, I liked going into a hundred years that made me think how everything in the future also will connect and will contribute more and more and yeah, that's that was good."

When prompted to indicate any other behavioral changes from activities there was a discussion about the gifts of reusable utensils and metal straws that was given to each student-participant by the researcher. None of the students had ever used bamboo utensils and metal straws and in general they expressed an interest in using them in the future. One student commented, "I got really excited about the metal straw!" There was a good deal of enthusiasm among the small groups about other activities and projects they could do in the future, and how to improve the unit. For example they discussed the idea of developing and implementing an actual intervention for a recycling project and suggested doing it at the public library. Another conversation ensued about trying to use the least amount of water to brush your teeth. Students continued to offer other ideas for future research. They appeared to have an interest in doing more research and in completing projects that would make a difference in environmental sustainability. One said, "… I'm saying like actually could I actually do it not just go come up with it, but do it." Another classmate followed with, "Yes, so then we can see the impact. I don't know how successful I would be but maybe you could challenge us to like use very little paper as possible or plastics. Like well instead of just measuring it, see how little you can do." Another said, "But like the part that I really like wanted to say is like go through with the plan actually from start to finish…with a longer period of time.

Another idea for further research included understanding the impact of the breakdown of plastics on the environment:

> The only other thing that I was curious about that I kind of wish we could have done was everyone was talking about how plastic can you know deteriorate over time and how the chemicals affect like actual plants and I wanted to see the actual effects; like see how it would change and like the toxic levels would rise. I don't know how you would exactly go about measuring that but I would be interested in seeing the extent of it.

Some also suggested making a flow chart of where trash and recycling occurs locally, as none of them knew where the solid waste and recycling center was and where the trash goes for landfill and recycling purposes. Students gave suggestions about collecting data for more days (7 days was suggested), and advised comparing paper and plastic use in different countries like Saudi Arabia and China versus United States.

PART FOUR: POST PROJECT SURVEY RESULTS

According to the Post Project Survey, students moved from having a limited understanding to having a good understanding of systems thinking after the project. On the final day of the project students were given time to answer the post-project survey online on Survey Monkey. Only 11 of 13 students completed the final survey as two students were absent for IB testing and they did not return to class for the remainder of the year. For Question 1: How well did you understand systems or linking thinking for environmental science before this project began? Answer choices were: Not at all, never heard of it 3/11 or 27.27% responded to this; Understood somewhat 8/11or 72.73% responded; Understood exactly 0.0% responded. One interesting aspect of this question was comparing it to Initial Survey: Question 3 “Have you ever heard of systems thinking?” from the initial survey on the first day of the project. The responses to this initial survey indicated that none of the students had ever heard of systems thinking prior to the implementation, compared with 72.73% indicating they understood somewhat when the project started; an interesting change in their answers to a nearly identical inquiry after two weeks. Figure 4.24 illustrates student responses.

Final survey question 2 asked “How well do you understand systems thinking for environmental science now that you have completed the project?” Student response choices were I do not understand what systems thinking is at all to which none of the students responded; I understand some of what systems thinking involves 1/11 or 9.09% answered; I have a good understanding of systems thinking related to environmental science issues 10/11 or 90.91%. This self-assessment is in stark contrast to the original student responses from the initial survey as referred to above in Initial Survey: Question 3 Have you ever heard of systems thinking?” to which none of them responded they had ever heard of systems thinking. The responses are illustrated in Figure 4.25.

Final survey question 3 allowed students to reflect on the activities implemented in the study asking “Select the most helpful strategy that helped you develop your own systems thinking.” The answer choices and responses are represented in Table 4.7 and Figure 4.26. Six choices were not selected and these included: Brainstorming session about different kinds of paper/plastic; Whole group review of graphing skills; Small group bar graphing activity with non-environmental topics; Design of method for

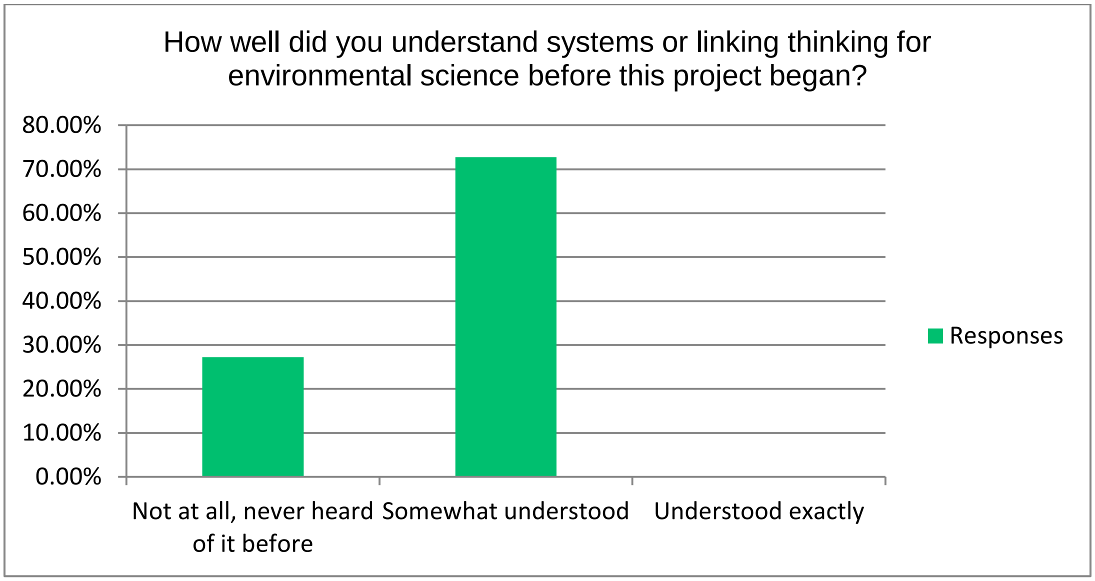

Figure 4.24: Final Survey Question 1 Pre-project responses- How well did you understand systems or linking thinking for environmental science before the project began?

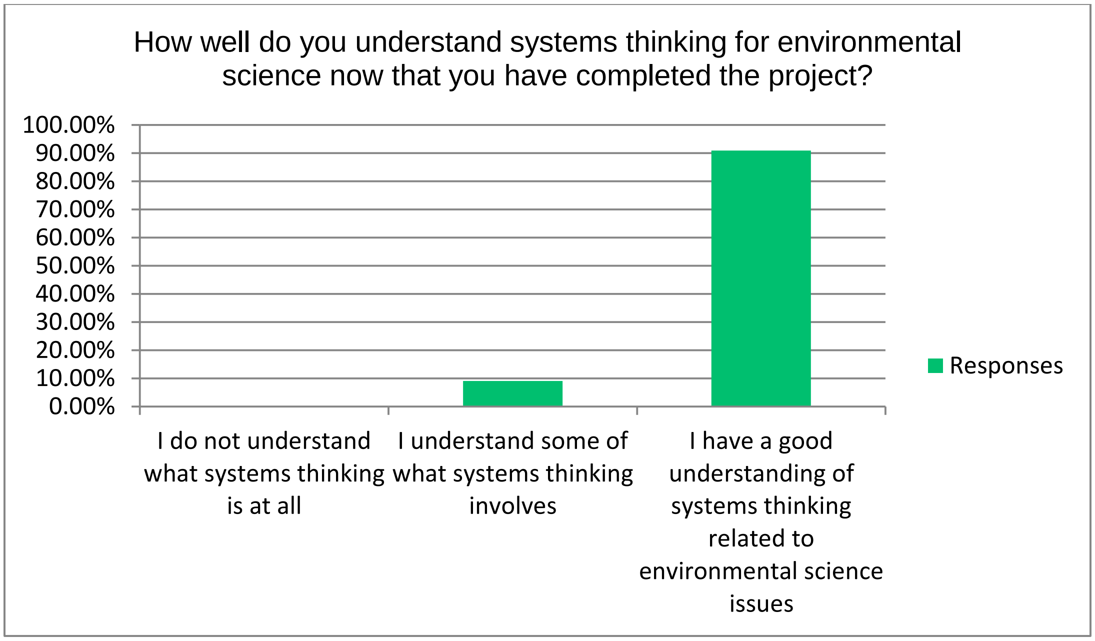

Figure 4.25: Final Survey Question 2 Post-project Responses- How well do you understand systems thinking for environmental science now that you have completed the project?

at-home data collection of paper/plastic; Interpretation and graphing of at-home paper/plastic collection; Extrapolation of at-home paper collection for future consumption. Single student selections included: Construction of bar graphs of data sets related to paper manufacture and consequences; Construction of line graphs of data sets related to trend analysis of environmental data sets; Research on reduce-reuse-recycle of paper/plastic products. Two respondents selected: Introduction to systems thinking with tree diagram; Brainstorming session about effect of paper manufacture and making a graphic organizer; Research on consequences of paper/plastic manufacture in the environment and linking to environmental sustainability for essay after completion of the project; Final reflective essay. These responses reflect similar choices given by the students in the pilot study but more of that group also selected the initial activities like brainstorming and making a graphic organizer as important in helping them understand systems thinking.

Table 4.7: Final Survey -Student's descriptions of the most helpful activities for systems thinking

Answer Choices	Responses percent/	number
Introduction to systems thinking with tree diagram	18.18%	2
Brainstorming session about effect of paper manufacture and making a graphic organizer	18.18%	2
Brainstorming session about different kinds of paper/plastic	0.00%	0
Whole group review of graphing skills	0.00%	0
Small group bar graphing activity with non-environmental topics	0.00%	0
Construction of bar graphs of data sets related to paper manufacture and consequences	9.09%	1
Construction of line graphs of data sets related to trend analysis of environmental data sets	9.09%	1
Design of method for at-home data collection of paper/plastic	0.00%	0
Interpretation and graphing of at-home paper/plastic collection	0.00%	0
Extrapolation of at-home paper collection for future consumption	0.00%	0

Research on reduce-reuse-recycle of paper/plastic products	9.09%	1
Research on consequences of paper/plastic manufacture in the environment and linking to environmental sustainability for essay after completion of the project	18.18%	2
Final reflective essay	18.18%	2

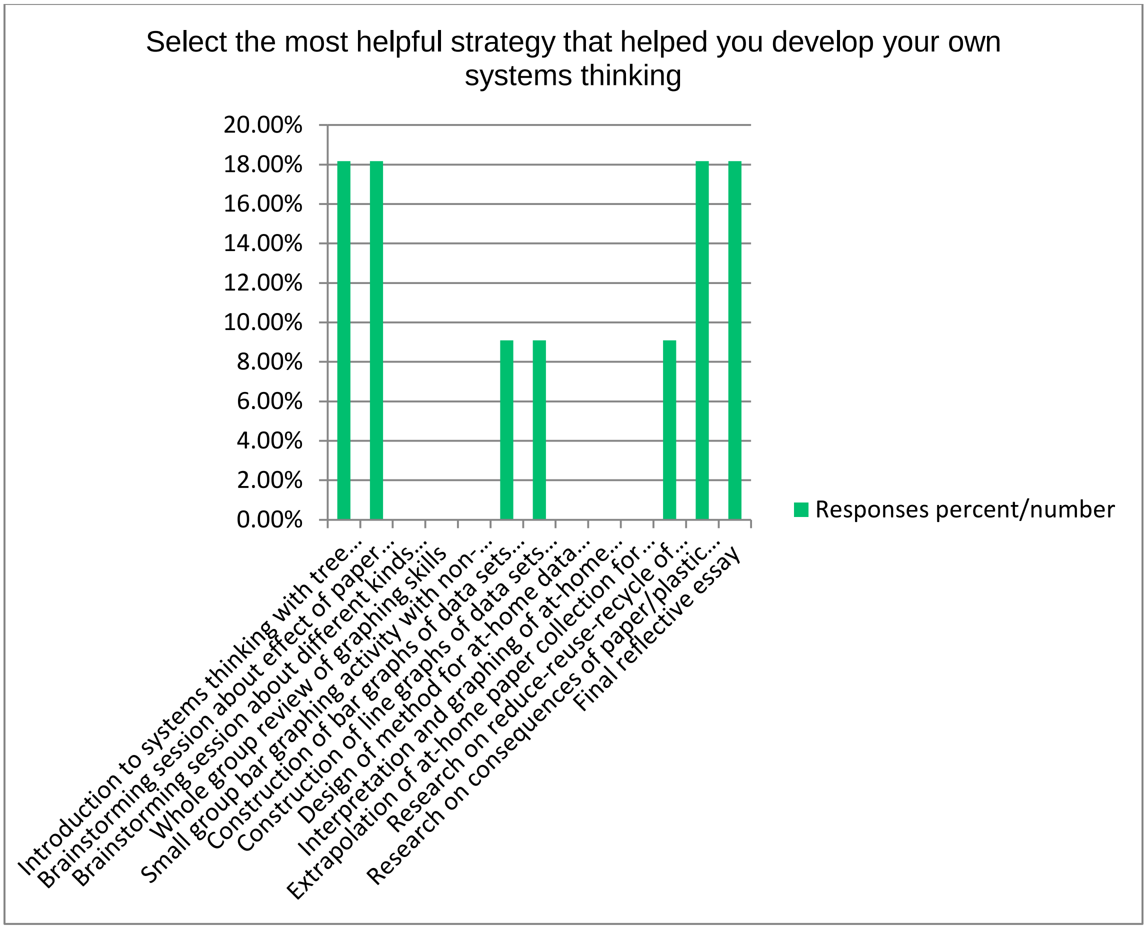

Figure 4.26: Final Survey Question 3 Responses- Most Helpful Strategies for Systems Thinking

Final survey question 4 also provided students the opportunity to reflect on the project activities in a different light asking them to "Select the most helpful strategy that helped you develop your data analysis and conclusions when writing your inquiry/experimental laboratory report." Table 4.8 and Figure 4.27 contain the summary data. Six of the answer choices were not selected and include: Introduction to systems thinking with tree diagram; Whole group review of graphing skills; Construction of bar graphs of data sets related to paper manufacture and consequences; Construction of line graphs of data sets related to trend analysis of environmental data sets; Interpretation and graphing of at-home paper/plastic collection; Research on consequences of paper/plastic manufacture in the environment and linking to environmental sustainability for essay after completion of the project. Three students 27.27% selected Small group bar graphing activity with non-environmental topics; and Design of method for at-home data collection of paper/plastic which were the most selected choices, while 2/11 or 18.18% picked Extrapolation of at-home paper collection for future consumption. Finally, one student or 9.09% selected three of the choices as most helpful in developing data analysis and conclusions when writing the inquiry/experimental laboratory report which included: Brainstorming session about effect of paper/plastic manufacture and making a graphic organizer; Brainstorming session about different kinds of paper/plastic; Research on reduce-reuse-recycle of paper/plastic products.

An interesting take away is that students did not appear to include the simple graphing activities in terms of helping them understand systems thinking, but they did include those choices when referring to which activities helped them analyze data and write conclusions for their inquiry laboratory. Also, they did not relate the systems thinking with tree diagram to this part of the project but some (18.18%) found that helpful in response to Question 3 regarding learning about systems thinking.

Table 4.8: Student's Descriptions of the Most Helpful Activities for Laboratory Report Data Analysis and Conclusions

Answer Choices	Responses Percent/number	
Introduction to systems thinking with tree diagram	0.00%	0
Brainstorming session about effect of paper/plastic manufacture and making a graphic organizer	9.09%	1
Brainstorming session about different kinds of paper/plastic	9.09%	1
Whole group review of graphing skills	0.00%	0
Small group bar graphing activity with non-environmental topics	27.27%	3
Construction of bar graphs of data sets related to paper manufacture and consequences	0.00%	0
Construction of line graphs of data sets related to trend analysis of environmental data sets	0.00%	0
Design of method for at-home data collection of paper/plastic	27.27%	3
Interpretation and graphing of at-home paper/plastic collection	0.00%	0
Extrapolation of at-home paper collection for future consumption	18.18%	2
Research on reduce-reuse-recycle of paper/plastic products	9.09%	1
Research on consequences of paper/plastic manufacture in the environment and linking to environmental sustainability for essay after completion of the project	0.00%	0

Questions 5, 6 and 7 from the final survey include personal opinions from the students. Question 5 asked them "How would you rate your level of engagement in this project?" 0.0% of the students responded they did not participate at all; 2/11 or 18.18% said I participated somewhat, but not fully: and 9/11 or 81.82% indicated I participated fully. Figure 4.28 on summarizes these results. Question 6 was "How would you rate your overall interest in the project?" to which 0.0% of the students indicated The project was not interesting to me at all; 5/11 or 45.45% selected The project was somewhat interesting; and 6/11 or 54.55% chose The project was very interesting to me. Figure 4.29 illustrates these results. Question 7 queried "How would you rate your overall enjoyment of the activities and project?" to which 0.0% answered I did not enjoy any aspect of the project; 4/11 or 36.36% indicated I enjoyed some of the project activities; and 7/11 or

63.64% indicated I enjoyed participating in the project. Graph 4.30 illustrates these results. Review of the data indicates overall the responses by the students to participation, interest in, and enjoyment of the study was positive.

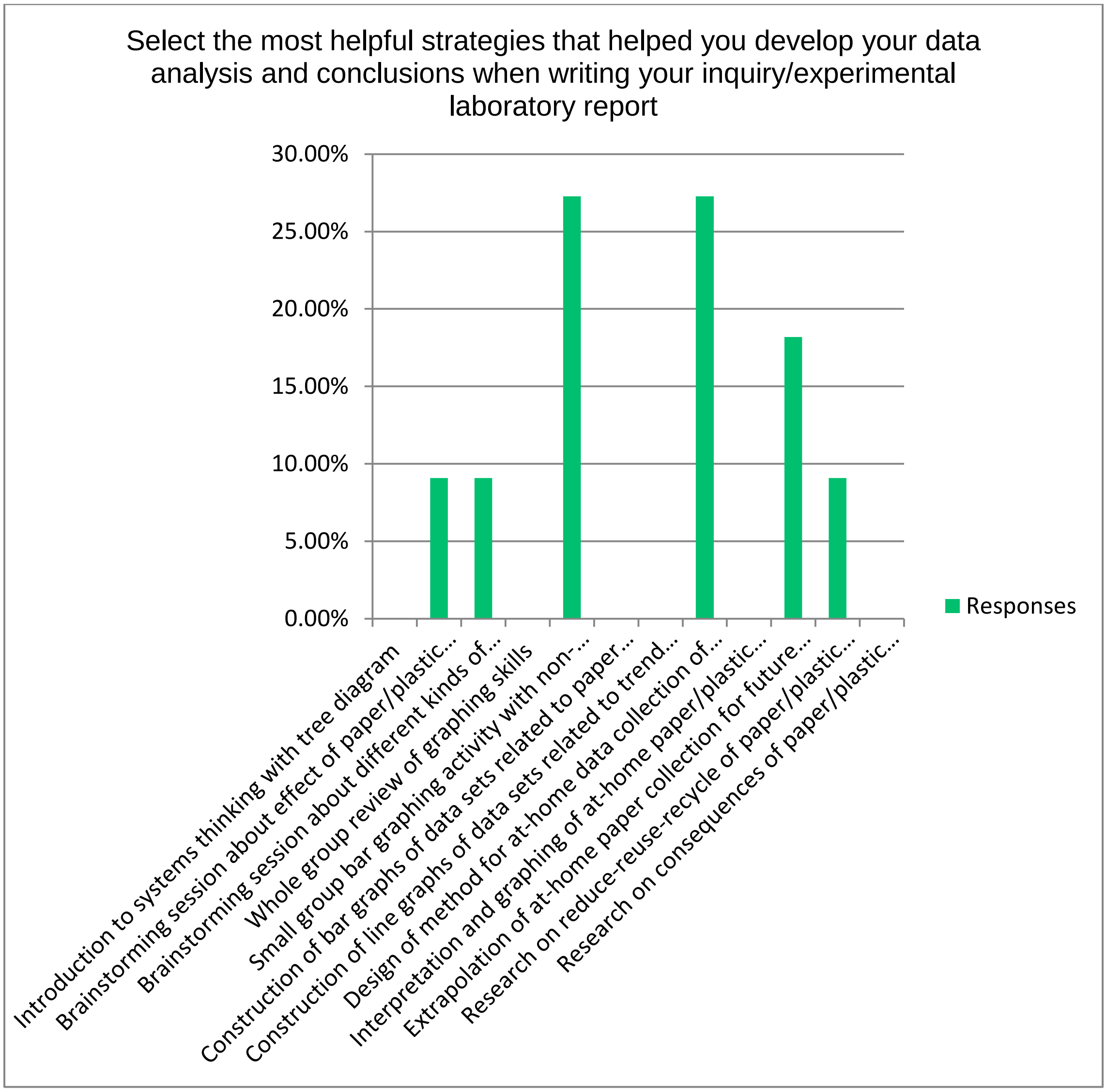

Figure 4.27: Final Survey Question 4 Responses-Most Helpful Strategies for Data Analysis and Conclusions in Lab Report

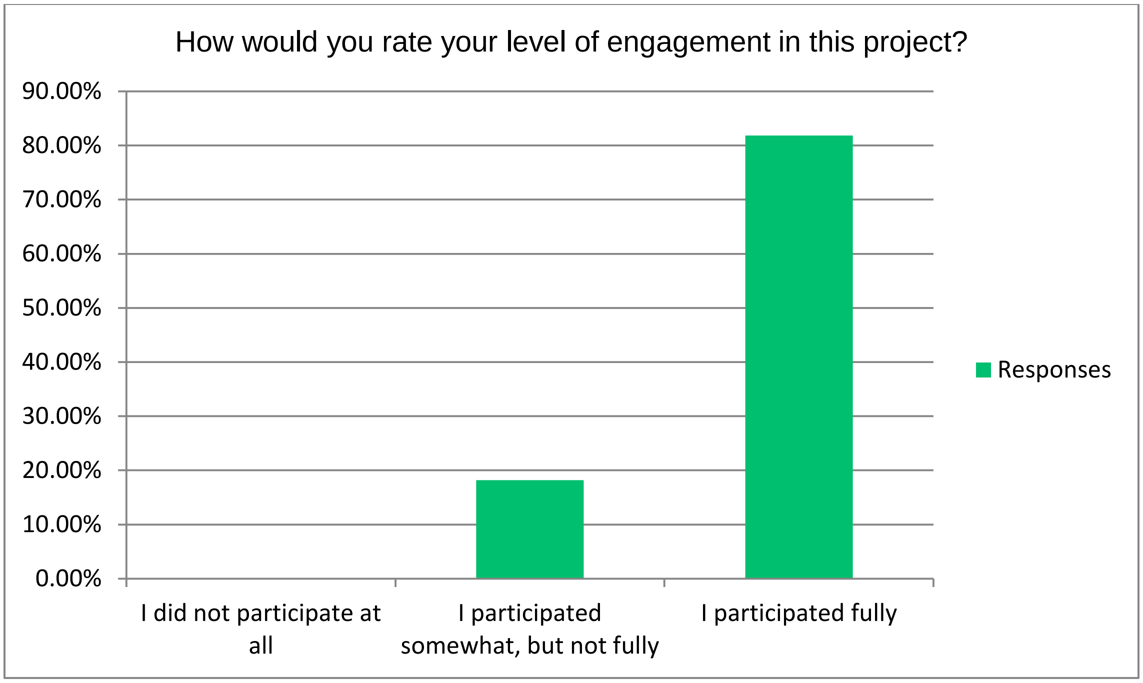

Figure 4.28: Final Survey Question 5 Post project responses- How would you rate your level of engagement in this project?

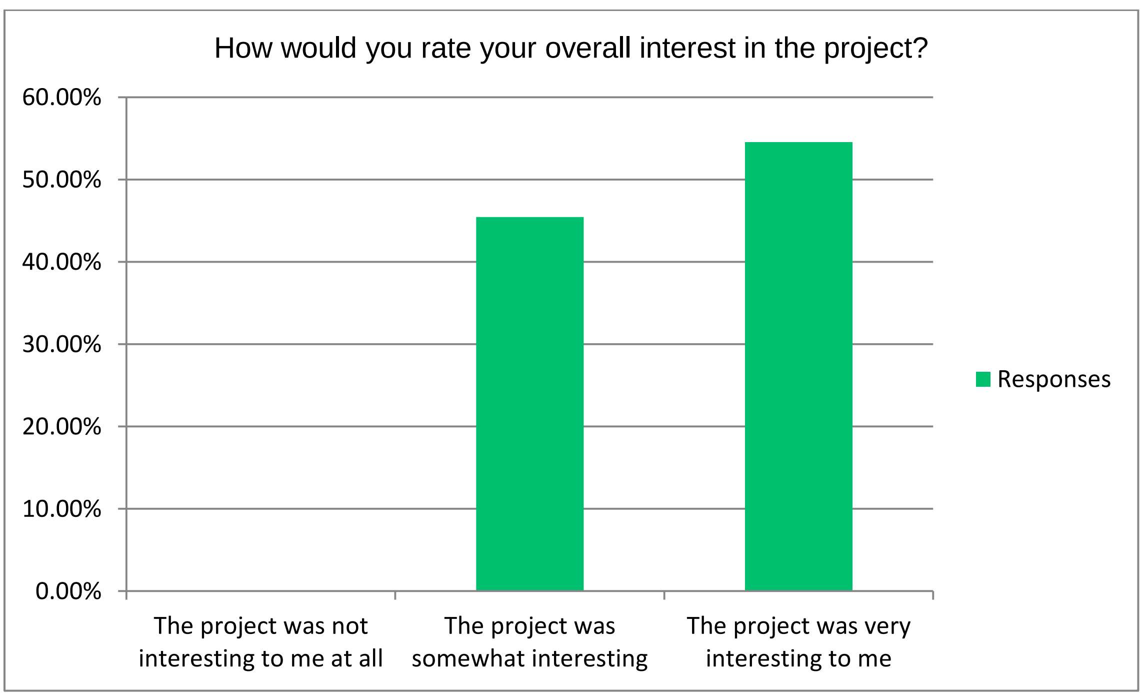

Figure 4.29: Final Survey Question 6 Responses-How would you rate your level of interest in the project?

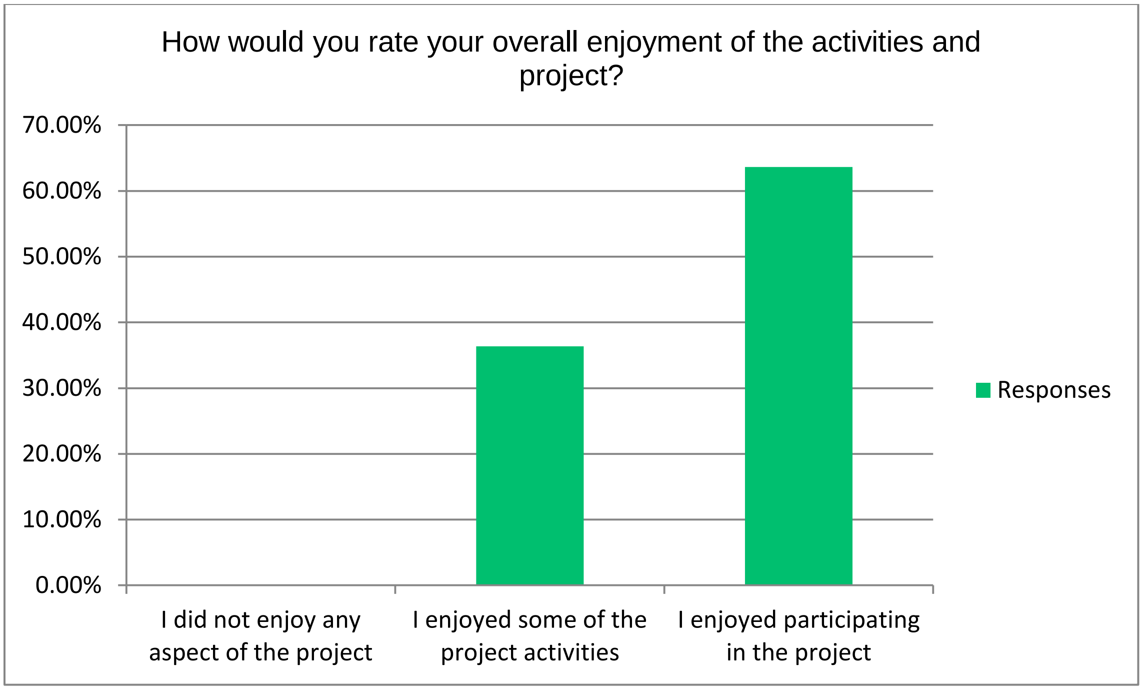

Figure 4.30: Final Survey Question 7 Post project responses- How would you rate your overall enjoyment of the activities and project?

Final Post Project Survey question 8 was designed to have students reflect on Learning Goal 4: Students will be able to evaluate the roles and responsibilities of individuals, groups and societies in general in terms of environmental sustainability by asking "Which sentence best describes how conducting this project influenced your opinions and behaviors about environmental sustainability?" 0.0% of the student responded The project did not influence me to change my behavior; 1/11 or 9.09% answered I have a better understanding about environmental sustainability but the project will not influence my behavior in the future; 4/11 or 36.36% answered I have a better understanding about environmental sustainability and the project will somewhat influence my behavior in the future; and the remaining 6/11 or 54.55% answered I have a better understanding about environmental sustainability and the project will definitely influence my behavior in the future. This data reflects 90.91% of the students surveyed as being either somewhat or definitely influenced in terms of their behavior in the future regarding environmental sustainability, and relates positively to the individual responsibility aspect of Learning Goal 4. Figure 4.31 displays these student responses.

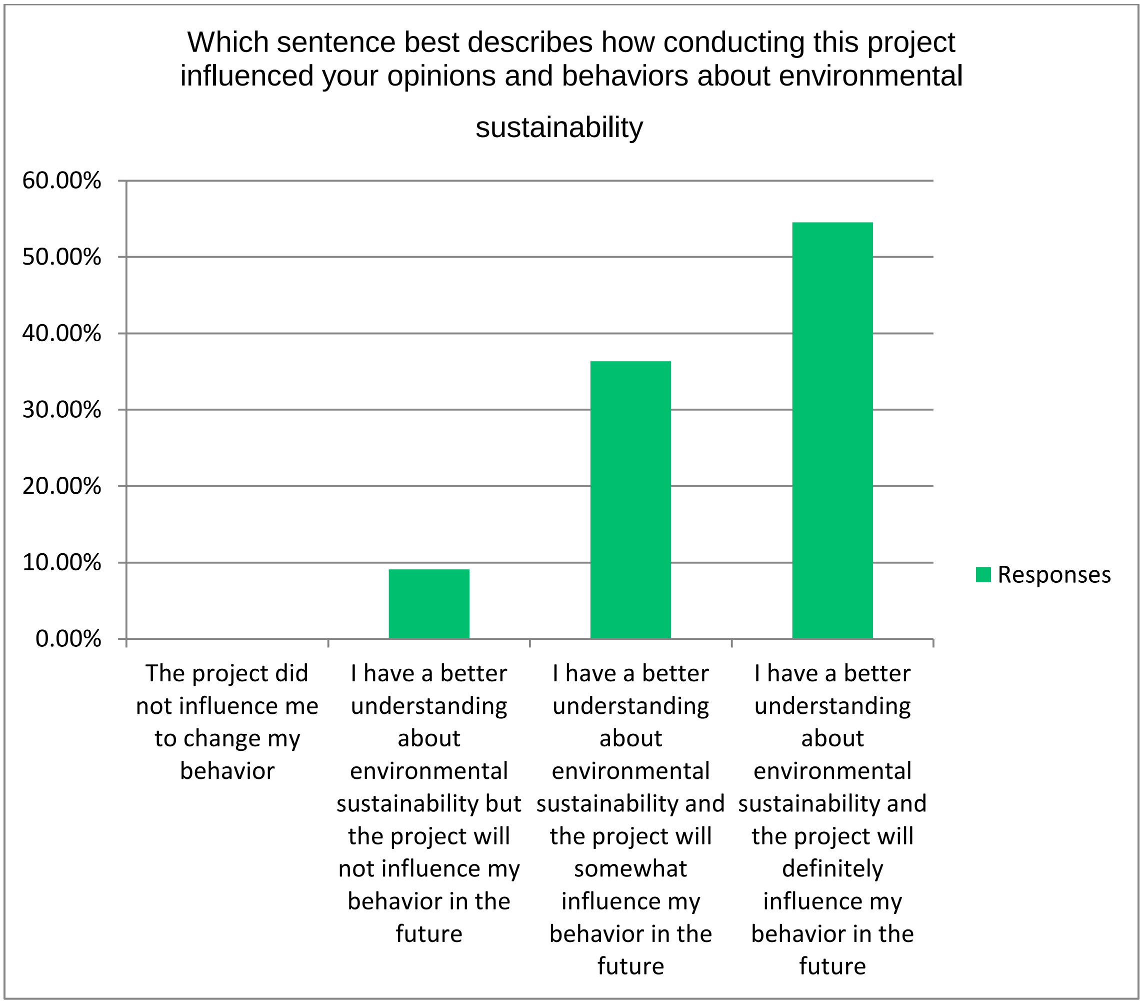

Figure 4.31: Final Survey Question 8 Post project responses-Which sentence best describes how conducting this project influenced your opinions and behaviors about environmental sustainability?

For Final Survey Question 9 students were asked to provide any additional comments for the researcher upon completion of the final survey on Survey Monkey: "Please feel free to add any comments about the four days you think would be helpful to the researcher." Five students provided written feedback as follows. Student #1 expressed enjoyment related to the project that collected plastic at home and noted that she/he was able to get her family to join in on her learning at school. This student also indicated a greater awareness of her/his own plastic usage. Student #2 made a specific comment about how the study helped her/him connect systems with pollution. Student #3 thanked the researcher for implementing the study. Student #4 indicated the timing of the project was an issue for them since it occurred at the end of the year. Student #5 gave two suggestions to include more time doing the paper or plastic collection at home and also to expand the focus to include individual countries and how they differ in paper and plastic use. This was actually covered somewhat in the activity where students made line graphs from environmental data sources provided. Although there were only five extra comments, there was at least some reference to the value of the project and a link to Learning Goal 1: Students will be able to understand how environmental systems interconnect by Student #2, and Learning Goal 4: Students will be able to evaluate the roles and responsibilities of individuals, groups and societies in general in terms of environmental sustainability by Student #1. Actual student written responses are provided below.

1. I enjoyed keeping record of the plastic my family used. This activity allowed for my family to join in on my learning at school. During and after this project, I became more conscious of all the plastic I use.

2. This helped me understand more clearly how different systems are linked and how paper/plastic pollution can affect them in an interconnected way.

3. Thank you

4. I liked the content that was taught, but I feel like I would have been more invested if we had not done this after we already took our IB final and while other finals were going on because that made me prioritize other things
5. Maybe more time than four days (for the plastic collection at home) and focus more on individual countries and how they differ.

CHAPTER 5

DISCUSSION

In this chapter, I will review important design components, present a model of the curriculum, and describe the value of the instructional activities and learning strategies in reference to the learning goals. Additionally, I will also discuss limitations and avenues for future research. Several over-arching themes were integrated in this investigation. The need to teach students about environmental sustainability was paramount and represents the end goal of the project. One of the main objectives was to create a series of instructional strategies and learning opportunities that could be successfully used by a classroom teacher to integrate systems thinking, specifically environmental systems, into a unit on sustainability. As an Educational Design Research (EDR) project it was anticipated that the proposed instructional strategies could become a model framework for other teachers who might conduct future iterations. The researcher and cooperating teacher also wanted to see if the activities would provide outcomes that positively influenced how students felt about environmental issues, and their personal values and behaviors in this context.

The research questions below defined the nature of this investigation:

1. Using Design Research and various instructional tools, how do students develop an understanding of systems thinking and relate it to environmental sustainability?

2. How does analyzing personal and classroom data on paper or plastic usage and recycling influence high school science students' understanding of global environmental sustainability issues through the lens of systems thinking?
3. How do students come to understand the impact of the effects of individual behaviors on broader issues of environmental sustainability?

Educational Design Research component

The Educational Design Research (EDR) process can be used to connect the practice of teaching creating opportunities for innovative learning and teaching environments. EDR can raise important questions for continued research, contribute to theories about learning and teaching, advance design knowledge, and increase the potential for educational innovation (Edelson, 2002; Design-Based Research Collective, 2003). Design based implementation research focuses on designing and testing interventions across different learning settings and grade levels (Penuel & Fishman, 2012). The basic conflict in educational design research is "the dual commitment to improving educational practices and furthering our understanding of learning processes." (Sandoval 2014, p.20). In other words, EDR includes the joint pursuit of practical improvement in teaching and theoretical refinement; cycles of design, enactment, analysis, and revision; and attempts to link processes of enactment to outcomes of interest. Design work is informed by ideas of how learning might happen or be made to happen and success of any design endeavor requires articulating what desired outcomes will look like and how they might be observed or measured. The design of learning environments is a theoretical activity, and learning environments embody hypotheses about how learning happens in some context and how to support it (Cobb et al., 2003; Sandoval, 2004).

There is a critique that simultaneous design evaluation and theory development is not possible with EDR (Phillips & Dolle, 2006). Salomon (1996) argued that studying learning environments involves finding “patterns of change.” His idea was that the complexity of naturalistic learning environments implies that they cannot realistically be broken into parts that have explicit effects. Instead, in specific settings unique designs lead to new patterns of change. Not every feature of a learning environment is “theoretically salient and designs do not lead directly to outcomes” (Phillips & Dolle, 2006, p.23). This idea was important for this study because within a dynamic learning environment, predictions about teaching strategies might not produce expected results. Cobb et al. (2003) framed the task of design research as recreating and interpreting outcomes across multiple settings given different contextual situations such as those represented by the pilot study and this research project.

In this study a cooperating classroom teacher served as a member of the research team and assisted in creating and implementing all activities and learning goals to support the overarching research questions. The research team looked for daily learning goals built upon natural developmental progressions or trajectories of the thinking and learning of high school science students, similar to those described by Clements’ Curriculum Research Framework (2007). To help identify a progression of learning in this project, four sequential Learning Goals were established as follows:

1. Students will be able to understand how environmental systems interconnect.
2. Students will be able to relate environmental systems to environmental sustainability.
3. Students will be able to analyze the effects of manufacture, production and use of either paper or plastic on environmental systems.
4. Students will be able to evaluate the roles and responsibilities of individuals, groups and societies in general in terms of environmental sustainability.

Learning Goals One and Two relate closely to the first research question, Learning Goal Three is aligned with the second research question and the third research question is supported by Learning Goal Four. Daily Observation Checklists completed by the cooperating teacher helped to link the efficacy of activities to both learning goals and ultimately to the research questions.

The learning environment for this study was a class of thirteen high school seniors who were taking International Baccalaureate (IB) Higher Level Biology, and who were finishing a unit on Ecology. An earlier iteration of this project was conducted as a pilot study with the same teacher but with a different group of secondary students who were eleventh and twelfth graders taking IB Environmental Systems course eighteen months earlier. The first iteration was for four days and included only a few of the teaching strategies that were employed in this two week project. Each class represented a different learning environment and students responded in different ways to similar activities. For example, the pilot study students were more enthusiastic and engaged in whole class brainstorming, completing the graphic organizers and their personal laboratory investigation on paper or plastic consumption. They also seemed more ready to stand up in front of their classmates to give oral presentations showing their graphic organizers and laboratory report findings. The IB Biology group tended to work more independently or with one partner and did not share and discuss within the classroom as much. This reticence to contribute ideas and collaborate with classmates created a different kind of learning environment which is typical in EDR cycles.

Sustainability/Education for Sustainable Development (ESD) Component

Science education can help to achieve appropriate sustainable development goals for society today and in the future. A main objective for Education for Sustainable Development (ESD) is to help students acquire skills, beliefs and perceptions to maintain sustainable activities in their lives. The Bruntland Commission Report outlined the goal of incorporating science education to help minimize human impacts on earth systems through sustainable development (SD) (1987). While the importance of education in helping achieve sustainable development has been emphasized, not much progress in affecting change in science education has been seen other than minor adjustments to existing curricula, texts, and teacher training (Pigozzi, 2010). Educational reforms outlined by the United Nations Conference on Environment and Development (1992) Agenda 21 suggesed that students learn the requisite scientific knowledge about the environment but ESD should help them gain insights and beliefs to promote their personal actions. Roberts (2007) supported these reform recommendations and notes that the role of curriculum should incorporate both science subject matter and its role in real life situations. Bybee (2010) suggested that science education must embrace personal, social and global contexts as well.

Countries worldwide have been in search of good implementation strategies of ESD in education since the *UN Decade of Education for Sustainable Development: 2005-2014* (UNESCO, 2005) emphasized ESD is for all schools and all learning settings. Teaching sustainability is also acknowledged as necessary in the United States within *A Framework for K-12 Science Education* (National Research Council, 2012). However, identifying and recognizing the scope of environmental sustainability topics for integrating the concepts, issues and values clarification is challenging for teachers (Rao, 2014). Environmental education and sustainability are often treated as stand-alone subjects and not integrated into the curriculum or included within school-wide learning initiatives (Benavot, 2014). Education for sustainable development has some properties which distinguish it from more general environmental education according to *Framework for the UNDESD International Implementation Scheme* (UNESCO, 2006), including being interdisciplinary and holistic, values-based, and addressing critical thinking and problem solving. This framework also recommends teaching ESD using mixed methods in which the teacher and the learners work together to acquire knowledge with different strategies and experiences as well as involving students in decision making about how and what they are going to learn. This study used this framework to develop a unit with multiple strategies and student activities. Additionally, students were permitted to make decisions about whether they were going to study paper or plastic and what kind of RRR implementation project they were going to design.

Aspects of ESD teaching should ensure that learning experiences are meaningful to students' daily lives and address local issues while linking to global ones. Gilbert et al. noted that challenges science educators are confronted with include providing instructional contexts that exhibit clear and purposeful relevance to students and the issues they may face (2011). Place-based education where students create personal and emotional connections to nature through lived experiences and hands-on learning of environmental issues are essential aspects of education for sustainability (Anderson, 2013). Warner and Elser (2015) described sustainability education as "an approach that generates, integrates, and links use-inspired knowledge to provide solutions to environmental-social problems...for normative and collaborative competencies in sustainability" (p.2). During this study, students were provided with scaffolded instructional experiences to facilitate students' deep understanding of complex environmental systems but also to help them develop more profound self-reflection about their own and larger societal actions. Collecting their paper or plastic at home for three days created a lived experience and students were able to extrapolate their use in the future to make it more impactful.

Systems Thinking Component

Sustainability education then should include an experience-based learning framework that allows for students to develop systems thinking. "System Thinking" or "Linking Thinking" (also referred to as "Holistic Thinking") has been proposed as an approach to help students conceptualize aspects that are environmental, social and economic (UNESCO, 2012). Hogan and Thomas (2001) stated "Thinking about complex systems is becoming an increasingly necessary skill for navigating information highways, making decision, and solving problems in both personal and professional realms" (p.319). Wiek et al. (2011) provided four key sustainability education competencies: systems thinking, futures thinking, normative competence, and action orientation, that they argued should be used to design and manage sustainable schools. Pickett et al. (1994) noted that within the realm of ecology there is a growing systems view of interactions between humans and the environment, biotic and abiotic factors, and the general idea of equilibrium. One goal of education then should be to encourage systems thinkers, "people who habitually analyze phenomena and problems as situated in larger contexts, consider multiple cause and effect relationships, anticipate the long-term consequences and possible side effects of present actions, and understand the nature of change over time" (Hogan and Thomas, 2001, p.319). A cross-cutting concept highlighted within *A Framework for K-12 Science Education* emphasizes systems and system models as tools to help students identify and analyze the interrelationships between collections of parts that function as a whole (National Research Council, 2012). Sandri (2013) noted that without having a grasp of and appreciation for complex systemic interconnections, learner's abilities to understand sustainability and put it into practice will be limited.

Using systems thinking means that students are engaged in a process of inquiry, using systems as a useful framework to define problems, processes and outcomes which sustainability seeks to address (Sandri, 2013). Within this study, students engaged in inquiry by conducting initial foundational research to find out how paper or plastic is manufactured, looking for the impact on environmental systems and also by conducting an independent investigation to determine their own use of paper or plastic. This investigation also required students to extrapolate their consumption into the future and make predictions.

Understanding relationships between system components is of critical importance as students, scientists, sociologists and governments study what appear as insurmountable global environmental challenges today. Sharma and Patil refered to these as complex, “wicked” problems (2017). Lester Brown, author of *Plan B 4.0: Mobilizing to Save Civilization.* (2008) and founder of the Worldwatch Institute described how the vicious circle of demographic pressure and poverty leads to the depletion of resources such as reduction in water tables, deforestation, overfishing, soil erosion, worldwide desertification, and others exacerbated by climate change and that eventually resource depletion produces failing state governments that cannot provide for their citizens. Today systems thinking approach is seen as essential in meeting big global challenges such as Sustainable Development Goals (Nature, 2020).

Donella Meadows helped create a movement in the 1970s with systems thinking approach in her ecology classes at Dartmouth College. Her methodology provided very simple explanations and examples for “naïve” students who had never been introduced to systems thinking. Her students developed skills in constructing various visual representations, especially dynamic simulation models or diagrammatic tools to build conceptual models. Similarly, in this research project, students were given time to work with a partner to construct a graphic organizer based on research to model the manufacture and use of paper or plastic. Mobus’ (2018) experiences in teaching systems science to students who had never been exposed to the concept of “systemness” previously acknowledged that once a person grasps the essence of the process they will embark on a new kind of thinking in which they will see the world differently. He observed "the majority of these students undergo a distinct change in their modes of thinking about the world and even their own lives… a person is able to use knowledge of systems to reason about the future states of the world based on those systems behaviors" (2018, p. 14). "The key observations, that naïve students do have the ability to develop systems sensibilities, that they can learn how to construct and use simple conceptual and mathematical models, and that they do see the world differently" (Mobus, 2018, p. 20). None of the students in this study had ever heard of systems thinking when surveyed before the project started; however, they all acknowledged in the final survey that they had improved their understandings of both systems thinking and environmental sustainability. Their work products also reflected greater understanding of interconnectedness in natural and man-made systems such as with their graphic organizers, formal laboratory reports, RRR projects and reflection essays.

With the traditional approach to teaching content knowledge within isolated science courses it is not possible to capture the complex nature of the concept of sustainability and its interrelationships. Systems thinking "requires recognition that observed phenomena result from underlying processes, and that these processes can interact to produce complex phenomena," (McNeal et al., 2004, p. 561). It enables students to achieve greater reasoning power about the real systems they encounter because they have an explicit template for the patterns that must exist in those systems regardless of the specific topic. In general students must have a conceptual understanding of the parts of systems and be able to interconnect them to look at the whole of a complex unified system. At the beginning of this study students were given an introductory lesson on systems thinking that used examples or spider webs, and tree visuals as templates for the kind of patterns that exist when learning about complex systems.

Systems thinking also requires one to understand that not all interactions are purely linear (Herbert, 2005; Raia, 2005). In this study students constructed a graphic organizer/mind map, the RRR project and the reflection essay. In each of these activities students had to make connections across different environmental systems in ways the demonstrated they were looking at interrelationships in a non-linear way. As mentioned earlier, studies of ESD have emphasized the importance of developing practical knowledge and providing hands-on experiences for students in order to understand important and complicated environmental issues (Anderson, 2013; UNESCO, 2014). For example, Caniglia et al., (2016) employed mental mapping as students conducted walks outside to help them understand complex connections between nature and an urban environment. Steiner and Posch (2006) discussed using real world case studies, cross-disciplinary thinking and problem solving, to generate ‘‘a demand for learning” in searching for the meaning of sustainability. Real-world learning environments and sociocultural activities may be considered “messy” but may represent a central role in understanding how people learn (Bransford, Brown, & Cocking, 1999).

Some of the research on teaching systems thinking has involved producing new digital tools, curricula and theoretical frameworks but “has not generated consensus on how to best support student learning” (Yoon, et al, 2018, p. 286). Pedagogy using problem- and project-based learning (PPBL) has been supported for teaching systems thinking and this study gave students the opportunity to look at the environmental problem of paper or plastic manufacture and use this knowledge in a number of activities through group interactions. Research on student learning about complex systems also suggests students tend to comprehend about immediate effects rather than cascading or indirect effects (Grotzer et al., 2015). Learning models and assessment tools have been generated from understanding how students learn when engaged in different activities related to relationships and interdependencies in systems.

The *System Thinking Hierarchical Model* by Assaraf and Orion (2005, 2010) is an example of a cognitive model consisting of eight hierarchical stages of system thinking skills development. Their findings suggested the cognitive skills that are developed in each stage serve as the basis for development of the next higher-order thinking skills, and this paradigm was used in part to develop the sequence of the instructional strategies in this study. It begins with identifying the components and processes of a system which is represented by foundational knowledge, then identifying relationships among a system's components as in the research for the graphic organizer. These eventually build into students' thinking temporally by using retrospection and prediction which can be demonstrated by the reflection essay and formal laboratory components in this study. Figure 5.1: Environmental Sustainability Learning Tree Figure 5.1: Environmental Sustainability Learning Tree illustrates the connections between the learning strategies and instructional activities with Systems Thinking. Based on the theory that people construct new knowledge and understandings based on what they already know and believe (Piaget, 1978; Vygotsky, 1978) ideas were presented in a constructivist, sequential way for students to build on their understanding of environmental systems. "The enterprise of education can be viewed as moving students in the direction of more formal understanding (or greater expertise). This will require both a deepening of the information base and the development of a conceptual framework for that subject matter," (Bransford, et al, 1999, p. 17). Bransford, et al further noted the selection of teaching strategies can become a "rich set of opportunities to develop an instructional program instead of 'chaos of competing alternatives'" (1999, p 23).

This research study fills a void in that there are limited resources about how to actually make the analytical process of Systems Thinking part of science classes, and there are few concrete teaching approaches to assist classroom teachers who want to attempt to use systems thinking concepts. The research team reflected on student progress on assignments and designed activities to help them develop greater understanding of the learning goals. "Students need opportunities to figure out the world around them, not just "receive 'correct' information and practices" so authentic assessment should give them that opportunity (Miller et al, 2018). Within the scope of this project students were assessed on their understanding of systems related to environmental sustainability in a number of ways through different instructional strategies and using different learning modalities. They created graphic organizers from research on paper or plastic manufacture, use and disposal which illustrated the depth of understanding related to interconnectedness of concepts. Graphing of current environmental data sets and trend analysis of global temperature change provided students opportunities to reflect on larger impacts and potential effects of human activities. These activities supported Learning Goals 1: Students will be able to understand how environmental systems interconnect and Learning Goal 2. Students will be able to relate environmental systems to environmental sustainability as well as Learning Goal 3: Students will be able to analyze the effects of manufacture, production and use of either paper or plastic on environmental systems. The

RRR implementation project gave them an occasion to develop solutions to problems of paper and plastic consumption and disposal, and the individual inquiry activity of collecting their own data helped support Learning Goal 4: Students will be able to evaluate the roles and responsibilities of individuals, groups and societies in general in terms of environmental sustainability. The analysis of their inquiry investigation and final reflection essay provided opportunities to further support all the Learning Goals.

The design research process helped determine the sequence of strategies in the unit as several of the activities had been tested previously in the pilot study. The results of the first iteration supported the inclusion of foundational knowledge, graphic organizers, graphing and an inquiry investigation as they were well received by the students in the study and suggested they could be effective in teaching aspects of systems thinking and environmental sustainability. As part of the EDR aspect of this project, changes to the information provided in foundational knowledge, and modification of some activities were made before and during the study. Additional activities were added to what was done in the pilot study to enhance students' understanding including more graphing, the RRR implementation project, the final reflection essay and a longer and more in depth inquiry investigation. Surveys were also conducted before, during and after the study to provide the researchers with more feedback from students as they progressed through the unit. Finally, a greater emphasis was placed on evaluating changes in students' behaviors and self-awareness about sustainability issues through the addition of small focus groups, and surveys, but also through classroom observations of student discussions. The scope of this study grew from the initial pilot study in order to help develop a possible curriculum for teaching sustainability education with systems thinking.

Overview of Instructional Unit

Several learning strategies arose from the study as important in developing the curriculum and included the following which will be examined further:

- Foundational knowledge about systems thinking and environmental systems
- Metacognition and use of graphic organizers
- Graphing and modeling skills for data collection and predicting
- Inquiry/Experimental design
- Real world connectedness: making environmental sustainability personal and something students care about

To provide necessary foundational knowledge, students were initially given instruction on systems thinking. Systems thinking was a novel idea for the entire class as indicated on the initial survey given before starting the project. Environmental systems and biogeochemical cycles were reviewed by the teacher to reinforce content presented in a prior unit. After this whole class introduction, students were given an opportunity to brainstorm about different kinds of paper and plastic and then they were asked to select either paper or plastic for their main focus during the two week unit. Learners are often faced with tasks that do not have apparent meaning or logic (Klausmeier, 1985) so it was important for them to have a choice (paper or plastic) for their inquiry project and other activities so they would be invested in it and therefore have a more personal connection.

The next step was for students to complete Internet research on the manufacture and use of paper or plastic and to create a graphic organizer of their research, while including aspects of environmental systems impacts. Students shared their work and classroom discussions ensued. Practice collecting data and creating graphs followed and was part of instruction on good graphing skills so they could use their knowledge to create data collection methods for an independent inquiry/experimental design-based research project on paper or plastic use in their homes for three days. The students collected data and made simple bar graphs within small groups. They then created bar graphs of Internet data sets on environmental topics that were germane to paper and plastic impacts on the environment. They also wrote summaries of the information they gleaned and then shared this with their classmates. Students then learned how to create trend analysis of a data set of world temperature change using Excel spreadsheets using decades of information from World Watch, and they extrapolated one hundred years into the future. The graphing practice of bar graphs and trend analysis as a line graph was important as support for students before they completed their investigation.

As part of the inquiry/experimental design component students created a method for collecting paper or plastic at home for three days, and then they not only prepared data tables and hypotheses predicting outcomes, they created another trend analysis for their own paper or plastic consumption for fifty years into the future thereby using their graphing skills again. They reflected on their consumption both in the formal laboratory report as well as in a final reflection essay about the impacts of paper or plastic use and global sustainability of resources while including effects on environmental systems. Laboratory report findings were shared with the class. They were also asked to prepare a digital poster of an implementation project along the lines of RRR, Reduce-Reuse-Recycle of paper or plastic which they also shared with classmates. Students also wrote a final reflection essay on the last day. Students used research that they started on the second day about paper manufacture, use and impacts on environmental sustainability and expanded on it throughout the study. They incorporated their research into graphic organizers, and eventually formal laboratory investigation background information, their RRR project and reflection essay.

Throughout the study students were surveyed about their initial knowledge of systems thinking and environmental sustainability, specific targets of understanding each day, as well as mid-point and final surveys to assess their impressions and usefulness about the various activities and how they impacted their understanding. Several questions in the final survey also required students to reflect on their changes in personal values and behaviors, and this was further examined during two small focus groups where students were encouraged to describe their perspectives about both the project and their views about sustainability going forward. Student work samples provided evidence of participation, connections to the research questions, and evaluation of their degree of understanding. Students were asked to self-reflect on their learning before, during and after the project using daily Mentimeter or Survey Monkey questions. This provided supporting evidence of their increased comprehension as well as their discernment about their personal beliefs.

A schematic model of the instructional activities for the unit was developed and is represented in Figure 5.1 in the form of a "Learning Tree." "Systems thinking" is represented by the roots of the tree as this is the basis for connecting ideas within the unit as a whole. "Environmental systems" represents the main trunk of the tree because it was hoped that students would relate each activity to different systems including biogeochemical cycles, hydrology, soil erosion and so forth. The lower branches of the tree represent the learning strategies that would be scaffolding for higher cognitive activities and included foundational knowledge, metacognition and graphic organizer, graphing and modelling, inquiry and real world connectedness. The outer tree branches and leaves include the main instructional activities associated with the learning strategies, but they were also interrelated to make real world connections for students. The entire study is subsumed under the tree "canopy" of environmental sustainability. The tree as a metaphor also can symbolize the expected growth of students in both content knowledge and understanding about interconnectedness of the natural world as a system. Other branches and leaves can represent activities and learning strategies that could be explored in future iterations of the project design.

Learning strategies

Foundational knowledge basics included whole class instruction and discussion on what is meant by systems thinking, and environmental sustainability; whole class brainstorming on types of paper and plastic; and research on manufacture and use of paper or plastic. Metacognitive strategies included construction of a graphic organizer, active listening and participation in class discussions, and the final reflection essay. Graphing and modelling included simple graphing practice, graphing of Internet environmental data sets as bar graphs, and constructing a trend analysis of global temperature using Excel spreadsheets, and eventually graphing data from their inquiry project. For inquiry students added to their research and made more connections with the prior learning about environmental systems. Activities included a digital poster of a possible implementation project the students might choose to conduct on their own which would deal with Reduce-Reuse-Recycle and a formal laboratory report of their inquiry/experimental design to collect paper or plastic at home for three days including a trend analysis. Most activities created real world connections for students which might influence perceptions of their own behaviors and accountability regarding sustainability issues.

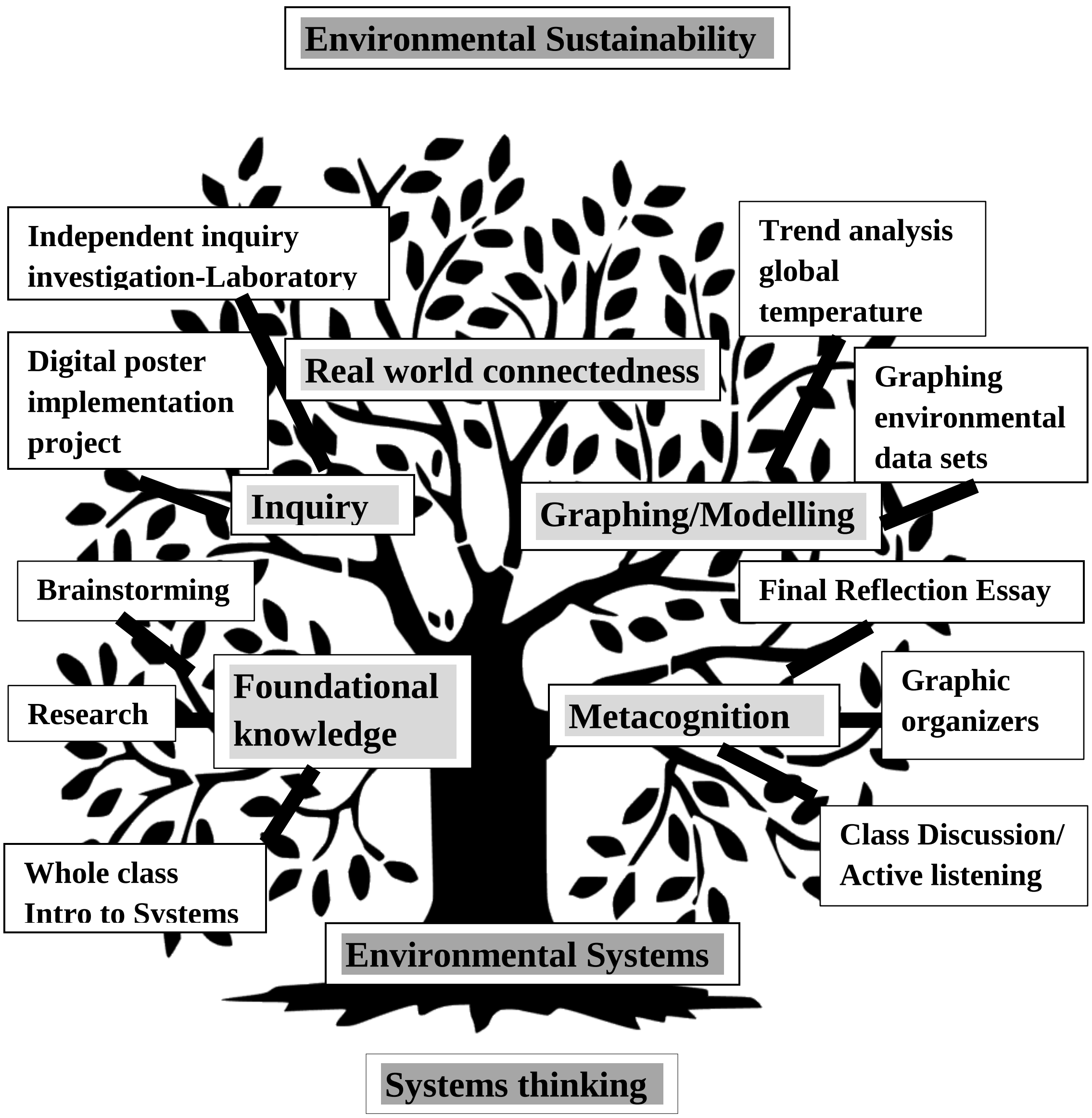

Figure 5.1: Environmental Sustainability Learning Tree

The instructional strategies and activities within this study require foundational knowledge. This basic information was necessary for students to identify the components and processes of environmental systems so a review of important cycles and systems, including natural and man-made were reviewed. After the foundational knowledge was presented to the students, they were provided with other activities to demonstrate understanding and make connections between environmental systems. Table 5.1 represents the Learning Strategies presented and their relationships to the Learning Goals.

Table 5.1: Learning Goals Supported by Learning Strategies

Learning Strategies / Learning Goals	Foundational knowledge	Meta-cognition	Graphing and Modeling	Inquiry/ Experimental Design	Real world Connect -edness
1. Students will be able to understand how environmental systems interconnect.	X	X	X	X	X
2. Students will be able to relate environmental systems to environmental sustainability.	X	X	X	X	X
3. Students will be able to analyze the effects of manufacture, production and use of either paper or plastic on environmental systems.	X	X		X	X
4. Students will be able to evaluate the roles and responsibilities of individuals, groups and societies in general in terms of environmental sustainability.	X	X	X	X	X

Essential Elements of an Environmental Sustainability Unit

Figure 5.2 helps to simplify the framework in order to visualize the structure of the instructional unit. Having foundational knowledge is the basis for greater depth of student understanding and assists with further applications within the study. For example, students need to know about the various biogeochemical cycles, basic hydrology including surface and groundwater supplies, soil construction, issues of erosion, runoff, and loss of soil fertility, deforestation, effects of mining and other topics to allow students to connect across different systems within the whole of the environment. Engaging students in various metacognitive instructional activities enables them to actively think, listen and speak while making connections about sustainability issues surrounding the foundational knowledge. Evidence from coding of whole class discussions and student presentations also supported the value of metacognitive strategies to improve students' reaching the learning goals. For example, students were engaged in whole class discussions that involved active listening, a type of metacognition. Students were not only prompted by the teacher to answer questions about environmental sustainability, but they engaged in lively discussions when classmates gave group presentations to the class of their graphic organizers, graphs of environmental data sets and their RRR implementation projects. This study found support for having students research and construct graphic organizers on manufacture, use and disposal of paper or plastic in the environment to enhance students' systems thinking as another metacognitive activity. This finding was based partly on classroom observations of student presentations and discussions which demonstrated students had a depth of understanding about systems interactions from their research about paper or plastic production, use and disposal.

Additionally, survey responses and small group interviews were valuable indicators because students gave positive feedback on the usefulness of the both the whole class discussions and graphic organizer activity for their learning about sustainability and environmental systems. In another aspect of metacognition, final reflection essays demonstrated that the students had gained a greater understanding of systems thinking within the focus of environmental sustainability. Students made clear connections between several different environmental systems such as the hydrologic cycle, soil degradation, deforestation, carbon cycle and others. They also made connections how human behaviors negatively impact sustainability.

Opportunities for students to engage in inquiry were provided by their independent investigation on collecting paper or plastic at home for three days, as well as by working with a partner to develop a Reduce-Reuse-Recycle (RRR) implementation project. When students engaged in these research, writing and analysis intensive activities, their prior work with graphing and reflecting on their choices aided their work. Figure 5.2 illustrates this connection with lateral arrows between these activities. Graphing and modeling were accomplished through various practices including a basic review, then construction of data sets from internet based information on environmental studies that related to the use of paper and plastic globally. The culminating activity involved construction of a trend analysis of global temperature data using Excel spreadsheets that allowed students to make predictions. These types of graphs assisted students in recognizing the effects of their own behaviors regarding paper or plastic by enabling them to collect data (inquiry project) and to predict their own impacts into the future. The students' predictions and reflection on their behavior provided mechanisms for them to understand sustainability and to connect to it in a personal way. Students wrote conclusions and discussions in their lab reports as well as their final reflection essay that demonstrated increased understanding of environmental systems and sustainability and this was also revealed in student survey responses.

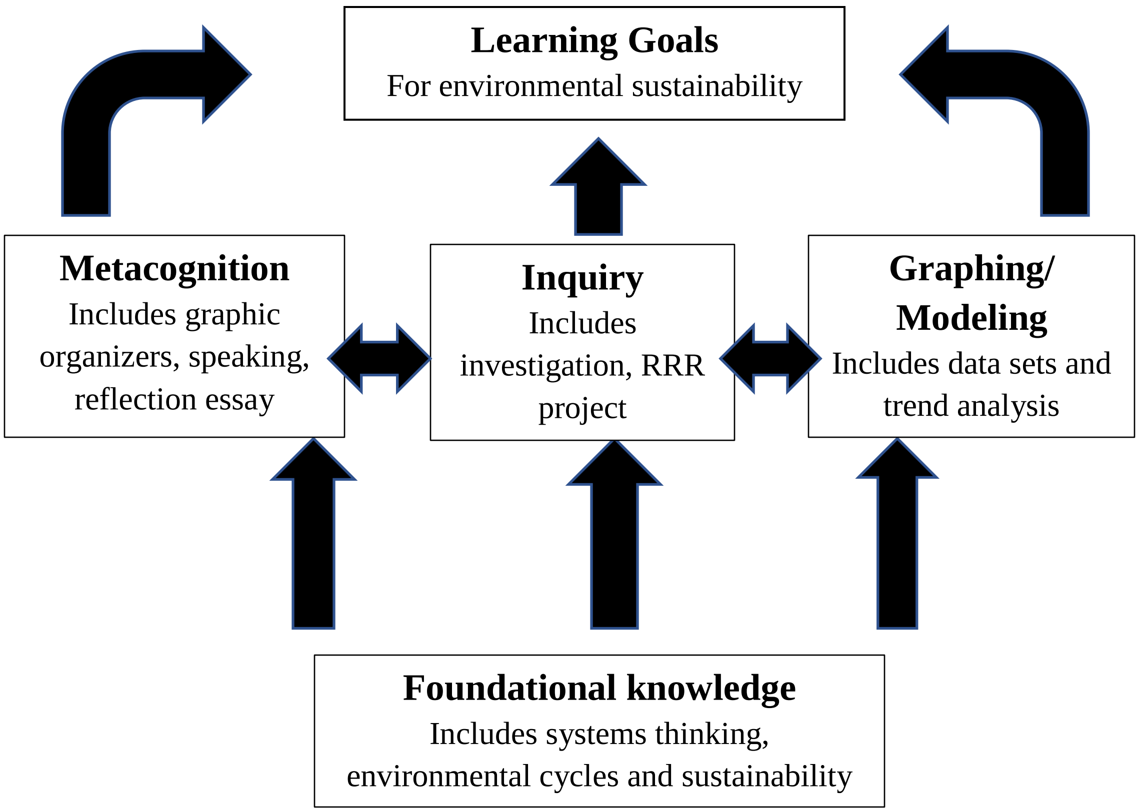

Figure 5.2: Explicit framework

Foundational knowledge

At the beginning of the unit students were given whole class instruction to introduce new concepts about systems thinking, followed by a review of environmental systems they had previously learned and a general introduction to sustainability. The teacher not only discussed examples of environmental systems, she helped students build visual system representations, and provided many specific examples. Prior learning was reviewed at the start of each new class, and concepts of systems thinking and environmental sustainability were reinforced by the instructional activities. Students to participated in discussion and posed questions, especially when they were presenting their work in front of the rest of the class and this overlapped with metacognitive aspects of active listening and thinking aloud (Vygotsky, 1978). When surveyed after the study about what students thought were the most important in helping them develop their own systems thinking the whole class instruction on systems thinking was the most selected strategy by 18% of the students which supports Learning Goal 1. Students selected three other activities equally as the next most valuable activities for helping them learn about systems thinking and these included research and creating a graphic organizer, research for laboratory report background, and writing their reflection essay.

At various times the students were asked to explain their work to their classmates so that they were not only producing physical products, but they had to make sense of them to their classmates. Having students perform research, write and speak in different settings, manipulate data using math and graphing, and conduct inquiry/experimental based activities supports the methods and suggestions set forth in *A Framework for K-12 Science Education* (National Research Council [NRC], 2012). Kang, et al. (2016) outlined several categories of research that link to impacts on student achievement including effective instructional methods such as those selected for the project. The foundational knowledge component of the study supported aspects of all four Learning Goals.

Metacognition

The instructional strategies in this study attempted to provide a firm foundation and depth of factual knowledge, while integrating metacognitive skills. Hattie and Donoghue (2016) suggested that instructional strategies could be organized along a continuum across a simple organizational tool that might be important to a model for comprehension instruction. One of the most important of these metacognitive skills was when students created the graphic organizer as it created an opportunity for students to visualize and organize the processes of paper or plastic manufacture and use. Visualizing, connecting and thinking deeper are examples of metacognition (Fisher & Frey, 2020).

After students received foundational knowledge about environmental systems and engaged in whole class discussion and brainstorming of ideas about different kinds of paper and plastic, they were instructed to conduct research and construct a graphic organizer. By conducting research on production, manufacture, use and disposal of paper or plastic the students found connections to different environmental cycles and systems. Putting this information together into a flow chart or other graphic design helped them understand the context and inter-relationships involved between individual parts of the whole in terms of systems thinking. Students were asked to use good references and provide them to the teacher, and were also told to prepare a short presentation of their graphic organizers to the class. Students made connections between different environmental systems such as carbon, water, nitrogen and other cycles as well as environmental impacts on soil, water, climate and others. Students in the study responded to short surveys using Mentimeter, such as one question which allowed students to reflect on what they learned about environmental systems and sustainability. For example, when asked to describe the impact of completing research and graphic organizer on production /use of paper/plastic 75% of the students responded in a positive way to the question with the majority acknowledging the activity made them more aware of systems and more concerned about sustainability. Putting together the various pieces of information about what is involved in production and manufacture of paper or plastic helped to give students understanding about environmental systems that are involved. This information was further enhanced by student research on many uses of paper or plastic that they may not have known about before, and this coupled with research about disposal issues helped to increase awareness of sustainability issues. In her daily Observation Checklist regarding the graphic organizer activity the teacher also found this activity a positive one related to Learning Goal 1. The teacher also acknowledged that the graphic organizer and research was exactly what was needed to address Learning Goal 3: Students will be able to analyze the effects of manufacture, production and use of either paper or plastic on environmental systems.

Other metacognitive skills included students writing a reflection essay at the end of the study, planning ahead when designing their inquiry experiment, and active listening with questioning during whole class instruction or when classmates were presenting. Additionally, students employed self-questioning when they considered their behaviors related to paper or plastic consumption. Finally, in the evaluation/conclusion/discussion section of their formal laboratory reports, several students gave the “number of days” for data collection as strengths for their projects while a few students stated this was a weakness. Other weaknesses several students included were the kind of scale used, and the lack of different categories, and students were able to critique themselves to a small degree. This kind of self-questioning related to strengths and weaknesses also reflects metacognitive processes because it involves students thinking about how they could improve their own thinking regarding how they designed their inquiry investigation.

The final reflection essay encompassed several parts for students to write about including these pertaining to Research Question One by asking "Discuss the environmental consequences of paper/plastic production and usage on a global scale. Include as many systems as you can think of that are impacted. What does environmental sustainability mean and how does it connect to systems you identified?" Overall student writing examples provided little specific linkage to environmental systems, they did not clearly describe the notion of sustainability, but students did suggest changes in behavior could have an impact for the greater good of the ecosystem. Students gave potential effects such as increased global temperature but did not give impacts such as desertification or soil degradation.

Graphing and modelling

The sequences of graphing activities in the project sought to review and then expand students' skills and make them part of both the inquiry/experimental design project but also to emphasize their own contributions to global waste related to Learning Goal 4, and Research Question 3. Research by Wilkerson-Jerde and Wilensky (2015) supported the emphasis on graphing within this study. They suggested that a greater effort on recognizing mathematical relationships in graphical representations can support learning about exponential growth, which is a typical outcome of complex systems and also in understanding indirect effects in ecosystems. During the mid-point survey students were asked “Which of the graphing activities completed were most effective in helping you review graphing techniques?” a majority stated that the graphing activities were not new to them but 30% had not engaged in trend analysis. In response to another survey question “Which of the graphing activities were new methods or skills for you?” most students noted that “None of the graphing activities were new to me” but a third acknowledged that working individually on the data sets provided with trend analysis was new to them. Students may have already had adequate basic graphing skills and this activity might be omitted in further iterations of the project depending on the group and their skill level. On the other hand, on the final survey about a third of the students selected the making of bar graphs with non-environmental topics as the most helpful for their development of data analysis skills. Since this was the basic skills activity an argument could be made to maintain it within the scope of the instructional sequence.

The teacher reflected on the environmental data sets, or sustainability graphs the students completed, along with a summary paragraph explaining the data relative to environmental systems and she felt this was multi-layered in that students made systems connections related to Learning Goal 1. The teacher also acknowledged students made connections to Learning Goals 2 and 3 but also noted relative to Learning Goal 4 the activity did not relate directly. In the final survey student answers suggest that some students found the graphing strategies to be effective learning tools for understanding systems thinking. Although the ability to use and understand graphs is essential in science and engineering we know little about how people know, understand, and learn about graphical representations (Bowen and Roth, 2002), and acknowledge that students of all ages have difficulty in using graphs. The graphing activities that students completed in this unit suggest they improved their ability to make a variety of graphs but also were able to interpret them in a meaningful way related to environmental sustainability. This was particularly evident in student graphs of environmental data sets where they wrote a summary paragraph explaining the bar graphs they created, and also evident in completion of trend analysis for their paper or plastic use with explanation of the consequences of that to future sustainability.

Students were engaged in numerous activities that were designed by the research team to increase in complexity and build students' prior understanding of content. Graphing activities in the instructional design represent a good example of how assignments were scaffolded for student learning. Initially students were given a whole class review of "good graphing techniques" by the teacher and completed a simple data collecting and bar graphing activity to make sure everyone could complete other tasks. This was followed by graphing using Excel spreadsheets into which they imported Internet data on environmental issues related to paper or plastic such as loss of forests in different parts of the world. The students were then asked to design a method to collect and graph data on paper or plastic use at home which represents part of the inquiry component. Students next learned how to graph a trend analysis for one hundred years in the future of global temperature data using Excel, and were expected to conduct a similar trend analysis to predict the paper or plastic usage their family would have in the future. The *National Research Council* notes that "scientific investigations produce data that must be analyzed in order to derive meaning and scientists use a range of tool including tabulation, graphical interpretation, visualization, and statistical analysis to identify the significant features and patterns in the data" (2012, p. 51).

Inquiry

The instructional strategies within this study helped to scaffold student content knowledge and move students towards deeper understanding of environmental systems and issues. The teaching approaches used in the study actively built on student knowledge that had the potential to be more relevant to students. Inquiry-based science was incorporated and is supported as a method of teaching science by Capps et al. (2012) and Loughran (2014). Loucks-Horsley et al. (1998) also emphasized inquiry-based learning, investigations, and problem solving to help develop pedagogical content knowledge. For the inquiry aspect of this study, students designed a method to collect and categorize paper or plastic consumption at home for three days. In the final survey almost one third of the students noted that small group bar graphing with internet data sets and designing a method for at-home data collection of paper/plastic were most helpful to them analyzing data and writing conclusions about their lab reports. These selections support the idea that students found value in the simple activity that reviewed basic graphing skills, and also in taking the time to set up their experimental design for paper or plastic collection. These choices represent activities that are building blocks for the next steps students needed to take such as graphing their actual data student selection of these indicate that they were still important to teach in terms of skill development. The next most widely selected choice was "Extrapolation of at-home paper collection for future consumption" which represents a trend analysis similar to the one they did in the graphing activity on global temperature change. This suggests students were interested in the potential future consequences of their behavior in terms of paper or plastic use.

It was observed that the class as a whole was able to quantitatively collect and display their data using tables, graphs and photos/drawings. Many students separated their collected plastic or paper into recyclable and non-recyclable categories and recorded mass for each day. Selection of categories had been reviewed with students in an earlier Mentimeter question and it was noted at that time that selections were mostly limited to three categories which does not seem adequate. Although the teacher did review the initial procedures for students before they completed the final draft of their formal laboratory report, she did not make clear suggestions for improving them. While the classroom teacher indicated that her students had written formal laboratory reports throughout the school year using the same grading scheme which was used in this study, there are significant omissions by the students, particularly in their background research and conclusions. Overall, it is suggested that students need to have a review of expectations for each section of the scoring rubric for the formal laboratory report and perhaps submission of a draft version for review by the teacher would be a good segue to finalize their writing. Communication of results and working like a scientist is a cross-cutting theme in *A framework for K-12 Science Education* (NRC, 2012). Writing and communication of their research and analysis of their own data supports the Learning Goals, especially to help the students make connections between environmental systems as well as their roles and responsibilities.

In another inquiry-based activity students created digital Reduce, Reuse, Recycle or RRR “posters” with a partner to suggest an implementation idea they could do. Generally the students’ RRR Posters were able to make the point of the importance of reducing, reusing and recycling of paper or plastic but the connections to environmental systems were not always clearly provided either in the poster itself or during the students' presentations. Some made links to effects on animals and food chains from plastic pollution and potential toxins released into soil or water. Simon (1980) noted that one dimension of acquiring greater competence is the increased ability to visualize and this activity supports this using a visual representation. Research on expertise suggested the importance of providing students with learning experiences that specifically enhance their abilities to recognize meaningful patterns of information (Bransford et al., 1989, p. 36). The teacher stated "Many of the photos and descriptions for reasons we should RRR were powerful and reinforced the interconnected-ness" when discussing Learning Goal One that students will be able to understand how environmental systems interconnect. She also stated that many of the descriptors the students used in their posters were related to environmental sustainability of Learning Goal Two: Students will be able to relate environmental systems to environmental sustainability.

Real world connections

While Bransford, et al (1999) acknowledged there is no universal best teaching practice (p.22) they suggested linking classroom learning to other aspects of students' lives. Mobus agreed that "students are more motivated to learn when the subject is couched in terms of a meaningful context." (2018, p. 20). This linking of concepts was accomplished in several ways in this study, particularly in the student-designed inquiry investigation into their consumption of paper or plastic, in projecting a trend analysis for the future and also by suggesting an RRR implementation project using their digital poster as well as the final reflection essay. It was important to the research team that learning strategies for students include activities that would link to the systems approach and context of sustainability based on the notion that scientific reasoning entails much more than logical thought processes, given that cognition is multi-faceted (Mayer, 1996).

The teacher addressed the impacts of the formal laboratory reports on the Learning Goals stating she did not feel the assignment connected with Learning Goals Two and Three as well as it did with learning Goal Four and stated “In the conclusion and evaluation, students reflected significantly on their own responsibility with regard to their paper (or plastic) consumption. Many also extrapolated to the community and nation.” Additionally, one student commented about the project during the final survey “I enjoyed keeping record of the plastic my family used. This activity allowed for my family to join in on my learning at school. During and after this project, I became more conscious of all the plastic I use.”

In the small focus groups students were asked whether doing the experimental design/inquiry activity was impactful for them learning about systems or environmental sustainability. They were more descriptive about environmental sustainability than systems. One student described how many water bottles her father used each day during his work and offered “It kind of made me aware how much like it's a daily need from him and like if we were to change and then it'd be like a hard process, but I think we can do something about it. It'll just be hard to get them to.” This shows a link to deeper understanding about her own behavior relative to Learning Goal Four and Research Question Three. Regarding the final Reflection Essay, which was also discussed as another aspect of metacognition the teacher noted she thought this was by far the best activity to address Learning Goal Four and Research Question Three and found it to be powerful reading. The students wrote from many different perspectives about the roles of individuals, societies, nations and global citizens and felt this was a great activity for encouraging introspection, supported by research.

One goal presented by United Nations Conference on Environment and Development (1992) was to help students improve thinking skills, values and perceptions to maintain sustainable activities in their lives, helping them understand why they should engage in activities that promote sustainability. Another was to help them develop ethical and personal values that promote these actions. UNESCO (2005) outlined that ESD should help students gain insights and beliefs to promote their personal actions especially regarding protection and restoration of the Earth's ecosystems. Students demonstrated they had developed awareness about environmental sustainability and the roles of individuals and larger communities in global sustainability issues.

CONCLUSION

Several aspects of the study were successful because of the cooperating classroom teacher who was very committed to the project, dynamic, and also had a strong understanding about systems thinking and environmental sustainability herself. Students in her class were attuned to her and gave her respect and attention which helped to set the stage for a positive learning ecology as describe by Cobb et al. (2003). They had been in her class for an entire school year so there were well established rules and procedures. Her emphasis on the importance of integrating different environmental cycles and human activities in a non-linear way was vitally important to scaling up student learning throughout the two weeks. Interconnectedness between environmental systems was stressed in research for and preparation of the graphic organizer, in evaluating impacts of environmental data set graphs, in the background information for their laboratory report, in developing the RRR project, and writing the final reflection essay. The researcher and teacher sought to include learning strategies that were not only aligned with the NRC curriculum framework (2012) but that would also be engaging, interesting, teach skills and build on prior knowledge while also addressing the Learning Goals.

Weiss et al. (2003) found that appropriate opportunities for students to make sense of the science ideas being taught were rarely coupled with hands-on, practical, and experiential studies. Banilower et al (2012) emphasized classroom learning needs to be connected to the development of deeper understanding. In a study of 500 classroom videos from five countries, Roth and Garnier (2007) found that teachers in the United States did not incorporate "various activities to support the development of content ideas in ways that were coherent and challenging for students" (p. 20), which results in activity without understanding. Based on teacher comments in Daily Observation Checklists, student work samples, classroom observations, student surveys and small focus groups the activities in this study reflected coherence to the desired curriculum and improved connections for students.

Education that lasts is of vital importance to anyone who teaches. In a study such as this one, it was hoped that students would not only learn content, and systems thinking method, but that they would also become personally invested in the issue of sustainability, especially through their independent inquiry project on paper or plastic use. Learners, especially in school settings, are often faced with tasks that do not have apparent meaning or logic (Klausmeier, 1985). Empowering students to make choices and clarify their values regarding global sustainability is essential, but the learning about the environment and experiences must be meaningful. "A sustainable curriculum for the future will involve learners intimately in what and how they learn, and why and how -this is imperative for their future," (Hays and Reinders, 2020, p.29). Murray et al (2014) assessed shifts in values orientations among undergraduate students following the completion of intensive values-based sustainability training workshops using pre- and post-tests. Their findings indicate that small but statistically significant shifts in participant views of their personal beliefs occurred correlating with sustainability issues. However, they acknowledged that more research is necessary to inform the design of educational encounters to help individuals understand their personal role in creating a more sustainable future, and their results do not assess whether the change in beliefs contributed to a change in behavior. In a longitudinal study teaching Education for Sustainability (EfS) curriculum to elementary students om Australia it was observed students moved between 'silo' or stand-alone thinking, and 'whole systems thinking' positions on a sustainability continuum, but the authors found students reverted back to the simpler understandings away from systems thinking after three years (Lewis, 2014). Likewise it is not known if these young students' sustainability education achieved a behavioral change.

Students need to develop the ability to teach themselves (Bransford, et al, 1999, p.50) but the authors also note that learning and behavior changes take time. Generating learning that lasts involves life-long pursuits. Sustainable Learning and Education (SLE), an emerging philosophy of learning and teaching founded on principles of sustainability, not necessarily education for sustainability but rather "sustainable learning," is a new and different idea (Hays & Reinders, 2020, p.29). Built on principles of sustainability, this way of thinking and the subsequent pedagogy direct thinking towards what is arising in the future and might be needed rather than resting in the understandings and skills of yesterday. Providing students with fundamental knowledge about environmental systems and issues of sustainability can influence their personal choices and attitudes toward local and global concerns. “With greater environmental and ecological literacy, students are more inclined to alter their behaviour regarding specific environmental issues. Environmentally-literate individuals are better equipped to see the links between specific issues and global environmental change,” (Wals and Benevot, 2017, p. 406).

Sandri (2013) stated that students are invited to reflect on the values that they bring when making judgments about limits of systems and environments and they should be conscious that they are constructing reality through subjective judgments. They in turn need to also assume responsibility for a world collectively created with multiple stakeholders. Within the scope of this project students were given the opportunity to conduct an independent inquiry investigation on paper or plastic consumption. This project also provided them with the methods to extrapolate that use into the future, and also to connect with their families while conducting the project. The RRR implementation proposal, graphic organizer, and graphing activities along with their reflection essay gave students opportunities to consider the future and issues of sustainability. They were able to evaluate their own behaviors and make judgments of the impact of these behaviors on environmental systems and sustainability in general and supported Research Question 3: How do students come to understand the impact of the effects of individual behaviors on broader issues of environmental sustainability?

When students were asked during small focus groups what activities were helpful in their understanding of environmental sustainability they were able to relate specific examples. For example, some students said doing the trend analysis was really impactful, and others said collecting their own plastic they used in a day was enlightening. Several students commented they really liked the graphic organizers they were able to see the "interconnectedness of everything." Other student comments indicate some of the students were thinking ahead as to possible relationships with environmental sustainability and their own individual roles and those of others. For example, at one point the teacher addressed the class regarding the trend analysis graphing, "Where do you think this is going in light of what we are doing with the project?" One student said, "Application to trend over time…yourself, your class, your community." Another student said, "Could end up being a bigger issue with sustainability."

At the end of the study one of the survey questions asked them "How would you rate your level of engagement in this project" 81.82% indicated "I participated fully" When solicited for they would rate overall interest in the project 54.55% chose "The project was very interesting to me." When queried how they would rate overall enjoyment of the activities and project 36.36% indicated they enjoyed some of the project activities and 63.64% indicated they enjoyed participating in the project. Review of these answers indicates that overall the responses by the students to participation, interest in, and enjoyment of the study was extremely positive.

Future Directions

Several conclusions can be made regarding advice for future iterations of this framework based on how students responded to the instructional activities in both the pilot study and this larger study. First there is a temporal consideration for when is the most appropriate time of the school year to implement the study. The initial pilot study occurred in mid-October, while the two week study was conducted in May as the culminating project for a group of students. The pilot study participants seemed somewhat more engaged and interested, and thus earlier in the school year may be a better time to introduce the unit. Although the group who participated at the end of the year were mostly or fully engaged based on their final project surveys, there were a number of end of year distractions for the students during the two weeks in May. Additionally, Advanced Placement and International Baccalaureate testing was occurring and several students were unable to participate on certain days because of that. The grade levels and group sizes of the students in the two different studies could also have had an impact on the level of interest. For example, the pilot study was a slightly larger group and was almost entirely eleventh graders. They seemed to take completing the assigned activities seriously and engaged more fully in class discussions and presentations. The current study was entirely high school seniors and the assignments for the project were being graded by the classroom teacher as their final grades as a culminating project for their IBHL class. The assignments for pilot study group were graded by the classroom teacher but there was not the same amount of pressure for final grades. Seniors sometimes are not as motivated at the end of the year especially if they have already been accepted to colleges or feel disconnected from school activities in anticipation of graduation.

Reflecting back on the components of this study, it is possible that not all of the activities would be necessary to enable students to accomplish the learning goals, however the learning trajectories for each learning goal would remain the same. For example, a modified version of the formal lab report for the inquiry investigation could be used. In this study the teacher required her students to complete a formal lab write up using her IB level rubric that the students had used throughout the year (see Appendix C). There are several parts of the lab report that were germane to the specific class, however another class might only require students to develop a hypothesis, data collection and evaluation methods which could then be followed by conclusions and predictions like a trend analysis. Although students in both the pilot study and the current study found the whole class brainstorming sessions about kinds of paper and plastic enjoyable and interesting, that activity might not be as important as others in helping develop systems thinking for sustainability. If the brainstorming session was eliminated, the whole class instruction of foundational knowledge would still be necessary for the learning trajectory. The digital poster implementation assignment for Reduce-Reuse-Recycle (RRR) is an activity that could be eliminated from the study, as it was something the cooperating teacher suggested for this study and it was not done in the pilot study. Instead of this activity students could engage in a longer inquiry project in which they implement their recycling suggestions.

One series of instructional activities that was found to be helpful for both groups of students in developing their ideas of systems thinking for environmental sustainability were those involving graphing. None of the students found the introductory lessons on graphing as a group or the bar and line graphs of internet based environmental data sets to represent new skills, but based on their survey responses they felt they were helpful reviews that contributed to their understanding of data collection and making predictions. The one graphing activity that all students found to be a novel one to them was constructing a trend analysis using Excel spreadsheets. Directions for creating this type of graph are located in Appendix A. The importance of learning how to make a trend line from existing data points is that students can visualize the impacts of what they are studying as a projection into the future, and as a model for predicting outcomes. Not only learning how to make trend lines of data, but using the data they had collected themselves during their inquiry project and projecting their own contribution to global paper and plastic use was very impactful and made the activity personally relevant to them.

Several of the instructional activities could be modified for schools or districts that do not have technology to support them. For example, the digital RRR poster/projects could easily be made on poster board, and graphic organizers can be made on any kind of paper. Graphing activities do not require Excel, but graph paper would be suitable. Even trend analysis could be implemented using graph paper and students could use a line of best fit, as a simple "rise over run," or linear regression to generate simple modelling and predicting from data. By keeping instructional activities pertinent to the students by connecting to real world issues helped to engage the students throughout the study. Additionally, students expressed during small focus group interviews that they liked sharing their research and activities with their classmates and this supports the concept of eliciting student ideas and their concerns throughout the study. Learning activities that provide opportunities to reflect on the broad issues of sustainability and also to self-reflect on their own behaviors are fundamental to encouraging students to understand personal and societal impacts.

Limitations in Systems Thinking component

One aspect of the study that did not always meet expectations of the researcher and teacher was students' ability to convey an in depth understanding of environmental systems in writing or orally. An example of this is from the background information a student wrote in his formal laboratory report in which the student describes plastics as "hurting the environment," "much water is used and wasted" during oil refining and "other chemical products" are formed. At a higher level of understanding for these three quotes the student might have discussed the impacts of micro-plastics in aquatic environments and animal tissues, or described the impacts on the hydrologic cycle and reduced drinking water supplies, or explained how significant toxic hydrocarbon residues are formed from oil refining.

Students did not reach mastery levels on par with what would be considered expert responses, especially in terms of linking their writing or explanations to biogeochemical cycles and environmental systems. Assaraf and Orion (2005) suggested this lack of mastery is expected for high school students in early stages of learning about systems. In addition, the cognitive hierarchical structure of systems thinking that includes cognitive steps in development of the next higher-order thinking skills may not be present in novices dealing with the behaviors and functions of complex systems (Hmelo-Silver et al., 2007). Glazer (1992) stated the expert knowledge that underlies the ability to recognize problem types has been characterized as "involving the development of organized conceptual structures, or schemas, that guide how problems are represented and understood" (in Bransford, 1999, p. 33).

Despite a lack of mastery when it comes to including numerous environmental systems in their graphic organizers, reflection essays, RRR posters and laboratory report background information, all students did include several of these systems. It is important to note that most students experienced significant changes in their understanding given that none of them had ever learned about systems thinking before the study began. Bransford et al. (1999) suggested learning science emphasizes the processes of knowing. They suggest experts' thinking seems to be organized around big ideas so it is encouraging that students identify with the big idea of systems thinking. Expert learners often use the concept of conditionalized knowledge, where topics are associated with specific situations. This has implications for the design of curriculum, instruction, and assessment practices that promote effective learning (Bransford et al, 1999, p.43). Furthermore, they conclude "It can be difficult for them to learn with understanding at the start; they may need to take time to explore underlying concepts and to generate connections to other information they possess. Attempts to cover too many topics too quickly may hinder learning and subsequent transfer" (1999, p.58). This suggests that another implementation of this study should be longer than two weeks to possibly give students time to better transfer knowledge.

McNeal et al. (2004) found that increased supporting (scaffolding) activities may be required for students in regard to developing higher-order thinking skills, specifically when making connections between systems, in order to reach a mastery level of understanding and build their confidence. Additional instructional activities on biogeochemical cycles such as Carbon, Oxygen, Nitrogen, Phosphorous, Sulfur, and Water/hydrologic cycles along with other systems review such as global wind patterns, groundwater flow, formation of sea ice and others would be good to include at the beginning of the unit. Based on discussions with the cooperating teacher before the start of the study, it was determined that the students already had a strong background in these topics, but upon reflection it would appear they could have benefited from greater content instruction in this area. A simple activity to add might be to have students create visual representations of different cycles and put them together as a booklet or as a Power Point to keep for future reference. Since factual knowledge of environmental systems represents the main "trunk" of the learning tree for this project, it makes sense to emphasize it more.

Study Limitations

Since this study included both qualitative and some quantitative data, it was necessary to have the classroom teacher assist in evaluation of student learning. Initial questioning and student surveys on their understanding of biogeochemical cycles, system thinking, sustainability and inquiry helped establish their baseline knowledge. Assessment of student work including experimental design, data collection and graphing, research, and writing samples was coupled with surveys, interviews, and observations to formulate the students' learning comprehension trajectory and interpretation.

It was important to capture the participants' perspectives without reading into them more than was there, just because I want things to be a certain way or to make sure they are successful when it is not the truth.

There may have been limitations in both development of the relationship with the cooperating teacher, as well as possible interpretation of student learning. Since I am no longer a secondary classroom teacher, and took on the mantle of researcher and university professor I anticipated that I might initially be considered an "outsider" to the teacher and students. I wanted to position myself so that the teacher considered herself part of the research team, as equal with me much like envisioned by Cobb and Jackson (2015). I communicated directly with the teacher about her own students and how best to achieve the research goals which helped develop a higher level of trust and move me more into being an "insider." I planned to be an observer and my direct participation with the students was minimal. I realized this was a big investment in time for the classroom teacher so I needed to develop a good rapport and achieve "buy-in" about the project. Also, as the observer-researcher, I needed to give the teacher my full support during the class period and withhold judgment about her performance and that of the students. I did not want my presence to influence the behavior of the teacher and students, so it was important not to be an obvious disruptive force in the normal classroom routine. Another limitation is that this study was conducted with one teacher and one classroom so the results are not necessarily generalizable beyond this population.

Implications and Further Research

Implications

The underlying purpose of this study was to examine a series of instructional activities through the lens of systems thinking to promote student understanding about environmental sustainability. Another important aspect was to help students evaluate their own behaviors and affect a change in student attitudes as they relate to sustainability. The results of the project suggest that a series of classroom activities can be designed to both develop greater systems thinking, particularly related to environmental systems while also engaging students in meaningful and enjoyable learning. The notion of presenting the unit in the constructivist perspective, building on prior learning was important, as was providing students with multiple learning modalities. Students responded well to the cooperating teacher and also completed all of the assignments. They also reflected on their own learning through many surveys and discussions in small focus groups.

Overall, the students made gains in their foundational understanding of environmental systems, and they successfully utilized research, graphing techniques, data collection, and inquiry to support their learning. Writing and speaking with emphasis on explaining and discussing environmental issues, designing graphic organizers and a visual digital poster also added to the variety of instructional devices used. Student surveys indicated that there was a consensus of positive responses about the impact of the entire project. They strongly agreed they engaged in the study and had more understanding about systems thinking specifically. Their perceptions, attitudes and personal behaviors as they relate to sustainability were increased and they appear to understand the role of individuals and others in global sustainability. Several recommendations by students for future iterations of the project include comparing paper and plastic usage among the class members and doing research about different countries. Several students also suggested that they be given the time to actually implement the RRR projects they had proposed so they could see them through, such as one to put recycling containers in local restaurants.

The learning tree idea presented earlier suggests that systems thinking with emphasis on environmental systems could be the foundation for integrating these and other assignments. If students conduct the instructional activities, always through a lens of environmental systems thinking they can construct deeper meaning about the impacts of human behaviors on a broad scale. One of the biggest takeaways was that the study could be revised to increase the review of specific biogeochemical cycles and environmental systems so that students could remember to include more when writing and talking about sustainability issues. It was also observed that students could have benefited from more explanation about writing hypotheses and designing their inquiry experiments, and that would also be added to a future repetition of the project. As mentioned, another revision for this educational design research would be to increase the length of time for the unit to give students a better chance of learning with deeper understanding and for self-reflection about sustainability in general. The basic format of the instructional unit however does provide a workable scaffold of activities that can direct students to achieve a better and more thorough understanding about sustainable lifestyles and potential issues in the future. Teachers at different levels from middle school through introductory college courses could potentially benefit from implementation of the sequence of strategies to teach education for sustainable development with modifications for their target populations.

Further research

Several changes for a future iteration of the study were suggested above but the topic is one that has a rich potential to develop into other research. One clear option for further research is to "scale up" the project and include many diverse classrooms and teachers. For example, it could be implemented with younger groups of students, secondary students who do not have a strong science background, those who have learning disabilities, as well as non-English speaking students. Anecdotal experience suggests that some of these subgroups are very interested in the environment in general and they can be highly motivated to become "environmental activists." There is a wide push in the United States and around the world to promote Civic Science and it might be possible to structure the activities, especially the collection of paper or plastic at home with non-school groups such as Osher Lifelong Learning, and various elder groups, scouts, and so forth. Civic science is learning based on real world issues that "challenge students to find personal meaning and civic solutions to society's most daunting problems that exist at the nexus of science, technology, and society" (Garlick, Bergom, & Soisson, 2020, p. 48) so this project could be enthusiastically accepted in non-science groups. Broadening the notion of science literacy by including both extrinsic and intrinsic aspects and considering science literacy as a lifelong process is necessary and consistent with current views of how people learn. Liu (2009) notes aspects of learning allow students to use dialogue and writing to make connections between science, personal values and civic life. "Current learning theories recognize the importance of both formal and informal education, and effective learning takes place in both formal and informal settings" (Liu, 2009, p.311). Since a new definition of scientific literacy includes both academic and non-school environments (Liu, 2009) this project could be modified for virtually any purpose.

Design based research (DBR) has also been described as especially applicable to technology-enhanced learning environments (Edelson et al,1999). There are some technology aspects to this study which include using Excel spreadsheets to prepare graphs and trend analyses. The use of other technologies to monitor collection of waste, or design an environmental implementation project could easily be included. Modeling is another suggested method of learning suggested by *A framework for K-12 science education* (National Research Council [NRC], 2012). Constructing a trend analysis of global temperature data, as well as trend analysis for paper or plastic consumption done by students in the inquiry component of this study represents examples of computer modelling, and a wide range of models of sustainability could be added. Specific models could result from study of the circular economy represented in the short film on the clothing industry in which students look at water usage to grow cotton, wool and other fibers as well as to produce the clothing.

Alternate topics for another iteration of this study include global climate change, ocean acidification, and the current issues related to antibiotics and other drugs released directly into both the environment and human waste stream. Any of these topics could be researched by students and generate possible experiments and data sets, but much of the information about environmental effects is still being studied.

Teacher training for SD is also needed as many teachers do not have the insight and experience to teach it and how to more effectively integrate sustainability in all levels (Yoon, et al, 2018, p. 314). Borko (2004) suggests effective professional development has both an individual focus where teacher knowledge and practices can change through intensive PD programs, and a group focus where strong professional communities can help foster teacher implementation of what they are taught. Unfortunately, Opfer (2011) noted that teachers had difficulty implementing what was taught in professional development due to unsupportive conditions in their schools, lack of coordination of curriculum and leadership, little collegial activity, and no genuine commitment to PD. Knapp (2003) described professional learning as demonstrable changes in relevant thinking, knowledge, skills, mental habits, or commitments. Science educators and teacher trainers need to design professional development opportunities that not only address the science content standards, but also help teachers plan and implement teaching methods that will model the reform standards which emphasize science inquiry and nature of science. Capps, Crawford and Constas (2012) evaluated many science education professional development programs and agree that although inquiry based instruction is not the only way to effectively teach science, it is thought to have a powerful influence on students' science learning. The instructional activities in this study could be modified to be used in a teacher training, professional development setting.

As a final suggestion for future research and possible implementation of another EDR project would be to work with the instructional strategies in coordination with Indigenous peoples, or in an effort to present the topics from these perspectives. Education for sustainable development promotes the value of diversity and respect for different viewpoints. This means moving beyond dominant anthropocentric, scientific and 'Western' materialist ways of viewing the world to include local and indigenous perspectives (Wals & Benavot, 2017, p.407). Traditional, indigenous knowledge plays an important role in environmental sustainability with ideas that are passed down generationally, usually by word of mouth and cultural rituals. Wals and Benavot also note that traditional knowledge has long been the basis for sustainable agriculture, food preparation, health care, socialization and conservation in indigenous communities but this knowledge has been ignored by many teachers and textbooks.

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APPENDIX A

2 WEEK INSTRUCTIONAL ACTIVITIES AND SEQUENCE

DAY 1: One 90 minute block period

Whole class lesson: The cooperating teacher will briefly introduce the researcher who will briefly describe the 2 week project. Students will be asked to use their individual laptops to answer a short online survey using Survey Monkey about environmental sustainability and systems thinking definitions and their current understanding of these topics. This will serve as a baseline of students' understanding of the main topics of the research.

The initial survey questions (using Survey Monkey)

https://www.surveymonkey.com/r/LLJJL2S will be:

1. Have you ever heard of environmental sustainability? Yes or No
2. Give a brief definition of what you think environmental sustainability means.
3. Have you ever heard of systems thinking? Yes or NO
4. Give a brief definition of what you think system thinking is.

When students complete the initial survey the researcher will provide an introduction to Systems thinking in Environmental Science using examples such as healthy eating, energy and resource consumption, etc. Students will engage in question and answer session initiated by researcher. Activities from World Wildlife Federation's *Linking thinking, education and learning: an introduction* (2016) can be used. https://www.dropbox.com/s/29no3d09wh005t2/linkingthinking-302.pdf?dl=0 For example 1.1 "Thinking like a box, thinking like a web" on page 3, and Activity using the tree on page 6. There will be teacher-directed initial brainstorming about how we use paper and plastic. Students can keep an ongoing list in their notebook or on the board for each.

Show students a short video clip about circular economy, such as this video about the garment industry:
http://www.bing.com/videos/search?q=circular+economy+clothing+video&src=IE-TopResult&conversationid=&ru=%2fsearch%3fq%3dcircular%2beconomy%2bclothing%2bvideo%26src%3dIE-TopResult%26FORM%3dIETR02%26conversationid%3d&view=detail&mmscn=vwrc&mid=5CCB3E4398977CA87A5B5CCB3E4398977CA87A5B&FORM=WRVORC

A brief whole class discussion will follow about how this topic also engages in sustainability and systems thinking.

Whole class: Classroom teacher will take over at this point. Teacher will direct students as a whole class to brainstorm all of the different forms of paper and plastic.

Small group activity: Students will be assigned a partner and the students must decide whether to use paper or plastic as their topic for the rest of the unit. They will use their individual laptops to begin to research how paper/plastic is made and how this contributes to usage of trees, fresh water, fossil fuels for production, transportation fuels, etc. They will brainstorm about global consequences of paper or plastic production and will use their research prepare a graphic organizer/concept map of what they find relative to manufacture of paper and the effects on the environment. They will be given a small amount of time the next period to finish if necessary.

Whole class: Students will be given a two-question exit ticket using Mentimeter

https://www.mentimeter.com/s/4f2dae98043ab5becebf74989124ddb6/ce20071c6b72

or go to www.menti.com and use code 46 96 54

The questions are:

1. How important is learning about Environmental Sustainability (ES) to you?
    a. I have no interest in learning about ES
    b. I have minimal interest in learning about ES
    c. I am very interested in learning more about ES
    d. I think ES is one of the most important things for us to understand
2. Give a word or short phrase that you associate with environmental sustainability. (NOTE-This will provide a Word diagram/"wordle"

DAY 2: One 90 minute block period

Small group activity: Students will finish their graphic organizer if they need more time

Whole class: Pairs of students will share their graphic organizers with the class and discuss them. The teacher will encourage class engagement and discussion, and students will be using oral presentations skills for this activity.

Whole class lesson: The cooperating teacher will make a brief introduction and review of making pie, bar, and line graphs as well as scatter plots using a power point. The teacher will review how to select the appropriate kind of graph for specific data sets, hot to determine dependent and independent axes, set up appropriate increments along the axes, and demonstrate how to title a graph.

The entire class will then circulate through 5-6 laboratory tables and enter their answers to simple survey questions located on each table. These questions will be set out on the tables by the teacher before class and she will suggest the actual questions. For example surveys for the students to fill out could include: number of pets owned by students, mode of transportation to school, student birth months, favorite pizza toppings, number of siblings, and favorite color.

Group practice graphing activity: The teacher will remind students about sample collection techniques, and the need to make graphic representations of data.

The class will then be divided into 5-6 groups of students (4 or more in each group as needed by class size) and each group will be assigned to take the data from the questions on their specific table and construct a properly labeled and designed bar graph of that information. They will share the results of their data collecting and bar graph with the whole class. The group graphs will be collected and reviewed by the researcher and teacher to see if students understand the process of bar graphing.

Whole class: Students will be given a two-question exit ticket using Mentimeter

Go to www.menti.com and enter code 63 55 43

The questions are:

1. Research and graphic organizer on production/use of paper/plastic______
   a. Did not help me understand environmental systems
   b. Helped me understand some environmental systems
   c. Made me much more aware of environmental systems
   d. Made me more aware of systems and more concerned about sustainability
2. How would you describe your skill at data collection and graphing?
   a. I do not understand how to represent data as a graph
   b. I am comfortable collecting data, not so sure about graphing
   c. I am confident about data collection and graphing

DAY 3: One 90 minute period

Small group activity: Students will work with a partner using sustainability data sets that are provided. Each group of partners will be assigned one to two data sets as time permits and the students will prepare their own bar graphs using Excel spreadsheets. Final graphs will be uploaded to the teacher's google classroom folder. Students will share their graphs with the whole class for discussion. Links to systems thinking will be made by the teacher who will also encourage student interaction and discussion as time permits. The following web-links will be printed and cut into strips and given to the student pairs for this activity. After they produce their graphs, students will write a brief summary paragraph of what the data represents.

http://www.statisticbrain.com/tree-deforestation-statistics/
Countries with highest deforestation of natural forests 2000-2005

http://www.statisticbrain.com/tree-deforestation-statistics/
Top 10 Most Endangered Forests

http://www.statisticbrain.com/paper-use-statistics/
Paper Use Statistics

http://www.statisticbrain.com/paper-use-statistics/

U.S. Paper and Paperboard Production

http://www.statisticbrain.com/paper-use-statistics/
Annual Paper Use Per Capita

http://www.statisticbrain.com/paper-use-statistics/
Top Paper & Paperboard Producing Countries

http://www.statisticbrain.com/environmental-recycling-statistics/
Environmental Statistics -graph only the data related to trees, paper and consequences of manufacture
http://www.statisticbrain.com/landfill-statistics/
Combine the data to graph what is related to paper production, and consequences

http://www.statisticbrain.com/paper-industry-statistics/
Production volume of paper and cardboard worldwide (in million metric tons)

https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/use/?cid=nrcs142p2_054028
Pick 1 of the data sets on soil degradation and graph them

http://vitalsigns.worldwatch.org/vs-trend/looming-threat-water-scarcity
Water availability by region

https://www.paperonweb.com/A1015.htm
Create a combined graph of the data provided

http://www.who.int/phe/health_topics/outdoorair/databases/cities/en/
Open the ambient air database (excel) on the right side of the screen and select 10 major cities around the world and graph the P10 data for each

http://vitalsigns.worldwatch.org/vs-trend/paper-production-levels
C**onvert the line graph to a bar graph**

http://library.wur.nl/isric/fulltext/isricu_i26803_001.pdf
Select one of the data sets and construct a bar graph

All student graphs will be submitted to the class Google Dropbox and reviewed by the teacher and researcher to assess their use of bar graphs and Excel spreadsheets as tools for data collection. Their summary paragraphs will also be reviewed for understanding. Students will present their graphs and summaries to the class and discuss environmental systems as related.

Small group activity: Students will work with their partner develop a method of categorizing their own family's paper/plastic usage at home in a data table for a 3 day period. Students are encouraged to brainstorm and work together to designate different kinds of paper/plastic products they use, including but not limited to newspapers, magazines, white office paper, non-white office paper, construction paper, brown paper, wax paper, stationary and cards, other. Similar types of brainstorming will be used for plastics. They must also determine how they will transport their paper/plastic to school to be weighed in kg or if they have an accurate kg scale at home for this purpose. They will need to keep each day's collection separate for individual weighing. Additionally the teacher should encourage students to develop other observations and tasks they might want to make such as photographing the paper/plastic piles, and so forth.

Note: Each student shows their data table to the teacher for approval or recommendations before they leave class.

Whole class: Students will be given a two-question exit ticket using Mentimeter

Go to www.menti.com and enter code 21 48 01

The questions are:

1. How many categories of paper or plastic did you create for your collection project?
    a. 1-3 categories
    b. 4-6 categories
    c. More than 6 categories
2. Predict what type of paper or plastic you and your family will have most during the three day collection period.

Homework: 1-Students begin to collect their paper used at home into piles for categorization as they designed above. (Day one of paper collection; students will collect their paper/plastic for three consecutive days or as directed by the teacher depending on class periods and contact days. Paper/plastic should be weighed at home and data brought to class, or paper/plastic should be brought in to class for measurement on final collection day which should correspond to Day 6of the unit).

DAY 4: One 90 minute block period

Individual activity Students will write an experimental design type laboratory report for their independent project on paper/plastic to be submitted to the teacher as a pre-laboratory assignment in the class Google Dropbox. The Pre-laboratory should include Purpose, Hypothesis, Materials, Procedure and data table for three days of paper or plastic consumption. A format for this type of document is in Appendix C- IA Laboratory report format and rubric. The pre-laboratory and post-laboratory write ups will be collected separately and reviewed by the teacher and researcher for understanding of scientific method, and inquiry. Students will have had prior experience with conducting independent inquiry, but the teacher may briefly review the expectations and format of the assignment.

Individual activity: Students will research their topics (paper or plastic) and begin to write part of their laboratory report discussion related to the effects of paper or plastic on environmental systems. They should create a bibliography in APA format of a minimum number of references they are using for research.

Whole class: Students will be given a two-question exit ticket using Mentimeter

Go to www.menti.com and enter code 91 08 62

The questions are:

1. What is your method of collecting data for paper or plastic over three days?
2. Give a word or short phrase to describe how you feel about the amount of paper or plastic being used world-wide.

DAY 5: One 90 minute block period

Whole class lesson: The teacher will begin with a brief introduction on making line graphs from sustainability data sets that are provided. The teacher will review how to determine dependent and independent axes, set up appropriate increments along the axes, and demonstrate how to title a graph. The teacher will differentiate between the bar graphs the students did on Day 2 and describe when the different graphing methods are appropriate for specific kinds of data.

Individual activity: The following data and directions are modified from the researcher's laboratory manual *Advanced Environmental Science*, Laboratory 7: Modelling Climate Change (Matthews & Weatherhead, 2008), and are provided below. Students will make trend graphs for global temperature levels using levels using Excel spreadsheets of the data provided. Students will learn how to model data as scientists do in order to predict many years into the future. The following directions and data will be provided to the students.

PROCEDURE Trend analysis of global temperature averages and carbon dioxide levels

- Enter the data provided in Table 1 for average global temperature into an Excel spreadsheet. (Competitive spreadsheet vendors require separate instructions.) The years will go into Column A and the temperature in Celsius degrees will be put into Column B. Your teacher may choose to do this for you and provide you with an electronic version of the information.

- *Step for inserting linear trend data*. Once you have entered the data set, highlight the entire data field using your cursor. Go to the lower right corner of the highlighted data, and when the cursor turns into a cross, click on the left mouse button and pull down for as many years as you need to project into the future. Try projecting for the next 100 years. Note: you may also want to experiment with the exponential graphing function if time permits. You may produce two different graphs this way.

- Highlight the entire data field using your cursor. Then go to your menu line and click on "Insert" and then "Chart." Microsoft's "Chart Wizard" then comes on.

- Under “Chart Type” select “XY (Scatter).” Just to be sure, check the button, “Press and Hold to View Sample”. Press “Next” twice.

- Insert titles, gridlines, and legend or data labels to suit your style. Since you only have one type of data matched to each year, you may want to unclick the legend button to give your data more room in the chart.

- Identify whether you want to save the chart as a “New Sheet” or an “Object within a sheet.” It will be easier to copy and paste the chart to another document if you save it as a “New Sheet.”

- Right click on one of the plotted data points, and then left click on “Format Data Series.” Under “Line” press the button “Automatic.” Press “OK.

- Use Average global temperatures data from NASA http://data.giss.nasa.gov/ and insert the year and temperature in degree Celsius

- For easier reading, at this point you may want to bold or enlarge the font sizes of the chart title, axis titles, or axis labels. Right click on the title or label you want to change, left click on “Format.” click on the folder “Font” and indicate the font size or boldness that you prefer.

- Put a copy of your graph into the class Google drop box

Individual activities: Students will weigh or measure their different paper/plastic categories and record in their data tables, if they bring in anything. They will continue to work on their experimental design and data collection as needed. Teacher will return the student inquiry pre-laboratories with comments and suggestions

Whole class: Midpoint Survey questions: https://www.surveymonkey.com/r/9DMYQGD

1. Which of the graphing activities completed were most effective in helping you review graphing techniques?

None of the graphing activities were helpful
All of the graphing activities were equally helpful
Working as a group on basic bar graphs was most helpful
Working individually on the environmental data sets (internet websites) was most helpful
Working individually on the data sets provided with trend analysis (global temperature and carbon dioxide) was most helpful

2. Which of the graphing activities were new methods or skills for you?

None of the graphing activities were new to me
All of the graphing activities were equally new to me
Working as a group on basic bar graphs was new to me
Working individually on the environmental data sets (internet websites) was new to me
Working individually on the data sets provided with trend analysis (global temperature and carbon dioxide) was new to me

Homework: Students will work on completing their data collection, revisions of their inquiry laboratory reports or other activities as determined by the cooperating teacher and researcher.

DAY 6: One 90 minute block period

Individual activities: Students will weigh their different paper/plastic categories and record in their data tables, if they bring in anything. ***Whole class and individual activities***: The teacher will instruct the students to create bar graphs of their different categories by weight (or other parameter the student has selected to measure) for the totals used over three days.

The teacher will instruct the students to create line graphs of their TOTAL usage by weight (or other parameter the student has selected to measure) per day for three days. Students can share their graphs and what their family used during the sample collection period.

The teacher will instruct students how to predict their paper usage over a month by multiplying the total used by 10 (3 days of consumptions measured x 10 = 30 days/month). They can then extrapolate the amount they might use in a year my multiplying the monthly total by 12. The connection to the trend analysis line graphs they made the day before will be included. Graphs of monthly, yearly and trend analysis of up to 50 years should be created and added to the laboratory reports.

Small group and individual activities: Students help each other do these calculations and make line graphs to demonstrate their own monthly and annual consumption of paper/plastic.

Students work on inputting their graphs into their inquiry laboratory reports, and begin to conduct data analysis and make conclusions as time permits.

Homework: Students finish their inquiry laboratory reports and submit to the class Google drop box. The teacher and researcher will review these for understanding of long term consequences of consumption and usage of their chosen material paper or plastic.

<u>DAY 7:</u> One 60 minute block period

Small group activity: Students will be put into groups of 2 and will research how paper/plastic can be reduced, reused and recycled (RRR) and how this benefits earth systems as well as economically. Each group produces a digital poster with their findings or they may create an implementation project for helping the community address the issue of environmental sustainability. Students are encouraged to discuss methods to reduce, reuse and recycle with a systems approach. Observations of discussions related to the degree of systems approach used by the groups will be made to judge how well they incorporate water cycle, biogeochemical cycles, pollution and climate change as well as other topics

Lesson wrap up, Whole class: Teacher calls on student groups to show their group posters or implementation projects. They will present the digital posters to the class and discuss impacts on environmental systems and sustainability.

Small Group: Some students may be included in small focus groups and interviewed by the researcher using the questions in Appendix E.

<u>Day 8:</u> One 180-300 minute block period

Whole class: Students can share the results of their three day data collection and the graphs they created. Group discussion led by the teacher should center around effects on systems and environmental sustainability. All final laboratory reports must be submitted to Google Classroom Dropbox.

Individual activity: Students will be given the following writing prompt and asked to write an essay during the last 20 minutes of class. "Discuss the environmental consequences of paper/plastic production and usage on a global scale. Include as many systems as you can think of that are impacted. What does environmental sustainability mean and how does it connect to systems you identified? What can you do <u>personally,</u> and what do you suggest for humans to do to <u>in general</u> to affect a change?" The essays will be collected and reviewed by the teacher and researcher to assess student's individual understanding of the project goals. The rubric for this discussion essay is located in Appendix D.

Small Group: Some students may be included in small focus groups and interviewed by the researcher using the questions in Appendix E.

Whole class: Students will also answer final survey questions on Survey Monkey related to the project and their understanding about systems thinking and sustainability after completing the unit.

The final survey questions are below and will be put into a Survey Monkey

Systems Thinking Student Survey:

1. How well did you understand systems or linking thinking for environmental science before this project began?
   Not at all, never heard of it before
   Somewhat understood
   Understood exactly

2. How well do you understand systems thinking for environmental science now that you have completed the project?
   I do not understand what systems thinking is at all
   I understand some of what systems thinking involves
   I have a good understanding of systems thinking related to environmental science issues

3. Select the most helpful strategies that helped you develop your own systems thinking
   Introduction to systems thinking with tree diagram
   Brainstorming session about effect of paper manufacture and making a graphic organizer
   Brainstorming session about different kinds of paper
   Whole group review of graphing skills
   Small group bar graphing activity with non-environmental topics
   Construction of bar graphs of data sets related to paper manufacture and consequences
   Construction of line graphs of data sets related to trend analysis of environmental data sets
   Design of method for at-home data collection of paper/plastic
   Interpretation and graphing of at-home paper/plastic collection
   Extrapolation of at-home paper collection for future consumption
   Research on reduce-reuse-recycle of paper/plastic products
   Research on consequences of paper/plastic manufacture in the environment and linking to environmental sustainability for essay after completion of the project
   Final reflective essay
   Work with small group on 3 R's or Implementation plan

4. Select the 3 most helpful strategies that helped you develop your data analysis and conclusions when writing your inquiry/experimental laboratory report
   Introduction to systems thinking with tree diagram
   Brainstorming session about effect of paper/plastic manufacture and making a graphic organizer
   Brainstorming session about different kinds of paper/plastic
   Whole group review of graphing skills

Small group bar graphing activity with non-environmental topics
Construction of bar graphs of data sets related to paper manufacture and consequences
Construction of line graphs of data sets related to trend analysis of environmental data sets
Design of method for at-home data collection of paper/plastic
Interpretation and graphing of at-home paper/plastic collection
Extrapolation of at-home paper collection for future consumption
Research on reduce-reuse-recycle of paper/plastic products
Research on consequences of paper/plastic manufacture in the environment and linking to environmental sustainability for essay after completion of the project

5. How would you rate your level of engagement in this project?
   I did not participate at all
   I participated somewhat, but not fully
   I participated fully

6. How would you rate your overall interest in the project?
   The project was not interesting to me at all
   The project was somewhat interesting
   The project was very interesting to me

7. How would you rate your overall enjoyment of the activities and project?
   I did not enjoy any aspect of the project
   I enjoyed some of the project activities
   I enjoyed participating in the project

8. Which sentence best describes how conducting this project influenced your opinions and behaviors about environmental sustainability

   The project did not influence me to change my behavior
   I have a better understanding about environmental sustainability but the project will not influence my behavior in the future
   I have a better understanding about environmental sustainability and the project will somewhat influence my behavior in the future
   I have a better understanding about environmental sustainability and the project will definitely influence my behavior in the future

Please feel free to add any comments about the four days you think would be helpful to the researcher

APPENDIX B

DAILY OBSERVATION CHECKLISTS

Sample

Date:________________________________

Activity observed:____.

Make specific observations related to the specific Learning Goal and give evidence below.

- In what ways did the activity support the following Learning Goals? What things do students say or do which let me know they have learned?
- Identify ways in which the activity did NOT support the Learning Goals

1. Students will be able to understand how environmental systems interconnect.
2. Students will be able to relate environmental systems to environmental sustainability.
3. Students will be able to analyze the effects of manufacture, production and use of either paper or plastic on environmental systems.
4. Students will be able to evaluate the roles and responsibilities of individuals, groups and societies in general in terms of environmental sustainability.

Table B.1: Daily Observation Checklist summary of activities by cooperating teacher, Day One

	Systems/Linking thinking introduction; using WWF	Circular Economy video
Goal 1: Students will be able to understand how environmental systems interconnect.	This introduction was perfect to demonstrate the interconnectedness of environmental systems.	This video demonstrated the importance of interconnections in fashion, and since everyone chooses what to wear, each person shared interest in the topic from this perspective.
Learning Goal 2: Students will be able to relate environmental systems to environmental sustainability.	This was not specifically addressed.	Students were able to consider the system thinking skills and their clothing.
Learning Goal 3: Students will be able to analyze the effects of manufacture, production and use of either paper or plastic on environmental systems.	This was not addressed.	This was the most focused goal of this activity. It made students consider the importance of their choices and responsibilities.
Learning Goal 4: Students will be able to evaluate the roles and responsibilities of individuals, groups and societies in general in terms of environmental sustainability.	This was not addressed.	This was also the most focused goal of this activity. It made students consider the importance of their choices and responsibilities.

Table B. 2: Daily Observation Checklist summary of activity by cooperating teacher, Day Two

	Mentimeter/Wordle	Graphic organizers
Learning Goal 1: Students will be able to understand how environmental systems interconnect.	The Wordle created showed all of the responses to the prompt. Since so many terms were duplicates, some were larger and interconnected.	Students created systems diagrams with inputs, outputs, stores and flows between paper OR plastic resources, processing, and products. This was especially powerful because students realized the only limits to the effects were the number of minutes in class! Many wanted to include more-saying the issue was like a domino effect-like it didn't really stop. Just ran out of time and space to display all of the ripple effects
Learning Goal 2: Students will be able to relate environmental systems to environmental sustainability.	Since this was still an introduction this was just terms, not substance yet.	This was more so for those that did paper than plastic. Paper groups focused on the processing and effects on the environment.
Learning Goal 3: Students will be able to analyze the effects of manufacture, production and use of either paper or plastic on environmental systems.	This activity didn't address this goal.	That was what this was all about!
Learning Goal 4: Students will be able to evaluate the roles and responsibilities of individuals, groups and societies in general in terms of environmental sustainability.	This activity briefly addressed this goal when asked how important it is to learn about Environmental Sustainability. However this activity was a hook; not necessary to the substance of lesson.	They especially focused on the effect on community and laborers.

Table B. 3: Daily Observation Checklist summary of activity by cooperating teacher, Day Three

	Mentimeter questions	Simple graphing
Learning Goal 1: Students will be able to understand how environmental systems interconnect.	Question 1 allowed students to reflect on what they learned about environmental systems	Did not impact the goal per se
Learning Goal 2: Students will be able to relate environmental systems to environmental sustainability.	Question 1 allowed students to reflect on what they learned about environmental sustainability	Did not impact the goal per se
Learning Goal 3: Students will be able to analyze the effects of manufacture, production and use of either paper or plastic on environmental systems.	Neither question related directly to the learning goal	This will be helpful for the future activities
Learning Goal 4: Students will be able to evaluate the roles and responsibilities of individuals, groups and societies in general in terms of environmental sustainability.	Question 1 allowed students to reflect on their own role in environmental sustainability	This will be helpful for the future activities

Table B.4: Daily Observation Checklist summary of activity by cooperating teacher, Day four

	Sustainability graphs and summary paragraph	Preparing data table for investigation/Menti-meter questions
Learning Goal 1: Students will be able to understand how environmental systems interconnect.	Mostly discussed the effects on forests and habitat destruction. This was multi-layered. Engaged students in learning skills about making the graphs was a prerequisite for the assignment but was VERY powerful once they could interpret the graphs they had made, and then to summarize.	Preparing the data table did not directly address this goal
Learning Goal 2: Students will be able to relate environmental systems to environmental sustainability.	This goal was many students' realization and part of the explanation and interpretation	Preparing the data table did not directly address this goal
Learning Goal 3: Students will be able to analyze the effects of manufacture, production and use of either paper or plastic on environmental systems.	This goal was more focused on manufacturing; the data was about the obtaining of raw materials (trees) which connected both	Making categories for the data table encouraged students to think about sources of paper or plastic which indirectly connects to the goal
Learning Goal 4: Students will be able to evaluate the roles and responsibilities of individuals, groups and societies in general in terms of environmental sustainability.	This goal was not addressed directly but indirectly students informally expressed concerns about responsibilities and whether or not people have options	Preparing the data table for collecting their own and their family's paper or plastic helped focus attention on their roles and responsibilities in terms of sustainability

Table B. 5: Daily Observation Checklist summary of activity by cooperating teacher, Day six

	Experimental Design/Inquiry Investigation data collection and methods	Trend Analysis Graph
Learning Goal 1: Students will be able to understand how environmental systems interconnect.	This did not directly support the goal	This was not as directly supported. By graphing global mean temperatures students were expressing concern for the trajectory of the future temperatures.
Learning Goal 2: Students will be able to relate environmental systems to environmental sustainability.	This did not directly support the goal	This was not as directly supported.
Learning Goal 3: Students will be able to analyze the effects of manufacture, production and use of either paper or plastic on environmental systems.	Students began to make connections to the use of paper and possible consequences	This was not as directly supported.
Learning Goal 4: Students will be able to evaluate the roles and responsibilities of individuals, groups and societies in general in terms of environmental sustainability.	Students began to understand what they and their families are doing that contributes to environment	Students did discuss climate change models and how everyone had to take some responsibilities. A few said they were concerned about leaving the area when they went to college because they were worried about sea level rise.

Table B. 6: Daily Observation Checklist summary of activity by cooperating teacher, Day Seven

	RRR "Poster"
Learning Goal 1: Students will be able to understand how environmental systems interconnect.	Many of the photos and descriptions for reasons we should RRR were powerful and reinforced the interconnected-ness
Learning Goal 2: Students will be able to relate environmental systems to environmental sustainability.	Many of the descriptors for the reduce, reuse and recycle sections were related to sustainability
Learning Goal 3: Students will be able to analyze the effects of manufacture, production and use of either paper or plastic on environmental systems.	The posters focused on the effects on air, land and water due to the manufacturing of paper and plastic. Many of the students also focused on a variety of animals affected—very engaging.
Learning Goal 4: Students will be able to evaluate the roles and responsibilities of individuals, groups and societies in general in terms of environmental sustainability.	Most of these focused on the individuals' roles, not larger societies.

Table B. 7: Daily Observation Checklist summary of activity by cooperating teacher, Day Eight

	Reflection Prompt/Essay	Formal Write-up of Inquiry investigation
Learning Goal 1: Students will be able to understand how environmental systems interconnect.	This was touched on, but not as much in the activity.	Students designed a method to collect data for 3 days-worth of paper or plastic. This involved many critical thinking skills as well as flexibility. Students needed to be sure their procedure was do-able. Much of this learning goal is referred to in the background information.
Learning Goal 2: Students will be able to relate environmental systems to environmental sustainability.	This was mentioned in many, but not as much in this activity.	This activity did not achieve this goal as well.
Learning Goal 3: Students will be able to analyze the effects of manufacture, production and use of either paper or plastic on environmental systems.	This was mentioned, but not as much on this activity.	This activity did not achieve this goal as well.
Learning Goal 4: Students will be able to evaluate the roles and responsibilities of individuals, groups and societies in general in terms of environmental sustainability.	This was by far the best activity to address this goal. The students settled nicely and wrote from many different perspectives about the roles of individuals, societies, nations and global citizens. Great activity encouraging introspection. This also included research and bibliography. Very powerful reading.	In the conclusion and evaluation, students reflected significantly on their own responsibility with regard to their paper (or plastic) consumption. Many also extrapolated to the community and nation.

APPENDIX C

IA LABORATORY REPORT TEMPLATE AND RUBRIC

Teacher produced document evaluation rubric below:

Title of Experiment:

"Title" is a bad title; So is "Experiment". Be creative.

RESEARCH QUESTION

What question is your experiment trying to answer? Is it justified? Are you demonstrating personal significance or curiosity? This cannot just be the same laboratory we already did in class(but if it was inspired by classwork, say that, and site it in the bibliography!) You need to have evidence of personal input and initiative in the designing and implementing of the experiment.

BACKGROUND INFORMATION

Do enough research to write appropriate background info paragraph about your topic and why it is important to you. Remember to site your sources as you go, even if your experiment is inspired by the textbook or Ms. Philips' guided notes, handouts, or laboratories.

HYPOTHESIS

This should be an "IF… Then…Because" statement.

VARIABLES

The IF is the Independent Variable, the THEN is the Dependent Variable.

Independent Variable (manipulated/changing factor)	How will it be manipulated	How will the IV be controlled

Dependent Variable (What will be measured)	How will it be measured (method)	How will it be measured in a consistent, controlled manner

Controlled Variable (external variables that need to be kept constant in each trial)	How will it be controlled	How would this variable affect the data if NOT controlled

MATERIALS/APPARATUS AND DIAGRAM

- Make a specific, metric bulleted list of all apparatus and materials you intend to use.
- Photograph set up and create a laboratory to show how you set up the experiment.

SAFETY, ETHICAL AND ENVIRONMENTAL ISSUES

Write a statement about how you addressed the safety, ethical and environmental issues associated with your experiment. If you intend to do anything with a vertebrate, hazardous chemicals, etc., be prepared for extra paperwork, like you would do for science fair.

METHOD

1. Use numbered steps like this.
2. Avoid all personal pronouns.
3. Use formal and direct tone.
4. Be sure your methodology addresses the research question.
5. Check that you have enough trials to collect relevant and reliable data.

DATA COLLECTION

Another name for this section is the Raw Data table. Include both Qualitative (what did it look like?) and Quantitative (real numbers). Include the uncertainties in your measurements on your data table.

PHOTO

Include a photo with a caption describing the set up: "Image 1 showing blah blah blah…"

DATA PROCESSING

This is where you describe what Statistics were done and why. Include a sample calculation. Examples of statistics are mean, median, mode, Chi2 and T tests.

ANALYSIS

This is where you insert your graphs. All graphs are made from processed data only, not raw. Remember Title, Labeled Axes, Units on Axes, Color coded key if needed. Be sure to include the Impact of Uncertainty on the Analysis. Carefully interpret the data (duh)

CONCLUSION

First, restate the hypothesis. Then focus the Conclusion on the trend. Was there a Trend identified in data? Use the Data (numbers from graph) to support conclusion. Describe and justify the conclusion making sure it is relevant to the scientific context.

EVALUATION

If you prefer, you can put this same info in a paragraph instead of the tables, just be sure to address the same number of talking points. Also be sure you have a clear understanding of the methodological issues. Are your improvements realistic and relevant?

Strengths	How did it assist your laboratory to get good results?

Weakness/Limitation	How did it affect your laboratory to get poor results?

Improvements	How would you change this in the future? Why?

APPLICATION
How is this related to the "Real World"? Is there a way this experiment can be used by others? Why? A few sentences or a paragraph is fine here.
COMMUNICATION This is where you include your Bibliography for Research. Go back and find it again if you need to. I can also give points here if you have the same verb tense in the paper (past is preferred), as well as sentence structure and coherence. (does the entire report make sense?)

IA Scoring Rubric

Student Name:			Level:
School #	**0914**	Session No.	**Spring 2019**

Investigation title:	
Syllabus topic(s):	

Teacher's Instructions and help given:

Candidate declaration:
"I confirm that this work is my own work and is the final version. I have acknowledged each use of the words or ideas of another person, whether written, oral or visual."

Signed (student): ____________________________________ Date: _________

Accepted (teacher): ______________________________ Date: ________

Criteria	Aspects	Level Achieved (✓)	Comment	Marks obtained (Max Marks: 2)
Personal engagement	Justifying the choice of research question			
	Demonstrates personal significance, interest or curiosity.			
	Evidence of personal input and initiative in the designing, implementation or presentation.			
Criteria	**Aspects**	**Level Achieved (✓)**	**Comment**	**Marks obtained (Max Marks: 6)**
Exploration	Topic of investigation is well identified.			
	Relevant, clear and fully focused research question.			
	Appropriate background information.			
	Appropriate methodology to address the research question.			
	Relevance, reliability and sufficiency of the collected data.			
	Evidences of full awareness of the significant safety, ethical or environmental issues.			

Criteria	Aspects	Level Achieved (✓)	Comment	Marks obtained (Max Marks: 6)
Analysis	Relevant and sufficient quantitative data.			
	Relevant and sufficient qualitative raw data.			
	Appropriate and sufficient data processing.			
	Impact of measurement uncertainty on the analysis.			
	Interpretation of processed data.			
	Valid and detailed conclusion.			
Criteria	**Aspects**	**Level Achieved (✓)**	**Comment**	**Marks obtained (Max Marks: 6)**
Evaluation	Described and justified conclusion relevant to research question.			
	Described and justified conclusion relevant to scientific context.			
	Strengths of investigation w.r.t to limitation of the data and sources of error.			
	Weakness of investigation w.r.t limitation of the data and sources of error			
	Clear understanding of methodological issues.			
	Realistic and relevant suggestions for the improvement.			
Criteria	**Aspects**	**Level Achieved (✓)**	**Comment**	**Marks obtained**

				(Max Marks: 4)
Communication	Well-structured and clear presentation of investigation.			
	Presentation of information is focused, well processed and coherent.			
	Presentation of information is relevant, concise and allows ready understanding of the process and outcomes.			
	Use of subject specific terminology and conventions.			

Notes:

APPENDIX D

REFELECTION ESSAY RUBRIC

"Discuss the environmental consequences of paper/plastic production and usage on a global scale. Include as many systems as you can think of that are impacted. What does environmental sustainability mean and how does it connect to systems you identified? What can you do personally, and what do you suggest for humans to do to in general to affect a change?"

Based on the Learning Goals:

1. **Students will be able to understand how environmental systems interconnect.**

Did the student make links to systems such as carbon cycle, other biogeochemical cycles, water cycle/hydrology, soil degradation, deforestation, atmospheric conditions climate change and others. Note how many different systems they identify.

Student made no links to specific systems 0	Student made 1-2 specific system links 1	Student made 3-4 specific system links 2	Student linked 5 or more specific systems 3

2. **Students will be able to relate environmental systems to environmental sustainability**.

Did the student define sustainability correctly? Did he/she identify how sustainability is related to different environmental systems? Did he/she identify specific systems that impact sustainable environments?

Student did not define sustainability or relate to systems 0	Student attempted to define sustainability; partially related to systems 1	Student correctly defined sustainability; did not relate to systems 2	Student correctly defined sustainability and related to systems 3

3. **Students will be able to analyze the effects of manufacture, production and use of either paper or plastic on environmental systems**.

Did the student appropriately explain the effects of manufacture production and use or consumption of either paper or plastic on environmental systems? How many systems did they identify? Was there a clear cause and effect in the discussion?

Student did not explain any aspect or identify systems 0	Student explained some of the effects of manufacture, production use but did not connect to systems 1	Student explained some of the effects of manufacture, production , use and connected to some systems 2	Student made a thorough explanation of effects of manufacture, production, use and clearly connected with several systems 3

4. **Students will be able to evaluate the roles and responsibilities of individuals, groups and societies in general in terms of environmental sustainability.**

Did the student thoroughly discuss the impacts of individuals and make suggestions for improving environmental sustainability in the future?

Student did not clearly evaluate roles of individuals, groups, societies on ES 0	Student discussed some impacts, roles and responsibilities of individuals, groups, societies on ES 1	Student evaluated and discussed some impacts, roles and responsibilities of individuals, groups and societies on ES 2	Student clearly evaluated and discussed impacts of individuals, groups, societies on ES and suggested solutions and changes 3

APPENDIX E

FINAL SMALL GROUP FOCUS QUESTIONS AND TRANSCRIPTS

1. What do you think environmental systems are?
2. How has your understanding of environmental systems changed, if at all, since you started this unit?
3. What does “systems thinking” mean to you?
4. How has your understanding of “systems” thinking changed, if at all since you started this unit?
5. What does environmental sustainability mean to you?
6. How has your understanding of environmental sustainability changed, if at all since you started this unit?
7. How effective were some of the different activities we completed in helping you understand systems thinking? (Researcher will list these if necessary)
8. How effective were some of the different activities we completed in helping you understand environmental sustainability?
9. Discuss specifically whether the graphing activities were helpful, and in what way they impacted your understanding of environmental sustainability. For example, did making bar graphs of sustainability make an impact? How about doing the trend analysis of global temperature data?
10. Discuss the experimental design /inquiry aspect of the unit, this is where you set up and collected paper or plastic for 3 days. Did you think it was a useful activity for learning about systems?
11. How did collecting your own and families paper or plastic impact your own personal understanding of environmental sustainability?
12. How did completing this unit change your perspective on environmental sustainability for the future? Did it make you reconsider your own behavior?
13. Did completing this unit enable you to make connections between environmental systems and sustainability? If so, describe how or why not.
14. How this project could be improved to be more impactful for you.
15. Make any other comments related to the project design that would give the researcher a better idea of the take-aways you have.

Summary of first small focus group:

When asked to define environmental systems in the initial question, the students did not have clearly thought out ideas, and were not able to express a definition or give an example without prompting from the researcher.

Student A: “I think environmental systems are like the systems that go on in our world that has like pertained to the environment …which is a lot of stuff.”

Student C: “It is most like about like our animal systems but as well as like nature and like the way the globe works in terms of like what environment is and how we interact with the world.”

When prompted to give a specific example of an environmental system, the students appeared to have difficulty.

Student A: “..like the so-called carbon cycle?”

Student B: “The phosphorous cycle. The water cycle.”

Student C: “CHONPS” (Note: this refers to the most common elements in living systems including Carbon, Hydrogen, Oxygen, Nitrogen, Phosphorous, and Sulfur. Students learning about this in class).

When asked how they think their understanding of environmental systems has changed if at all since starting this project two weeks ago, the student responses were somewhat vague.

Student A: “Well before it I never heard, and didn't talk about it. And now I've kind of gone over it a bit. So, okay, so I started getting some knowledge on it.”

Student B: “Like before I knew the plastic and paper was a big issue. But now I'm kind of like realizing every time I throw away piece of plastic or paper, I'm like this isn't good, right? And it would maybe, how would it, well, be a problem.”

When asked to discuss what systems thinking means to them the students made slightly better definitions and expressed more understanding.

Student A: “…system thinking was like, oh not thinking inside the box but like more like a web.

Student B: “When you're thinking about how the like chain reaction of your actions …would go and so how it would affect other things in the future.”

Students were asked how they think their understanding of system thinking has changed since they started the project, had they ever heard of it before and did they know more now. In general they seemed to emphasize garbage, making connections about trash in the environment and not really a generic system thinking answer.

Student C: “Many think that they (trash) just they just disappear but you know, like you realize the problem definitely …the pictures of the landfills and stuff.”

Student A: “… if it falls out of the truck and into the wild or next to the landfill and it's just, you know, piling up the landfill or if it falls into the ocean just kind of like if it even is making it into the ocean of how much trash is already in it was just like too much work to clean, terrible.”

These students seemed to have a better understanding of environmental sustainability than either environmental systems or systems thinking, and were also able to relate how their understanding of sustainability has changed.

Student C: "Just making sure like doing certain I guess like things to make the environment stay healthy and like not a control on too much negative stuff like plastic or global warming … just keeping it so that you can keep living here for a good long time…so just for us and our future generations."

Student A: "It's like ensuring that your environment can sustain like the people living in it and the population not just for now the like for the future so that like prosper for a long time."

Student B: "Like keeping the world as close as it was when it was first created."

It is unclear where Student B encountered this idea as it was not suggested in any of the activities.

Regarding whether their understanding of environmental sustainability has changed after completing the unit, students spoke in general about their views on sustainability and somewhat indicated how the project activities had changed their understanding.

> Student B: …it's kind of like stayed about the same but I realize now how much more difficult it is to keep it sustainable and how much we're going the opposite direction with plastic use and like using and carbon emissions, that kind of thing and doing the like the activities with the drawings and all that stuff… you realize like how quickly it happens…and like it's finally like the consequences of it can come out…so it makes me like think this much more relevant than we think. That it is a problem for like the future but it's probably gonna' happen soon if we don't do something about it.

Student C: "Yeah even through one video we watched about the textiles… how it's like not circular… all people are just as though they keep like constantly buying clothes and it's not like recycling."

When students were asked what activities were helpful in their understanding of environmental sustainability they were able to relate specific examples they completed without any prompting by the researcher.

Student B: "The trend analysis with short term and long term effects was really impactful."

Student A: "Collecting your own stuff for just measuring how much plastic is used in the day was kind of eye-opening."

Student C: "When I went to Europe… people there they like use little tiny trash bins because they like know how not to create trash like we do, and they do compost."

When asked if any of the graphing activities specifically helped them understand sustainability, the responses were positive.

Student A: "I think so because it made us more easily be able to like make comparisons and like relationships with what we were studying and also like I'm a visual person so like being able to see the like trend line go up and stuff has really helped."

When asked about the usefulness of the experimental design/inquiry aspect of the unit students made connections to the graphing of their own data. Student B responded saying bar graphs of their collected data which were separated it into categories were helpful.

Student B: "… that let me show like which kinds of plastic are in my life."

Student A: “When I was creating my trend graphs there was like three days of data and I feel like it would have been a lot more accurate if there was like seven days but like it still worked.”

Student C: “So I saw like how much I was doing to contribute to like the global average…”

Student B: Yeah, I think it did because it makes you more aware of like how relevant it is to your life. I feel a lot of people like promote recycling, but don't do it themselves. So what are you really doing? So I feel like more of a need to like water recycle, especially seeing how many water bottles. I used a lot.

Student A: “Yeah, it showed me that I should definitely limit like certain types of plastic, too because it showed like which ones I use more; which categories of plastic…I don't use any plastic bottles, but for me it was trash bags…to think on plastic bags.”

When prompted to indicate any other behavioral changes from activities there was a discussion about the gifts of reusable utensils and metal straws that was given to each student-participant by the researcher. None of the students had ever used bamboo utensils and metal straws and in general they expressed an interest in using them in the future.

Student A: “I got really excited about the metal straw!”

When discussing the influences of the project overall they liked the movie “Trash Inc., the secret life of garbage” by CNBC which was shown to the class the day before the project started with the researcher. They also liked the short Internet video on circular economy of fashion industry that was shown on the first day. They thought those films were good for helping them visualize the environmental problem of sustainability.

Students gave suggestions about collecting data for more days (7 days was suggested), and advised comparing paper and plastic use in different countries like Saudi Arabia and China versus United States. They also suggested making a flow chart of where trash and recycling occurs locally, as none of them knew where the solid waste and recycling center was and where the trash goes for landfill and recycling purposes. They also suggested working in groups of four. They understood that because each of them has a different sized family, this represents a source of unreliability in the overall data. They liked completing the worldwide sustainability bar graphs and felt the trend analysis activity was impactful. These students discussed the local issues of ban on single use plastic bags and phase in ban of plastic straws, and this topic came up without any prompting by the investigator. When asked if they liked sharing their activities and results with the whole class group, they had positive responses. Overall, the small group felt they understood more about systems and sustainable environments and impact of paper and plastic on these than when they started.

Summary of second small focus group:

Similar to the first small focus group, the students did not appear to have clear understanding about what an environmental system represents. One spoke more about systems thinking.

Student F: When I think of it, the first thing that comes to mind is mind maps just because that's what I know a lot. That was something that I used a lot during TOK. So whenever I think of mind maps I think about how everything for me. It's just the way that things along the way you interconnect all the things that you're thinking about the way that you formulate your thoughts.

Student D: It just depends on how broad or narrow you mean so the one that we were discussing with like plastic usage as well as versus paper usage just because that kind of thing is such a big problem that we have currently like a global issue and t hen we're all seeing the different ways like the solutions to be able to reach. I guess in a sense make our world better in a way that's kind of showing all the systems that relate to the environment but also from like our community like social status.

When the question was restated to ask for specific examples of environmental systems they were able to delineate a few.

Student E: "Nutrient Cycles, water cycle for sure and carbon cycle."

Student F: "I mean there's soil chemistry, the soil of roads and you know it loses nutrients."

In response to how their understanding of environmental systems changed during the two week project, students had more well developed answers.

Student D: I had never thought about how they all interconnect and for example, even with the topic of paper and plastic they (the systems) all interconnect back to paper and plastic and the processes of how it's made and how we use it and how it decomposes and the environment. Like matter is not created nor destroyed is just passed on from cycle to another cycle.

Student F-Yes also adding on to that (circular idea) these two weeks like because I don't think I look into these things on like my free time but these two weeks has definitely like opened my eyes and kind of like made me go out there and search more… and it's interesting how like I read a lot about the crude oil and the processes of making plastic that compounds, the complex compounds that go into like the mixing to make plastic and that's just very like shocking. You know that I really think of other systems are in the plastic like oil, and these other materials and you never think about it like that. You just think plastic.

When asked to discuss what environmental sustainability means to them, students in this group had some connections to future events for humans and other organisms.

Student E: “Using our resources in a limited way so that there's more for the future generations will be able to sustain life in the future.”

Student F: Yeah, the way we use our fossil fuels will influence the amount of like carbon emitted, which will then influence like the global change in temperatures and then that will go back to like melting icebergs. And then think of the polar bear that we saw in one of our classmates’ posters where the polar bear was like really skinny and starving.

In response to the question about whether their understanding about sustainability had changed while doing the project, students made some personal connections about how they view sustainability now.

Student F: Yes, and it has… once again like looking back at how everything is interconnected and I think it's made me more aware of my choices. Now when I use a plastic bottle it’s like, oh man like to reuse it a little longer and it's… I hesitate when I want to open a wrapper because it's plastic and I hadn't thought about that as much as now, yeah.

Student D: I'm aware more of it now. I have a large family. So I think of plastic disposal. It's like a large amount every day. My dad probably goes through 10 plastic water bottles because he works in construction, even though I'm not even telling him not to anymore because it's so hot outside. And you know, like I tried this weekend, not this weekend, like the last three days. I was like, okay, what if we buy those big bottles or jugs and then just like take it with you because you know- learning about this-and then big coolers then I don't know. I think it's because he told me that it's easier. So I really think that sometimes we kind of look at the easier way than rather than the correct way to do thing.

Students in this focus group gave specific examples of activities they did during the project that helped them better understand systems thinking. The effectiveness of the various graphing activities also came up in this discussion before the researcher could ask the question about it.

Student E: "I really like the mind maps like (Student F) said because once again you are able to see the interconnectedness of everything."

Student D: "Yeah, and even though in my mind map I was missing some arrows I could have connected more boxes…"

Student F: Also something that really helped me was the activity we did we did with the graphs and like the trend line she gave us in the drop box. Yeah, I liked going into a hundred years that made me think how everything in the future also will connect and will contribute more and more and yeah, that's that was good.

Student D: For me it was when we did …graph projects when we were kind of like the ones that we were like a little pairs, I think it was. And we all were getting like a new partner. I really like that personally just because I felt that I was able to see something different. Like everyone got like a different section of data…I like what one person's looks like, I wasn't really aware of it. I just wasn't really like conscious of it is the best way to put it; like subconsciously I knew about it, but it wasn't something I really looked into so when I actually saw like, I guess qualitative data on it, it just made me realize like the greater effect.

Further discussion about the impact of the bar graph data sets which were described above by student D, as well as the trend analysis methodology ensued. It was somewhat surprising to find these advanced science students who were seniors in high school claimed they had not been using graphs during the year.

Student F: "Actually I did learn like how do you them because honestly this semester we haven't, I haven't used graphing. I haven't created graphs. Her going over that and like I found that helpful."

Student D: "Yeah, and I had never extrapolated."

Student E: "Yeah, you know, I've never done the trend. It was easy though."

Students were asked whether doing the experimental design/inquiry activity was impactful for them learning about systems followed by environmental sustainability. They were more descriptive about environmental sustainability than systems.

Student D: For me yes because my mom kind of help me keep it organized because I wasn't home. We were together three nights, but she did help me and we collected the like I said like the plastic water bottles, where I told my dad to going to bring them. But wow that was nice of him and it's a lot like it's a full box of like just plastic water bottles. It kind of made me aware how much like it's a daily need from him and like if we were to change and then it'd be like a hard process, but I think we can do something about it. It'll just be hard to get them to.

The student answers and discussion began to segue into how the project impacted their own personal understanding of environmental sustainability and whether the unit changed their perspectives and make them reconsider their own behavior.

Student F: It just made me want to honestly search for more ways to like change things.

Is I think the only experience I guess that I really had regarding like actually thinking about my usage of like plastic and paper was when I was hearing like I think it's a documentary. It was like regarding like cruelty free products, our products and like the usage of that. So I only really knew about that aspect. I didn't really know more about actual damage the plastic and paper could do...you think it goes back to Earth and It wouldn't take that long and then I'm like, oh, yeah, I thought about that.

Student D: "And even like based on it our parents were involved, even got a little taste of what we're learning because they were helping…I have a sister in here and at home too, other one."

Student F: "Yeah. I think it was because of this project that yes, no two days ago. We went to Barnes and Nobles and she (her sister) actually took her metal straw (this was provided by the researcher) there. So there was one less plastic straw."

During this small focus group interview it was determined that students D and F were sisters who were taking the same course. When selecting the topic for their experimental design/inquiry for this project, one of them chose to collect paper and the other chose plastic. They explained that they wanted to collect data on different items so they could compare their results and they also indicated that they got their whole family involved in the process. One of the students suggested that it would have been interesting to work with a partner they did not usually work with in the class, but partners were generally selected by the cooperating teacher. The students also discussed the idea of developing and implementing an actual intervention for a recycling project and suggested doing it at the public library. Another conversation ensued about trying to use the least amount of water to brush your teeth. Students continued to offer other ideas for future research. They appeared to have an interest in doing more research and in completing projects that would make a difference in environmental sustainability.

Student E: "… I'm saying like actually could I actually do it not just go come up with it, but do it."

Student F: "Yes, so then we can see the impact. I don't know how successful I would be but maybe you could challenge us to like use very little paper as possible or plastics. Like well instead of just measuring it, see how little you can do."

Student D: "But like the part that I really like wanted to say is like go through with the plan actually from start to finish…with a longer period of time."

Student E: "Well, that would be a longer process and that that would like make us research more like way more than that."

Student F: "The only other thing that I was curious about that I kind of wish we could have done was everyone was talking about how plastic can you know deteriorate over time and how the chemicals affect like actual plants and I wanted to see the actual effects; like see how it would change and like the toxic levels would rise. I don't know how you would exactly go about measuring that but I would be interested in seeing the extent of it."

APPENDIX F

STUDENT LABORATORY REPORT SAMPLE ARTIFACTS

Student sample 1artifact

Extrapolating Amount of Plastic Waste Over 3 Days

RESEARCH QUESTION

How much plastic is used by an average household and how much is too much?

BACKGROUND INFORMATION

Just to create plastic takes enough effort and environmental damage already, but if that plastic turns into something that is used once then disregarded and thrown away, then it truly is hurting the environment. Plastics are derived from natural organic materials like coal, natural gas and crude oil. To refine the oil, it goes to an oil refinery where much water is used and wasted. Crude oil and natural gas are refined into ethane propane and other chemical products. These are then used in factories to shape the plastics into things we use every day and the carbon emission caused by this is great. All of this going into the environment just for us to use the plastic once and throw it away to then cause more environmental problems is just an awful waste especially if we can prevent it.

HYPOTHESIS

If more than 60% of the plastic waste in kg is non-recyclable, then it is too much and there must be a change in how much non-recyclable plastic is used.

VARIABLES

Independent Variable (manipulated/changing factor)	How will it be manipulated	How will the IV be controlled
Weight in kg	By changing category of plastic	By measuring multiple plastics in the same category multiple times.

Dependent Variable (What will be measured)	How will it be measured (method)	How will it be measured in a consistent, controlled manner

Too much plastic waste or not	If plastic waste is over 2 kilograms	Using the same scale for each measurement making sure it is accurate

Controlled Variable (external variables that need to be kept constant in each trial)	How will it be controlled	How would this variable affect the data if NOT controlled
Different specific plastics have different weights	By measuring over 3 days	Weights would be inaccurate to be used as an average
Inaccurate scale	Make sure it is correct by measuring a known weight (50-gram weight)	Inaccurate weights would be recorded

MATERIALS/APPARATUS AND DIAGRAM

- Digital scale
- Tablet to record data digitally
- All plastic items

SAFETY, ETHICAL AND ENVIRONMENTAL ISSUES

When collecting the data, it was made essential that all plastic was that was recyclable would make its way into the recycling bin and not discarded along with other non-recyclable waste. After all the collected plastic was recorded, it was sorted accordingly as to not harm the environment.

METHOD

1. Organize all plastics into categories.
2. Weigh all plastics about to be thrown away with the digital scale in kilograms.
3. Organize weights into either recyclables or non-recyclables
4. Repeat 1 time each day for a total of 3 days. (3 trials total)

DATA COLLECTION

Quantitative:

recyclable	Water bottle	Ziploc bag	Plastic bag	Containers	Detergent Bottles
Weight in KG	0.043	0.002	0.0055	0.0124	0.937

non-recyclable	Caps	Utensils	Trash bags	Saran Wrap	Wrappers
Weight in KG	0.005	0.0025	0.212	0.721	0.003

recyclable	Water bottle	Ziploc bag	Plastic bag	Containers	Detergent Bottles
Weight in KG	0.051	0.0017	0.0043	0.0119	1.121
non-recyclable	Caps	Utensils	Trash bags	Saran Wrap	Wrappers
Weight in KG	0.0032	0.0023	0.301	0.692	0.0041

recyclable	Water bottle	Ziploc bag	Plastic bag	Containers	Detergent Bottles
Weight in KG	0.037	0.0024	0.0041	0.0131	0.812
non-recyclable	Caps	Utensils	Trash bags	Saran Wrap	Wrappers
Weight in KG	0.0063	0.0031	0.194	0.648	0.0046

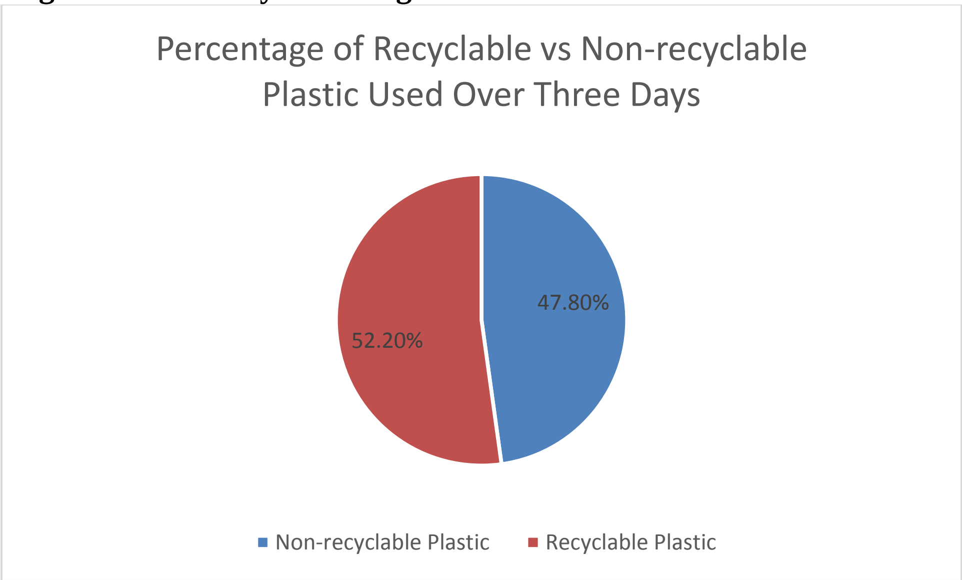
Qualitative

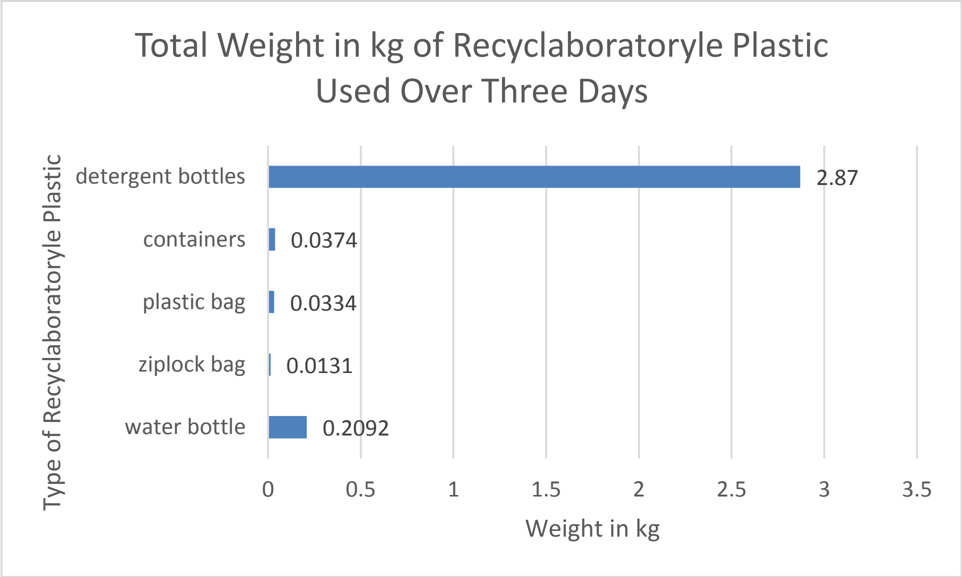
recyclable	Water bottle	Ziploc bag	Plastic bag	Containers	Detergent Bottles
Qualitative Information	Clear with a plastic wrapper around it. Plastic cap that is thrown separately since it is not recyclable.	Clear plastic bag with a green plastic zip	Dark green and light green plastic bag with a Walmart logo	Clear plastic container with red plastic cover	Large red plastic bottle that is wider on the bottom and gets less wide on the top

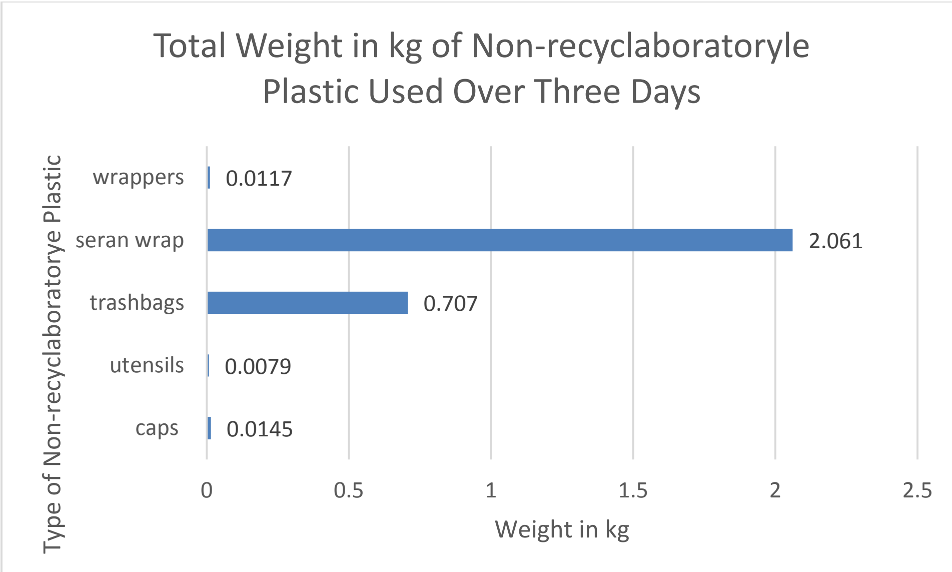
non-recyclable	Caps	Utensils	Trash bags	Saran Wrap	Wrappers
Qualitative Information	Clear plastic bottle cap	White plastic fork, spoon, and knife	Large white plastic bag with a pink seal along the top	Thin, clear plastic wrap that is sticky to touch	Brown snickers/ milky way wrappers with the logos on it

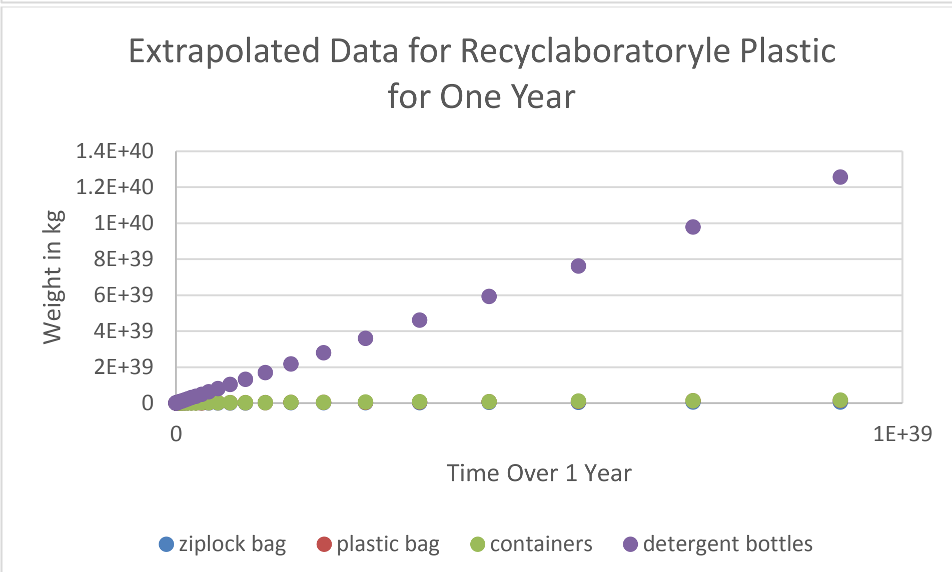
PHOTO
The pictures show the water bottles collected, a diagram of the water bottle, and a picture of recyclable plastic waste saved at the end of a day.

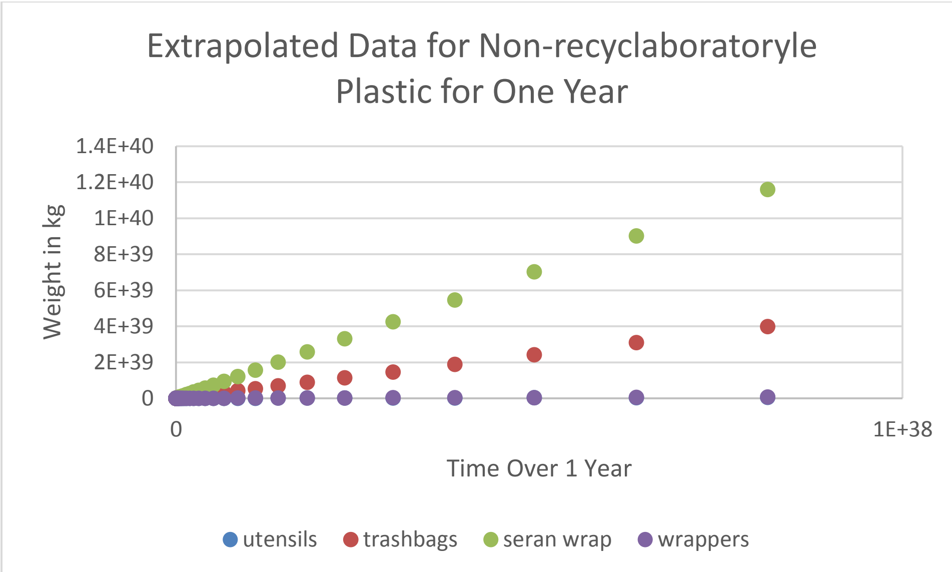
DATA PROCESSING
Creating a percentage of non-recyclable plastic vs recyclable plastic was used as a calculation by adding up all the waste in kg to equal 5.8605 kg and adding up all the non-recyclable plastic to equal 2.8021 kg and dividing 2.8021 by 5.8605. This gives us 47.8 which is the percentage of all the plastic waste that is non-recyclable. This is important because the goal was to determine whether the non-recyclable plastic was above 60 percent of the waste in the household.
ANALYSIS
Degrees uncertainty +/- .02 kg






Total Weight in kg of Non-recyclaboratoryle Plastic Used Over Three Days
Type of Non-recyclaboratorye Plastic
wrappers
0.0117
seran wrap
2.061
trashbags
0.707
utensils
0.0079
caps
0.0145
0
0.5
1
1.5
2
2.5
Weight in kg


Extrapolated Data for Recyclaboratoryle Plastic for One Year
Weight in kg
1.4E+40
1.2E+40
1E+40
8E+39
6E+39
4E+39
2E+39
0
0
1E+39
Time Over 1 Year
ziplock bag
plastic bag
containers
detergent bottles



CONCLUSION

The hypothesis "If more than 60% of the plastic waste in kg is non-recyclable, then it is too much and there must be a change in how much non-recyclable plastic is used" was disproved because in the pie chart, it can be shown that only 47.8% of the plastic used was non-recyclable meaning that the majority of the plastic being used wouldn't be harming the environment as waste. It shows that our households are doing our part in contributing to ecological sustainability and that more people should follow this trend. There were certain types of plastic however that were used much more than others which is an indicator of what we do throughout the day and how we can change our habits to cut down our waste. It leads us in the direction of a clean future and lets us know what we are doing wrong. For instance, saran wrap and detergent bottles were used the most by far out of all the other plastics and by extrapolating the data, we can see how using it at that rate over a year can build up to a lot of waste. Therefore, with this data, we can find alternatives to what we use and cut back on things that are necessary.

EVALUATION

Strengths	How did it assist your laboratory to get good results?
Extrapolation of data	We can see how over time, there is a big impact on the environment because we cannot see how big of an impact a little saran wrap can have on the environment over three days but over a year it is a lot.
Use of percentages when comparing	It helps us visualize how much of our waste is being used efficiently and how we can cut back in certain areas to make sure we protect the environment as much as possible.

Weakness/Limitation	How did it affect your laboratory to get poor results?
Plastics chosen	Some plastics may not be used as much as others and some weigh more than others so it isn't as representative of what type of waste is being thrown away through percentages because each plastic is different.
Household tested	Each household needs different plastics for different habits so my data isn't representative of everyone as an average.

Improvements	How would you change this in the future? Why?
Amount of data	The amount of data used made the extrapolation extremely difficult because there were so many columns to deal with and error was more likely to occur.
Source of Plastic	The source of plastic waste was myself and my partner so our lifestyles are biased to two people and a national average would be more accurate to the average household.

APPLICATION

This experiment is related to the real world because we can see what percent of our plastic is being used once then wasted and how much that contributes to changes in the environment. It keeps us conscious of how much we are wasting and forces us to make an effort to change our habits to be more ecofriendly.

COMMUNICATION

https://www.afpm.org/how-a-refinery-works/

https://www.plasticseurope.org/en/about-plastics/what-are-plastics/how-plastics-are-made

https://www.sea.edu/plastics/exchange/how_does_plastic_affect_the_carbon_cycle

https://www.ehn.org/plastic-environmental-impact-2501923191.html

Student Sample 2

Title of Experiment:

Extrapolation of Daily Plastic Use and its Effect on the environment

RESEARCH QUESTION

Which type of non-reusable plastic will weigh the most over three days and how will this affect the environment?

BACKGROUND INFORMATION

Most plastic waste does not get reused or recycled and experts believe that 50% of plastic is single-use, meaning it is used once before being discarded. Single-use plastic includes plastic water bottles, plastic packaging, plastic grocery bags etc. While getting rid of plastic waste is the primary environmental problem, the production process is a leading cause of carbon emissions contributing to global warming. It takes a lot of energy and resources to make plastic, with more than 90% being produced from fossil fuel resources. Experts believe that if current trends continue, in 30 years' time 20% of global oil consumption and 15% of global carbon emissions will be associated with plastic production. Creating bottled water takes 2000 times the energy than it does to produce tap water.

HYPOTHESIS

The highest weighted type of plastic will be the water bottle, since that is used more daily and in larger numbers.

VARIABLES

Independent Variable (manipulated/changing factor)	How will it be manipulated	How will the IV be controlled
Number of Plastic	Each day, the consumer will use different amounts of plastic and different types of plastic	The number of plastics used will only be non-reusable and once used, will be put into a bin to keep track of what was used

Dependent Variable (What will be measured)	How will it be measured (method)	How will it be measured in a consistent, controlled manner
Weight of Plastic	Using a digital scale, the plastic will be put on the scale and the weight will be recorded	Each item will be measured on the same scale, and with the same unit of measurement, which is kilograms

Controlled Variable (external variables that need to be kept constant in each trial)	How will it be controlled	How would this variable affect the data if NOT controlled
Scale as form of measurement	Each item weighed will be weighed with the same scale and measurements	If different measurements were used it could lead to unreliable data

MATERIALS/APPARATUS AND DIAGRAM

- Digital scale
- Ziploc bag
- Water bottle
- Vinegar Bottle
- Orange Juice Bottle
- Plastic Container
- Bin

SAFETY, ETHICAL AND ENVIRONMENTAL ISSUES

All the plastic that will be collected will have any hazardous material either in them or on them. Gloves will also be worn to handle any pieces of plastic that have sharp edges or any other features that could cause cuts if mishandled.

METHOD

1. Collect item that contains plastic that has been used
2. Place item into a bin
3. Repeat steps 1 and 2 with any other items with plastic that are used
4. Once collected, separate items into categories based on type of item (i.e. bottles, bags, straws, etc.)
5. Place each category of plastic onto a digital scale, and record the weight
6. Repeat for two more days
7. Use data to complete data table and extrapolate the data

DATA COLLECTION

Day 1 Data Table

Category	Weight (kg)
Water Bottles	0.078
Ziploc Bags	0.011

Day 2 Data Table

Category	Weight (kg)
Water Bottles	0.078
Ziploc Bags	0.011
Plastic Container	0.052
Orange Juice Bottle	0.081

Day 3 Data Table

Category	Weight (kg)
Water Bottles	0.078
Ziploc Bags	0.011
Plastic Container	0.047
Vinegar Bottle	0.089

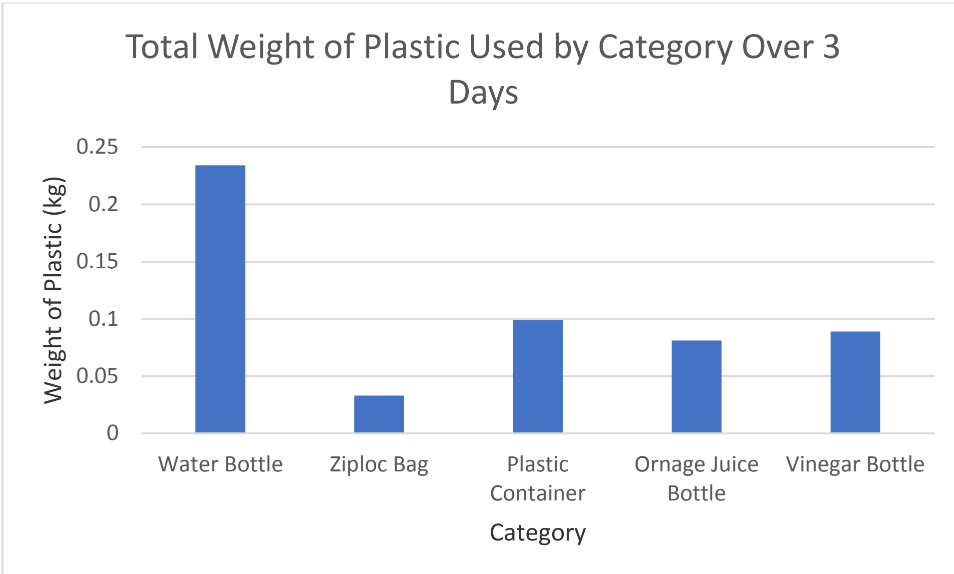
PHOTOS

Day 1 Plastic Collection

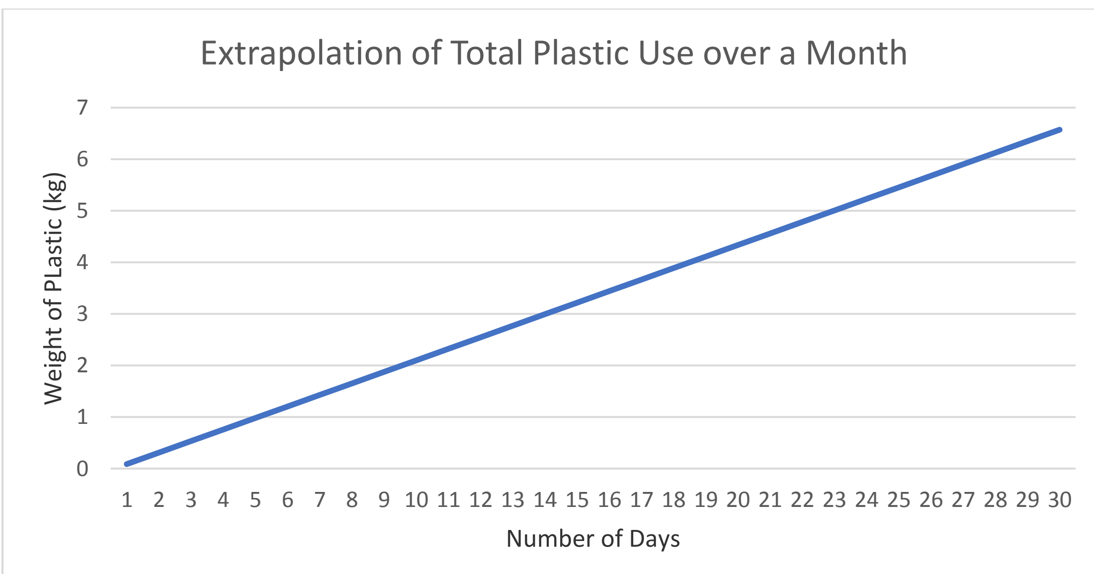
Day 2 Plastic Collection

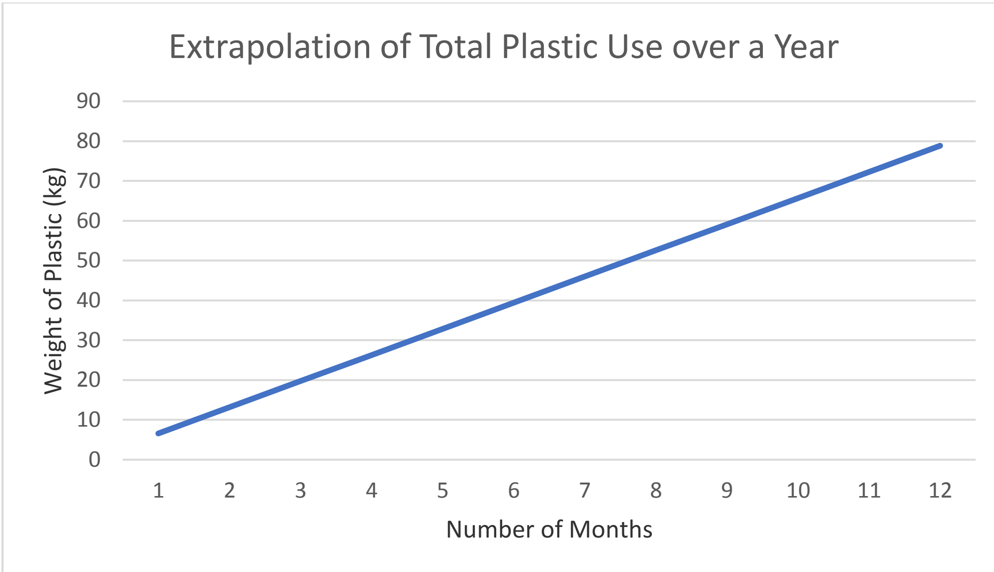
Day 3 Plastic Collection

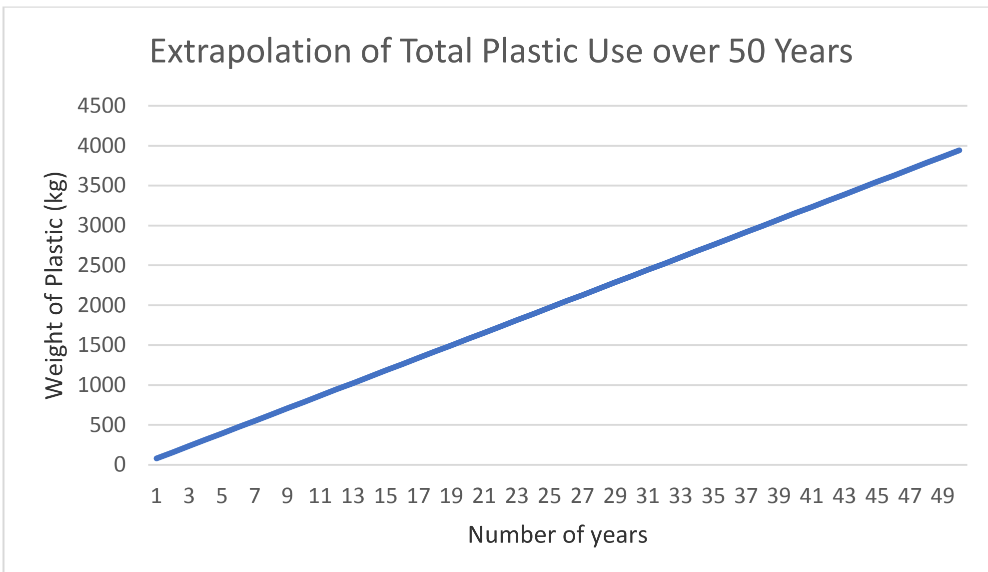
DATA PROCESSING



ANALYSIS







To extrapolate the total weight of plastic used for a month, the total amount used over the first three days were used, and then using excel, estimated how much total plastic would be used over 30 days. Then, to estimate how much would be used in a year, the total from the 30 days was used, and that was used as the first data point in excel and was then estimated over 12 months. Finally, to estimate the use over 50 years, the total from the 12 months was the first data point and excel estimated the next 50 years.

CONCLUSION

In conclusion, the expected weight of plastic used after extrapolation was much higher than expected. According to the data, if the amount of plastic that was used over the course of three days continued for up to 50 years, it amounts to nearly 4,000 kilograms worth of plastic. This was very surprising because the amount of plastic used in three days wasn't even 1 kilogram, but over the course of 50 years, that still adds up to be a lot. However, regarding just the data over the first three days, the water bottles were expected to be the highest in weight because these are used in the most daily.

EVALUATION

Strengths	How did it assist your laboratory to get good results?
Data Collection	The data was collected in a consistent manner, so it was easier to organize the plastics that were used. Also, since the method of collection was to put it in a bin, it eliminated the possibility of losing some of the data
Number of Days	Since the data was collected over a three-day span, it helped give the experiment more accurate data than if the amount of plastic recorded was only from 1 day, and then extrapolated.

Weakness/Limitation	How did it affect your laboratory to get poor results?
Scale	A better more precise scale could have been used, since the empty water bottles and Ziploc bags were so light. The measurements recorded with this scale could be less reliable than if a better, and more accurate one was used.
Lack of different categories	For this experiment, only non-reusable plastics were gathered. This doesn't give an accurate representation of how much plastic is really used, since other re-usable types of plastic are used daily.

Improvements	**How would you change this in the future? Why?**

Using a better scale	In the future, I would use a scale that is more fit for weighing lighter objects than the one used in this experiment. This scale measured the weight of plastic in kilograms, and a scale that measured in smaller increments could help improve the results.
Including re-usable plastics	In the future, I would I also collect the re-usable plastics that were used. This would help give a more accurate understanding of how much total plastic is used, instead of only measuring the non-reusable type.

APPLICATION

This is experiment is very important and has a lot of real-world value. This experiment outlines how much plastic just one household uses and disposes of in up to 50 years, and the numbers are staggering. This experiment can help people think about just how much plastic is being used daily, and how much and how fast that amount adds up. If too much plastic is used, then it can disrupt different environmental systems, such as the carbon cycle and the water cycle.

COMMUNICATION

"Reducing Plastic Waste - Why Is It Important?" Environmental Monitoring Solutions, www.em-solutions.co.uk/blog/reducing-plastic-waste-why-is-it-important/.

APPENDIX G

CONSENT FORMS

UNIVERSITY OF SOUTH CAROLINA

CONSENT TO BE A RESEARCH SUBJECT

INTEGRATED TECHNIQUES TO INCREASE SYSTEMS THINKING FOR SUSTAINABILITY EDUCATION OF HIGH SCHOOL SCIENCE STUDENTS USING EDUCATIONAL DESIGN RESEARCH

PURPOSE AND BACKGROUND:
You are being asked to volunteer for a research study conducted by N. Kathryn Weatherhead. I am a doctoral candidate in the Department of Teaching and Learning, at the University of South Carolina. The University of South Carolina, Department of Teaching and Learning is sponsoring this research study. You are asked to participate fully as a co-researcher in a Design Research project to study the effects of different integrated learning activities on students' understanding of environmental sustainability. This form explains what you will be asked to do, if you decide to participate in this study. Please read it carefully and feel free to ask questions before you make a decision about participating.

PROCEDURES:
If you agree to be in this study, the following will happen:

1. You will be asked to identify one class that will be used to implement the activities selected for the project. These lessons will be observed and video recorded by the principal investigator.
2. You will be asked to collaborate with the researcher as a co-researcher on development and sequence of activities to be implemented, as well as instructional materials for teaching content and assessment.
3. You will be asked to complete a daily observation checklist for the purposes of reflecting on the effectiveness of the classroom activities on the specific learning goals for the project.

DURATION:
Participation in the study will take place over a two week period. Each study visit will last the duration of the science lesson being observed.

RISKS/DISCOMFORTS:

Loss of Confidentiality:

There is the risk of a breach of confidentiality, despite the steps that will be taken to protect your identity. Specific safeguards to protect confidentiality are described in a separate section of this document.

BENEFITS:

This research may help researchers understand how students learn about environmental systems and sustainability and assist in preparing appropriate teaching methods to enhance student learning. This research may also contribute to understanding of how students may alter behavior in light of their understanding of sustainability.

COSTS:

There will be no costs to you for participating in this study.

PAYMENT TO PARTICIPANTS:

You will not be paid for participating in this study.

CONFIDENTIALITY OF RECORDS:

Unless required by law, information that is obtained in connection with this research study will remain confidential. Any information disclosed would be with your express written permission. Study information will be securely stored in locked files and on password-protected computers. Results of this research study may be published or presented at seminars; however, the report(s) or presentation(s) will not include your name or other identifying information about you. Where necessary, pseudonyms will be used in place of actual names.

VOLUNTARY PARTICIPATION:

Participation in this research study is voluntary. You are free not to participate, or to stop participating at any time, for any reason without negative consequences. In the event that you do withdraw from this study, the information you have already provided will be kept in a confidential manner. If you wish to withdraw from the study, please call or email the principal investigator listed on this form.

I have been given a chance to ask questions about this research study. These questions have been answered to my satisfaction. If I have any more questions about my participation in this study, or a study related injury, I am to contact. N. Kathryn Weatherhead at 843-290-7450 or nkweatherhead@yahoo.com.

Questions about your rights as a research subject are to be directed to, Lisa Johnson, Assistant Director, Office of Research Compliance, University of South Carolina, 1600 Hampton Street, Suite 414D, Columbia, SC 29208, phone: (803) 777-7095 or email: LisaJ@mailbox.sc.edu.

I agree to participate in this study. I have been given a copy of this form for my own records.

If you wish to participate, you should sign below.

Signature of Subject / Participant   Date

Signature of Qualified Person Obtaining Consent   Date

May 9, 2019

Dear students,

I am a researcher from the University of South Carolina, pursuing a PhD. I was a secondary science teacher for thirty eight years at Hilton Head Island High School. I am currently working on a study about environmental education and I would like your help with my research project: *Integrated Techniques to Increase Systems Thinking for Sustainability Education of High School Science Students*. This is a follow up to a pilot study I conducted at HHIHS in 2017. I am interested in learning more about how using experimental design or inquiry, graphing techniques, and other strategies can assist your learning about environmental sustainability. My goal is to also see if these methods can help you develop a systems thinking approach to global environmental issues.

Your teacher will be doing instruction as usual and I will be an observer in the classroom for two weeks. Each class period will be videotaped but no images, or personal information will be shared with anyone at any time, and I will not be provided with any specifics about you. You will be asked to respond to several anonymous surveys, and may be asked to participate in small focus group interviews at the end of the project. Your teacher will assist me in evaluating some of your work that you produce for her, but she will retain all original copies to be graded for her class as normally expected.

Please ask any questions you would like to about the study. You may reach me at nkweatherhead@yahoo.com, or by phone at 843-290-7450. I am working through the University of South Carolina and you may contact the Office of Research Compliance (803) 777-7095 if you have other questions.

Please sign this letter as informed consent and ask your parent/guardian to sign as well. Signing your name below means you have read the information (or it has been read to you), and that your questions have been answered in a way that you can understand, and you have decided to be in the study. You can still stop being in the study any time.

Thank you for allowing me to visit your classroom.

Print Name ____ Age ________

Signature of Student____ Date________

Signature of
Parent____Date________

N. Kathryn Weatherhead
University of South Carolina