Science and Mathematics Education Centre

Design and Evaluation of an Inquiry-Oriented after School Genetics Program Using a Multidimensional Conceptual Change Perspective

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Declaration

To the best of my knowledge and belief this thesis contains no materials previously published by any other person except where due acknowledgement has been made.

The thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Human Ethics The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Number #SMEC-02-19

Signature: Martin David Coon

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Abstract

Background: Science inquiry has been promoted as a solution to low student performance in science education for over 50 years. However, reform efforts embracing inquiry have failed to bring about needed improvements. Educational researchers suggest two reasons for this failure: 1) Teachers possess an inadequate vision of science teaching and learning, and 2) There is a lack of effective pedagogical support to implement the enriched vision of science promoted by researchers. This enriched vision advances an expansion of learning goals beyond conceptual, to include epistemic, social, and affective dimensions. Learning within the enriched vision is viewed as a process of conceptual change.

Purpose: The thesis addressed this problem through two related studies, each containing two phases. The first study examined the problem through both practice and theory-based perspectives (Phase 1), and then developed an educational intervention (e.g. pedagogical model) aimed at solving the problem (Phase 2). The second study evaluated the effectiveness of the intervention in promoting attainment of teacher and student learning goals (Phase 3), and initiated plans for using the intervention in broader contexts (Phase 4).

Sample: The intervention was developed and tested within an after-school program called the *Genetic Diversity and Human Health Cohort Program* for middle school students (grades 6-7). Biodiversity and human health connections at the level of genes/DNA were investigated. Students attended the program after school two times per week (4-6pm) over the course of a semester for a total of 56 hours. The curriculum the students experienced was developed as part of the thesis, and was based on a research-based learning progression on evolution developed by Catley, Lehrer, and Reiser, 2005. There were 18 students (11 female; 7 male) and one teacher in the study. Data were collected at three separate points: 1) Pre-measures (pre-test; surveys) were administered before implementation, 2) Classroom observation data were collected during implementation, and 3) Post-measures (post-test; surveys) were again administered at the end of implementation. Final data were collected one month after the program ended using a semi-structured interview protocol with six students and their parents.

Design and Methods: A four-phase educational design research approach supported embedded mixed method over the course of the two studies. Supporting the thesis theoretically was a multidimensional conceptual change perspective.

Results of Study #1 - Intervention Design: Based on the results of problem exploration that occurred during Phase 1, a detailed intervention was iteratively developed during Phase 2. The data collected during Study #1 were used to inform the design itself (e.g. soundness, preferability, and appeal). The intervention was designed to help the teacher and students implement the enriched vision of science and promote conceptual change.

Results of Study #2-Intervention, Implementation and Evaluation: During Phase 3 classroom observations determined that the teachers and students used the intervention with fidelity. Pre and post-test comparisons showed significant increases in student content knowledge ($p<0.05$ in all cases) that arose from the intervention. Science performance (e.g. epistemic practice), which was evaluated within student journals, showed increases for each of five content knowledge areas ($p<0.05$ in all cases) as a result of the intervention.

Questionnaires designed to measure student attitudes and interest in science determined that student interest remained high throughout the program, in contrast to well-documented reports of normal student decline of interest within this age group. Through interviews with six students and parents it was determined that the implementation was personally meaningful to the students and that their learning transferred to outside settings. The ability of students to transfer knowledge beyond the learning context is an important finding for conceptual change research. During Phase 4 these results were used to guide research activities aimed at exploring broad use of the intervention.

Conclusions: Study #1 successfully developed an educational intervention aimed at promoting conceptual change in support of an enhanced vision of inquiry-based science. Study #2 demonstrated that the intervention promoted the attainment of learning outcomes by supporting both the teaching of, and learning through, inquiry-based science. It was determined that the intervention was likely responsible for significant increases in student content and performance (e.g. science as epistemic practice). It was also determined that students entered the study with a high level of interest and positive attitudes toward science, which did not decrease over the course of implementation. Based on the outcome of the evaluation the intervention was refined and plans for broad dissemination of the intervention explored. A multidimensional conceptual change perspective proved to be an effective referent in support of the design and evaluation of the intervention.

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Chapter 1 Introduction

1.0 Rationale for the Research Problem to be Investigated

Science inquiry has been promoted as a solution to low student performance in science education for over fifty years (Duschl & Grandy, 2008). Educational researchers have suggested that one reason the inquiry-based reform initiatives of the 1990's, for example AAAS Project 2061 (Rutherford & Ahlgren, 1990) and the National Science Education Standards Project (NRC, 1996), failed to bring about needed improvement to the teaching and learning of science in the 2000's is that these projects promoted an inadequate vision of exactly what exemplary science learning was, and how science learning should be implemented in classrooms by teachers (NRC, 2007). These two related ideas form the problem being addressed by this doctoral thesis.

Recent research suggests that an enriched vision of inquiry-based science is needed to bring about the solving of this problem (Duschl, 2008). An enriched vision of science education suggests that low student performance in science will improve when instruction equally focuses on, and has goals for, the conceptual, epistemic, and social/affective dimensions of learning (Duit & Treagust, 2012; Duschl, 2008). Embracing this enriched vision, Duschl (2008) strongly argues that teachers need to shift the focus of learning from the delivery of content (e.g. memorizing what is known) to the process of learning science by doing science. Additional research within the social dimension suggests that powerful science learning occurs in authentic contexts or learning communities. (Duschl, 2008, Duschl & Grandy, 2008; NRC, 2007). The Next Generation Science Standards (NGSS Lead States, 2013) also supports the need for an enriched vision of science learning by promoting similar ideas such as students should learn and meaningfully apply science understanding by engaging in the practices of science. Conceptual change theory promotes the important idea that knowledge is personally constructed, and is developed and refined through a process of social negotiation (e.g. sense making) with members of the learning community (Hatano & Inagaki, 2003; Leach & Scott, 2008; Miyake, 2008; Vosniadou, 2007).

1.1 The Research Problem and the Two Studies

However, research also indicates there is a lack of pedagogical tools and effective models of classroom instruction needed to support implementation of this enriched vision of inquiry-based science (NRC, 2007). Hence, the lack of pedagogical tools and effective models of classroom instruction teachers need to support implementation of the enriched vision of scientific inquiry presents a gap in both research and practice. This thesis was designed to address this gap by applying a mixed-method educational design research approach, informed by a multidimensional conceptual change perspective, to complete two related studies aimed at solving this problem.

The first study involved the design of an intervention aimed at helping teachers implement the enriched vision of science teaching and learning in their classrooms. Study #1 is presented in chapters 4 and 5. The second study was undertaken to implement the intervention with teachers and students and evaluate its effectiveness in both supporting the implementation of the enriched vision of scientific inquiry, and the promotion of student learning. Study #2 is presented in chapters 6 and 7.

The study site for this research was a teaching and learning laboratory operated by an education institute. The education institute will be referred to as the *local context* throughout the thesis. In addition to the researcher, one teacher implemented the intervention at the local context within a 56-hour out-of-school time biology program.

1.2 Research Design and Theoretical Perspective Used to Explore the Problem

This thesis used an embedded mixed-method educational research design (Creswell & Plano Clark, 2007), guided by a multidimensional conceptual change perspective, to design and evaluate an intervention to address the research problem. The research methods will be fully described in chapter 3. The enriched vision of science promotes learning as a process of conceptual change with student learning outcomes developed within conceptual, epistemic, and social dimensions of learning. The thesis unfolded through the two related studies described in section 1.1 over the course of four phases. Study #1 spanned the first two research phases and involved the exploration the problem (Phase 1) and the eventual design and refinement of an intervention aimed at providing a solution to the problem (Phase 2). Study #2 was designed to evaluate the intervention within the context of an actual classroom (Phase 3) and to explore how the intervention might be used within broader contexts Phase 4). Figure 1.1 was created to help the reader understand the flow of the research through these two studies and related phases. Figure 1.1 will repeat through the thesis with appropriate phases highlighted for clarity.

Study # 1: Intervention Design		**Study # 2: Intervention Evaluation**	
Phase 1: Problem Exploration	**Phase 2: Intervention Design & Refinement**	**Phase 3: Intervention Evaluation**	**Phase 4: Planning for Use in Broader Context**

Figure 1.1. Two studies and related phases to address the problem

A multidimensional theoretical perspective was chosen to guide the thesis because it aligned with, and clarified, the enriched vision of science education by viewing learning from multiple vantage points (e.g. epistemological, ontological, social/affective, learner characteristics), and acknowledged both individual learner and social/contextual factors as being important to learning (Duit, Treagust, & Widodo, 2013). This viewpoint was critical to facilitate the design of an intervention that aligned with the enriched vision of science education (Duschl, 2008).

1.3 Overview of the Intervention Designed to Solve the Research Problem

The intervention developed was formatively evaluated and refined over the course of three iterative design mini-cycles during the first study. After the first design mini-cycle the intervention was essentially a pedagogical tool intended to support the goal of science as epistemic practice, and even though developed using current research referents, ended up functioning like an expanded version of the P-O-E learning strategy (e.g. activity structure). The P-O-E activity structure was originally developed by White and Gunstone (1992). In its original form, the P-O-E strategy was used by teachers to organize lessons where students were first asked to predict (P) what they thought would be observed. After the observation (O) was completed the teacher or students would explain (E) the observation, thus completing a P-O-E cycle. Sreerekha, Arun, and Sankar (2016) report that the P-O-E strategy was effective is supporting student learning in secondary students. These ideas were elaborated on during thesis phase one, when both a Question (Q) and an Evaluation (E) component were added to P-O-E strategy (e.g. Q-P-O-E-E). A graphic was designed with arrows to show relationships between components. The researcher named the elaborated strategy Q-POE2 (Cue-POE). The Q-POE2 process, as designed, functions as a fluent (e.g. nonlinear) activity structure intended to be used by students to support the design, conducting, and communicating of investigations.

The Q-POE2 Process of Scientific Inquiry (e.g. activity structure) was designed to be nonlinear so that students would be able to enter the structure from various components. For example, students could first complete observations (O) with the goal of generating Questions (Q) to investigate. To support the implementation of Q-POE2, color-coded stickers of each component (Question-Prediction-Observation-Explanation-Evaluation) were developed and put into packets for students to use. To build student expertise in using the Q-POE2 process the teacher was asked to use a teacher journal and document camera with students to guide and model the path of an investigation. For example, the teacher could place a Question sticker into the journal and then write the investigation question down. Students would mirror these activities in their own journals. This process continued as the class placed and responded to appropriate Q-POE2 stickers as the investigation unfolded. In this way teachers and students were able to co-construct investigations together.

The teacher was encouraged to think about how much to have students write in their journals, versus how much could be modeled whole group using a teacher journal. When students developed expertise in both the use of the Q-POE2 stickers and the phenomena under investigation, they were encouraged to use the journal/ sticker process independently. Used in this way, Q-POE2 stickers provided both structure and the ability of students to follow unique, often quirky, investigation pathways. This is further elaborated in chapter 4. Figure 1.2 presents Q-POE2 portion of the intervention as it looked after the first design mini-cycle.

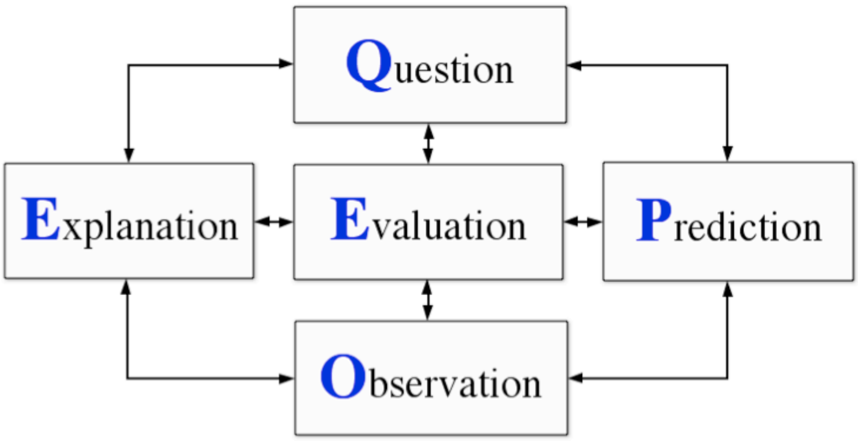


Figure 1.2. Q-POE2 Portion of the Intervention After First Design Mini-Cycle

Through continued research, testing, and the application of conceptual change theory (which is discussed in detail in chapter 3), the intervention was refined during the second design mini-cycle to include four additional supporting ideas: knowledge probe, investigation plan, data analysis, and application. A knowledge probe section was added to provide a conceptual place for teachers to instructionally activate, represent, and have students use their personal knowledge during the learning process. This is a critical first step in instruction aimed at promoting conceptual change and the idea that knowledge is constructed and refined. The Knowledge Probe component was also viewed as the place for the teachers to provide, or the students to look up, important secondary scientific knowledge and or theories that the students would interact with, and integrate, during learning. An investigation plan section was added to provide a place for the investigation steps and procedures to be conceptualized and represented. Data analysis, being the critical and creative thinking that occurs to transform observations (data) into evidence, was added to the model to support the development of explanations (knowledge claims supported with evidence and reasoning). Finally, an application section was added to the model to instructionally support the meaningful use of newly constructed knowledge. Figure 1.3 presents the intervention after the second design mini-cycle.

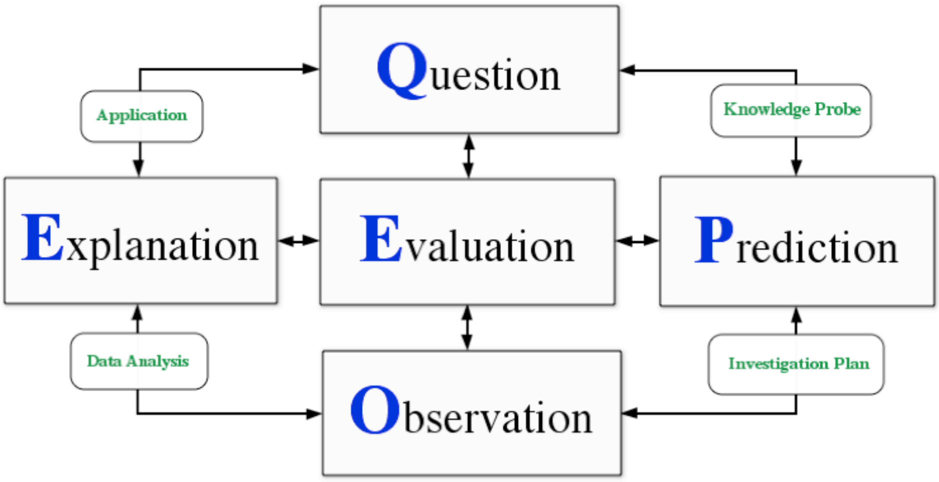


Figure 1.3. Q-POE2 Portion of Intervention After Second Design Mini-Cycle

After further formative testing, research, and the application of conceptual change theory, the intervention was refined during a third design mini-cycle. To fully support the implementation of the enriched vision of science inquiry, additional components were deemed necessary by the researcher to make the model function as intended.

The researcher did not believe that the Q-POE2 process would be sufficient to bring about the needed changes to science teaching and learning that would solve the problem of low student performance in science. Using a local instructional theory (see section 5.5.3) as a guide, the researcher decided to add socio-cultural components to the intervention. To accomplish this, the idea of scientific habits of mind was added to the intervention. The idea of including habits of mind in science education originally stemmed from the important research report Science for All Americans: Project 2061 (AAAS, 1990), and supported by the Next Generation Science Standards (Achieve, 2013). As described, scientific habits of mind emerge from, and are valued by, the scientific enterprise because of their critical role in facilitating and enhancing scientific investigations. Based on previous practice-based implementation projects, the researcher predicted that when scientific habits of mind were intentionally taught and nurtured within the classroom-learning environment, culture would be produced. This culture would help create the kind of learning environment called for within the enriched vision for science education. For example, a classroom where habits of mind, such as curiosity, are both valued and nurtured would be a very different place than a classroom that did not. Six habits of mind were eventually selected for the intervention based on the recommendations within Science for All Americans (AAAS, 1990).

It was clear to the researcher that teachers would also need support in designing the kind of social environment called for by the enriched vision of science education (Duschl, 2008). The social environment envisioned by the researcher and supported within the intervention during the third design mini-cycle was intended to promote both a socially and language rich environment. As embodied in the intervention, learning environments can be socially rich when learning occurs within varied and purposeful collaborative structures, where students interact meaningfully with the teacher, work independently by themselves, or work together with their classmates in small groups. Within these varied collaborative structures, members of the community interact cooperatively to negotiate meaning. This kind of classroom learning environment supported by the intervention would function as a discourse community (Yerrick & Roth, 2004). Language becomes a key promoter of learning and conceptual change within this kind of socially and language rich learning environment. After the three design-mini cycles, the detailed intervention was finished and ready to be evaluated as shown in Figure 1.4.

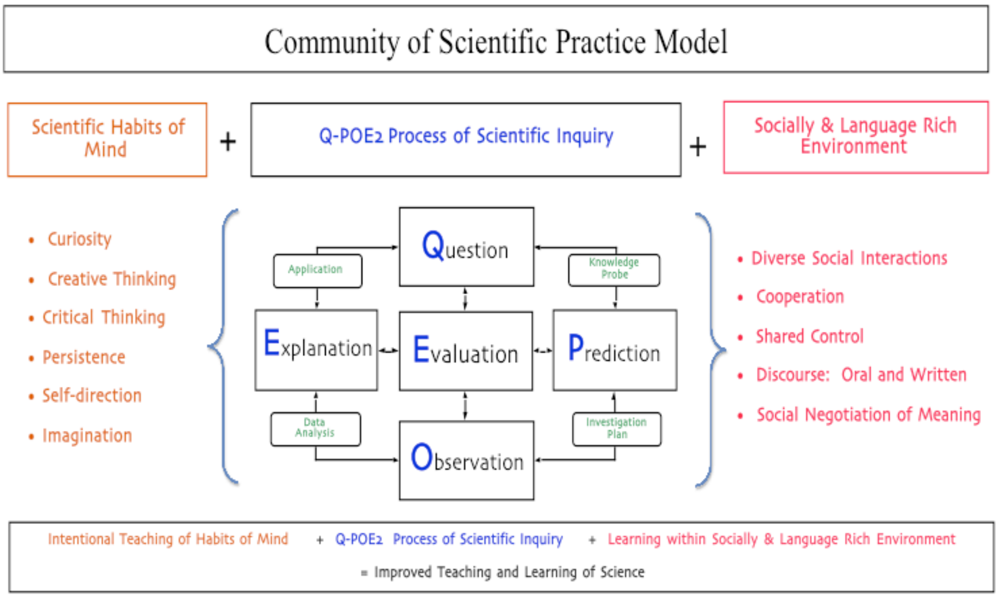


Figure 1.4. Detailed Intervention Design

1.4 Research Questions

Research questions guided the development of the intervention that was described in the last section. Early during the development of the intervention, in Research Phase 1, Research Problem and Question Exploration, the researcher asked two initial questions:

1. How does the identified problem manifest itself in practice?
2. How can the problem be interpreted and clarified with existing literature and theory?

After exploring these two initial organizing questions, the researcher developed research questions for Study #1 (the design phases) and Study #2 (the implementation and evaluation phases). Two kinds of research questions were developed – those that explored student learning and those that explored the kind of learning environment that would be needed to support the student learning envisioned. The research questions for Study #1 are presented in Table 1.1.

Table 1.1

Research Phases and Associated Research Questions for Study #1

Research Phases	Student Learning (SL) Focus Research Questions (RQ)	Student Learning (SL) Focus Research Questions (RQ)
Phase 1: Research Problem and Question Exploration	What did inquiry-based student learning look like in the study teacher's classroom before intervention implementation? (SLRQ1)	How did the teacher design the classroom learning environment before intervention implementation? (LERQ1)
Phase 2: Intervention Design and Refinement	What is an optimal design for an intervention that supports student learning, especially in light of: a. What is known about factors that promote conceptual change (SLRQ2a) b. The enriched vision of science learning? (SLRQ2b)	a. What kind of learning environment is needed to support the student learning focus? (LERQ2a) b. How can the intervention be designed to support the envisioned learning environment? (LERQ2b)

After the detailed intervention was designed, Study #2 was initiated to facilitate its evaluation (Research Phase 3), and to begin to explore possible broad impact applications of the intervention (Research Phase 4). The research questions for Study #2 are presented in Table 1.2.

Table 1.2

Research Phases and Associated Research Questions for Study #2

Research Phases	Student Learning (SL) Focus Research Questions (RQ)	Student Learning (SL) Focus Research Questions (RQ)
Phase 3: Intervention Implementation and Local Impact Evaluation	What does inquiry-learning look like in the teacher's classroom because of intervention implementation? (SLRQ3a) How did the intervention impact inquiry-learning in the teacher's classroom? (SLRQ3b)	How did the teacher design the classroom learning environment before intervention implementation? (LERQ1)
Phase 4: Broad Impact Planning And Implementation	How has the intervention impacted student learning in other contexts? (SLRQ4)	How can the intervention that was implemented in other contexts be described? (LERQ4a) How did the intervention support how the teacher designed the learning environment in other contexts? (LERQ4b)

1.5 Student and Teacher Learning Outcomes

Learning outcomes were developed for both students and the teacher based on ideas developed from conceptual change theory and science education practice literature. From the student perspective the intervention was designed to promote learning within epistemological, conceptual, social/affective dimensions as discussed in section 1.0. From the epistemological dimension a key goal was developed to have students learn science concepts through a process of scientific inquiry experienced as an epistemic practice. Epistemic practice was viewed within a framework of students designing, carrying-out, and communicating scientific investigations. Conceptual learning outcomes for students addressed two life science concepts: 1) Human health depends on genetic diversity within species and habitats, and 2) DNA causes biodiversity.

From the teacher perspective, the intervention was designed to help the teacher design the supportive social/contextual learning environment needed to implement the enhanced vision of science education. Teacher learning outcomes developed focused on teacher understanding of how to use the intervention with fidelity with the students. The teacher outcomes also addressed the understanding of how to develop appropriate classroom norms/rituals to promote the social epistemology of science. To do this, teachers needed to know how to assist learners with both the construction and evaluation of knowledge claims, and how student attitudes and feelings affected science learning. The specific learning outcomes are listed in Table 1.3.

Table 1.3

Teacher and Student Learning Outcomes

Student Learning Outcome	Teacher Learning Outcomes
The student will know or be able to: 1. Develop, and/or maintain positive attitudes and feelings toward science. 2. Design, carryout, and communicate the results of science investigations. 3. Evaluate and confront the epistemic status of personal knowledge claims. 4. Explain how health depends on genetic diversity found in species and habitats. 5. Explain why certain organisms are used as models to learn about and improve human health. 6. Describe how plant and animal cells are alike and different. 7. Explain how DNA causes biodiversity.	The teacher will know and be able to: 1. Use the intervention to teach students how to design, carryout, and communicate the results of science investigations. 2. Use the intervention to guide the design of a socially and language rich learning environment. 3. Use the intervention to guide the design of a learning environment that nurtures the habits of mind of their students.

1.6 Research Context

The thesis unfolded within an educational design research laboratory (e.g. Innovation Laboratory) operated by an education institute. This program was called the Genetic Diversity and Human Health Cohort Program, an after-school program for middle level students.

1.7 Importance of the Study

There are three intertwined areas of educational significance for this study: research, teaching, and learning. By using educational design research, this study had a pragmatic goal of designing and evaluating the effectiveness of an intervention designed to improve the teaching and learning of science. The research had an explicit aim to actually accomplish an end. The intervention was refined based upon the results of the thesis. Finally, broad impact through diffusion, adoption, and/or adaptation planning and implementation was initiated.

The research had a personal significance to me, the researcher. Through the exploration of the interplay between design, research, and context I constructed, refined, and extended my personal and professional knowledge about inquiry-based teaching and learning, conceptual change, conceptual change research, and educational design research. In addition, the knowledge constructed as a result of this thesis has an additional goal of improving and guiding inquiry-based teaching and learning in other contexts.

1.8 Limitations

This thesis has limitations that are inherent in mixed method educational design research. One limitation is that the intervention designer is also the person who evaluated the design, which is often the case with this type of research (van den Akker, Gravemeijer, McKenney, & Nieveen, 2006). This situation creates the potential for conflicts of interest that need to be addressed in the research design. Another limitation is the complexity of students' learning processes, coupled with the additional complexity of the designed learning environment, makes it very difficult to account for everything that occurs during the course of a study (Cobb, Confrey, diSessa, Lehrer, & Schauble, et. al., 2003). A third potential limitation within educational design research is the use of both qualitative and quantitative data in the same study (Tashakkori & Teddlie, 2003). The basic idea of mixed methods research is that by mixing both kinds of data sets the researcher is provided with a greater level of understanding than either set analyzed alone. However, for this not to be a limitation the researcher must specify exactly how the data will be mixed as part of the research design (Creswell & Plano, 2007). Issues of research limitations are addressed in Chapters 3 and 8.

Chapter 2 Literature Review

2.0 Chapter Overview

This literature review, completed as the third step of the 16-step research model used in this thesis, contains nine sections. Section 2.1 introduces the reader to educational design research, which emerged as a research method motivated by the frustration that traditional educational research was not designed to impact actual classrooms. Educational design research seeks to solve educational problems (called problems of practice) in the context where they are found through the design, implementation, and refinement of practical interventions. At the same time educational design research seeks to contribute to the knowledge base through the development of design principles and/or instructional design theories that guide the development of the intervention.

Section 2.2 explores the failure of the recent science education reform initiatives to bring about meaningful change in the teaching and learning of science. This section concludes with recommendations for both practice and research, which in summary presents the research problem that this thesis addresses: *There is a lack of pedagogical tools and effective models of classroom instruction teachers need to support implementation of an enriched vision of science learning called for by educational researchers.* This enriched vision of science promotes inclusion of student learning goals within conceptual, epistemic, social, and affective dimensions.

Section 2.3 explores how constructivist epistemology supports the implementation of the enriched vision of science education by moving teachers away from "transmission" views of learning to a more student-centered view of learning where individual knowledge construction is mediated by social factors within the learning environment. Section 2.4 links the ideas of a constructivist epistemology and conceptual change theory. Conceptual change is generally described as the integration and reorganization of knowledge. Conceptual change theory seeks to understand the factors involved with the integration and reorganization of knowledge, and how it can be promoted. Section 2.5 discusses in more detail three conceptual change perspectives that seek to explain cognitive factors of individual conceptual change: theory change, framework theory, and ontological shift. The perspective of "*ontological shift*"*,*" will be explored in greatest detail.

Section 2.6 provides an overview of the classical view of conceptual change. Criticisms of this perspective taking an overly cognitive stance are considered. Section 2.7 explores the need to embrace a balanced view of conceptual change, where both individual/personal factors and socio-cultural processes operating in the learning environment are equally valued and promoted through the design of the learning environment. Section 2.8 identifies additional conceptual change perspectives that need to be considered when designing learning environments that promote conceptual change: breadth of coverage of the curriculum, order of acquisition of concepts involved, taking into consideration students' prior knowledge and experience, facilitation of student metacognitive and metaconceptual awareness, and learner characteristics influencing conceptual change. Section 2.9, which concludes the chapter, considers how a multidimensional framework of conceptual change, originally described by Venville & Treagust (1998), was updated based on recent research. This model was used to analyze and interpret the learning that occurred as a result of the intervention.

2.1 Introduction to Educational Design Research

Educational design research was used in this thesis to develop an intervention aimed at solving the research problem. What is educational design research? Educational design research developed as a response to the failure of traditional education research, which was not designed to intentionally impact actual classrooms (Juuti & Lavonen, 2006). Educational design research has two main goals: 1) Solving educational problems in the real-world contexts where they manifest, and 2) Contributing to the academic knowledge base design principles and/or instructional design theories (Anderson & Shattuck, 2012; Collins, Joshep, & Bielaczyc, 2004). Educational design research intentionally links the research activities to a real-world context for implementation and refinement (Edelson, 2002; McKenney & Reeves, 2012). Shavelson, Phillips, Towne, and Feuer (2003) describe design-based research (DBR) as follows:

> Such research, based strongly on prior research and theory, and carried out in educational settings, seeks to trace the evolution of learning in complex, messy classrooms and schools, and to test and build theories of teaching and learning, and produce instructional tools that survive the challenges of everyday practice. (p. 25)

This description suggests three very important, deeply connected goals for educational design research activities—research, design, and practice. In a process of educational design research, research and prior research are used to create and analyze an intervention, which is improved through subsequent iterations of implementation and analysis. In some projects educational design research is carried out in teams that might include researchers, designers and the teachers responsible for implementation (Brown & Edelson, 2003; Cobb, 2000), each of whom take responsibility for their particular role. Joseph (2004) describes how a single researcher can take on all three roles, and suggests, that such a design provides a unique context for a research to investigate how design, research, and practice questions can be powerfully connected to each other. In the research described in this thesis the researcher was also the intervention designer. The research team also included one teacher who was responsible for both implementation and providing feedback to the researcher.

Educational design research begins with a meaningful problem in an authentic context (Edelson, 2002) and proceeds to both a literature review, and an evaluation of how the problem is manifesting in practice (Bannon-Ritland, 2003; Joseph, 2004). Through the research process an intervention is designed, implemented, and revised within a real-world context (Bannon-Ritland, 2003). The pragmatic goal of improvement of the context of classroom practices is a central theme (Juuti & Lavonen, 2006). The impact of the intervention is evaluated (Collins, Joshep, & Bielaczyc, 2004), and through an iterative process, is refined (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; Collins et al., 2004). The whole research process is guided by theory (Bannon-Ritland, 2003). Educational design research is complementary to conceptual change research approaches because it is also informed by an interdisciplinary set of referents. Similarly, design research often utilizes multiple theoretical perspectives (Juuti & Lavonen, 2006).

Design-based research (Anderson & Shattuck, 2012) is labeled in many different ways including "development research" (van den Akker, 1999), "design research" (Reeves, Herrington, & Oliver, 2005), "developmental research" (McKenney & van den Akker, 2005), "educational design research" (van den Akker, Gravemeijer, McKenney & Nieveen, 2008), "design experiments" (Brown, 1992; Collins, 1992), and "formative research" (Newman, 1990). Educational design research, as described by these researchers, is similar to action research, but differs in a significant way. Educational design research generates and uses theory to solve practical problems. This is not the case in action research, which seeks to solve practical problems, but has no explicit connection to theory (Reeves, Herrington, & Oliver, 2005).

Consequently, educational design research yields both practical and theoretical results (McKenney & Reeves, 2012). Theories develop over time through a process of verification, falsification, or refinement, and have the power to describe, predict and explain real world phenomena. Theories also can be used for prescriptive, cause and effect, purposes that allow researchers to recommend activities that will yield desirable effects. Educational design research often uses theory in such a prescriptive way, to understand and prescribe how interventions work in the classroom environment (McKenney & Reeves, 2012). "Intervention theory" was first introduced by Plomp (2009), and "design theory" was coined by Reigeluth and Frick (1999), to describe the prescriptive power of theory use in educational design research. However, "design principles" is the more common term used to describe how theory-based understanding guides, informs and is refined by educational design research (Kim & Hannafin, 2008; Mishra & Koehler, 2006; Quintana et al, 2004; van den Akker, 1999).

Theories used in educational design research can be categorized by levels, and are described as local theory, middle range theory, and high-level theory. Theories that are developed, used, and refined within the context of small educational design studies are often called local instructional theories. Cobb, Confrey, diSessa, Lehrer, and Schauble (2003) called these local theories "relatively humble", and stressed that these types of theories have the power to describe, predict, explain, and prescribe. Middle-range theory develops as interventions mature, and is used by researchers to connect local theory with high-level theory. High-level theories develop when intervention implementation guided by a certain theory is studied across several contexts in several different educational design research projects (McKinney & Reeves, 2012). High-level theories are rare in educational design research (Barab, Dodge, Carteaux, & Tuzun, 2005). This thesis, being a small educational design project, developed and refined a local instructional theory aimed at solving a problem of practice (e.g. the research problem) within a specific classroom context. This problem of practice will be explored in the next section.

2.2 Inquiry-based Teaching, Learning, and Science Education Reform

"Inquiry" as a term has endured as a central focus within the United States science education reform movement (Abd-El-Khalick & Akerson, 2004). The theme of exemplary science education as inquiry was central in *Project 2061,* the long-term initiative of the American Association for the Advancement of Science (AAAS). AAAS produced two historically important research summary and recommendation documents that continue to inform current science education, *Project 2061: Science for All Americans* (1989), and a companion report *Benchmarks for Science Literacy* (1993). *Science for All Americans* highlighted the importance of inquiry-oriented teaching and learning and presented a view of teaching science that is consistent with the nature of scientific inquiry. It offered a particular focus on what it means to be literate in science. Several key recommendations emerged from these reports: 1) student inquiries should be organized around questions about nature, 2) students should be organized in teams, 3) the inquiries should focus on the generation and use of evidence which support student explanations, 4) there should be a focus on developing student oral and written language, and 5) do not separate knowing from the act of finding out and deemphasize the memorization of technical vocabulary.

Another important theme articulated in *Project 2061: Science for All Americans* was the importance of science teaching that embraces science as a social activity that is promoted with human values including scientific values or habits of mind. Habits of mind that emerge from and are considered important by the scientific community include welcoming curiosity, rewarding creativity, being open to new ideas, and valuing skepticism. An important idea from this report is that student inquiries are enhanced when they occur within a classroom culture that promotes the habits of mind that are valued by the scientific community. *Benchmarks for Science Literacy* (1993*)* articulated what students should know and be able to do, and how progress toward this knowledge progresses across a students' K-12 experiences.

The third important historical reform-minded document, published by the National Research Council, is *The National Science Education Standards* (NRC, 1996), which also recommended teaching science as inquiry. This document described what students should know and be able to do throughout their K-12 experiences, and contained content standards, standards for teaching, professional development, assessment, school science programs, and the educational system as a whole. Inquiry was presented as:

> … a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and considerations of alternative explanations. (p. 23)

The three documents fueled a science education reform era that lasted for over 15 years. However, the consensus report, *Taking Science to School: Learning and teaching science in grades K-8* (NRC, 2007) claimed that after these 15 years of extensive, standards-based reform based upon these initiatives, little improvement to U.S. science education could be claimed. To try to understand why, the NRC (2008) evaluated the recent research base for updated knowledge around three important questions:

> (1) How is science learned, and are there critical stages in children's development of science concepts? (2) How should science be taught in K-8 classrooms? (3) What research is needed to increase understanding about how students learn science? (p.1)

At the conclusion of this evaluation a series of recommendations were presented about what it means for students to be proficient in science, conclusions about what students know and how they learn, and recommendations about what, when and how to teach. The recommendations were intended to act as learning goals to guide a next wave of science reform. A key failure noted was the artificial separation of content and process outcomes within the reform documents, essentially presenting content and process standards as separate chapters (NRC, 2007). This false dichotomy of science being presented as separate content knowledge and process outcomes led to teacher confusion during the last reform initiative about what inquiry-based science was, and how it should be implemented (NRC, 2007).

Duschl and Grandy (2008) elaborated on the idea that teachers lacked clarity of what counts as science inquiry and also what research is needed to help alleviate this problem.

Three key focus areas for research were suggested. First, they suggested that science education research should focus on the importance of cognitive, social/affective, and epistemic dimensions of learning being explicitly addressed through instruction. Duschl and Grandy (2008) suggest that teachers need an enriched vision for science education inclusive of these dimensions in order for meaningful improvement to occur. Instruction based on these dimensions needs to center on having students experience science within authentic, extended, inquiry experiences, which should occur as epistemic practice within supportive community environments. Secondly, there must be a focus on conducting and implementing research that seeks to provide interventions (e.g., pedagogical tools) to effectively support teachers implementing inquiry-based science learning based on these dimensions. Thirdly, a key focus area for researchers should be to implement the interventions they have designed in real classrooms. Through these implementations, models of effective classroom instruction will develop (Duschl & Grandy, 2008).

However, Duschl and Grandy (2008) also suggest that teachers lack effective instructional models and tools they need to implement such an enriched vision of science learning. This presents a gap in both research and practice. Exploring how to close this gap through the design, implementation, and evaluation of an intervention, was the aim of the thesis.

2.3 Constructivist Epistemology

The recommendations and conclusions described in the last section point toward a needed shift in teacher understanding and practice in order for an enriched vision of science education to take hold in classrooms. Helping teachers shift to a constructivist epistemology would help them tie scientific practices to the resulting student learning. "Constructivism is a theory of learning, and it is also a theory of knowing. It is an epistemological concept and theory of learning that draws from a variety of fields, including philosophy, psychology, and science" (Walker & Lambert, 1995). In order for a theory of learning and knowing to be useful, it must inform all situations where learning occurs (Cakir, 2008). An important constructivist idea is that learning does not happen passively by the "transmission" of knowledge from the teacher to the student (Treagust, Duit, & Fraser, 1996). Constructivist theory describes learning as a personal construction of meaning as an individual struggles to make sense out of the world (Treagust, Duit, & Fraser, 1996). Learners do not passively absorb knowledge, but actively create and modify knowledge structures (Carey, 1985). Constructivist theory states that prior knowledge interacts with/integrates with/ synthesizes with new information during knowledge construction (Cakir, 2008). Constructivist-oriented research focusing on student learning discovered that students' everyday ideas about concepts are very different than scientific views, and that students strongly hold onto their conceptions even when faced with mounting evidence to the contrary (Chavan & Patankar, 2015; Duit, Treagust, Widodo, 2008). These unrecognized "alternative conceptions", consequently, have tremendous implications in curriculum design and how teachers most effectively present concepts. An important principle of constructivism is the idea that an individuals' conceptions guide understanding (Cakir, 2008). Essentially, learners use their existing knowledge, goals, interests, etc. to interpret new information and experience. During interpretation, conceptions may be revised or modified. Each individual's conceptual knowledge is continuously being restructured (Duit, Treagust, Widodo, 2008). This restructuring is called conceptual change.

Social constructivism is another perspective within constructivist epistemology, and considers the role the socio-cultural environment plays in learning. Social constructivism developed out of the thinking of Lev Vygotsky, a Russian psychologist who died at the age of 37 in 1934. Vygotsky considered the role of society, language, and culture to be critically important dimensions of learning (Lemke, 2001). Vygotsky believed that knowledge is socially constructed and occurs in specific socio-cultural contexts. Interaction with the socio-cultural sphere provides learners with specific ways of interpreting the world. Through this process of "enculturation", learners become accustomed to cultural community (Vygotsky, 1978). The idea of more experienced members within the community acting to scaffold, or guide, the learning experiences of less experienced members is important within this perspective as described by Palmer (2005):

> Through language, students are able to share ideas and seek clarification until they understand. The emphasis is on a communication-rich environment in which students are given opportunities to interact with adults and peers in order to negotiate meaning. (p. 1855)

Both perspectives within constructivist theory have a strong influence on the way in which we view knowledge acquisition and how children construct and reconstruct understandings. Section 2.4 explores how conceptual change perspectives embrace a constructivist epistemology, provide a useful framework within which to interpret learning, and to design effective learning environments.

2.4 Conceptual Change Theory

Educational design research uses theory to guide the development of an intervention aimed at solving a problem of practice. In order for teachers to understand how to help students construct knowledge as an outgrowth of their inquiry-based activity (e.g. not separate from), the researcher focused on linking the ideas of constructivist learning theory to the research base on conceptual change. Constructivist learning theory suggests that new information is actively filtered through what one already knows, which is referred to as a process of conceptual change (Schnotz, Vosniadou, & Carretero, 1999). "Conceptual change theories evolved in order to explain shifts or reorganization of conceptual knowledge, and have emerged from a constructivist theory of learning. Conceptual change research had its origins in misconception research that reached its heyday during the 1980s" (Appleton, 2007, p. 511). Seeking to understand more precisely how conceptual change works has been one focus of educational research. "For decades scholars recognized that conceptual change is at the heart of meaningful learning. Over the years, conceptual change has been represented as a process of achieving structural insight, accommodative learning, understanding of relations, deep learning, or… more recently, mental model building" (Mayer, 2002, p. 101).

Some differences in the interpretation of the idea of conceptual change are noted by Duit and Treagust (1998), who point to agreement among important proponents of the theory. Basically, conceptual change approaches aim to restructure a students' pre-instructional conceptions during instruction (Duit & Treagust 1998). These authors caution that the name "conceptual change" has often been misinterpreted to mean a wholesale exchange between student ideas and science ideas, which research has shown to be impossible. Duit and Treagust (1998) state:

> The key assumption of conceptual change approaches is that learning has to start from certain already-existing conceptions and that learning pathways have to be designed so that they lead from these preconceptions toward the conceptions to be learned. (p.12)

If student conceptions are compatible with the science to be learned no major restructuring of cognitive structures is necessary for learning to occur. If student science ideas are in opposition to the science ideas being taught, learning pathways need to be developed that will bring about the needed conceptual change (Duit & Treagust, 1998)

Chinn and Brewer (1998) argue that other factors are needed to support conceptual change. One factor is the relationship between belief and knowledge change. Some students may not undergo a process of conceptual change because they simply do not believe in the change. Even in the face of mounting evidence they will stubbornly hold onto their failed beliefs. However, Chinn and Brewer (1998) point out that it is possible for students to construct new knowledge in the absence of belief, which can change later. It is also possible for students to transition to belief in new knowledge by rejecting both their prior knowledge and the new information. They simply do not know what to believe at that point in time. Finally, Chinn and Brewer (1998) state that it is possible for individuals to believe in a theory that they do not understand.

2.5 Additional Perspectives within Conceptual Change

Many perspectives focusing on cognitive factors of individual conceptual change have emerged out of recent research. Three of these perspectives are explored in more depth:

theory change, framework theory, and ontological shift. The last perspective, *ontological shift,* is explored in greatest detail.

2.5.1 Conceptual Change Perspective: Theory Change

One perspective looks at conceptual change as theory change. This view postulates that concepts of the learner are embedded within intuitive theories that need substantial restructuring during a process of conceptual change (Carey, 1985, 1991, 1999; McCloskey, 1983; Smith, 2007; Wisner, 1995). This restructuring is needed in order for a child's conceptual understanding to resemble those of an adult or scientist. This view was directly inspired by the work of Thomas Kuhn (1970), in his landmark work *The Structure of Scientific Revolutions*. Theory change, as noted in Vosniadou (2009):

> Conceptual change according to Carey (1991) requires the re-assignment of a concept to a different ontological category or the creation of new ontological categories-as when the concept of the earth becomes subsumed under the category of astronomical objects as opposed to physical object. (p. 3)

2.5.2 Conceptual Change Perspective: Framework Theory

A second cognitively focused perspective on conceptual change draws heavily on ideas from other perspectives, but radically opposes the idea that learners' initial conceptions are theory-like (diSessa, 2008). This view is known as the "framework theory" (Vosniadou, 2002; Vosniadou & Brewer, 1992; Vosniadou, Vamvakoussi, & Skopelitti, 2008; Vosniadou, 2013). This view suggests that as new ideas are discovered, assimilation is influenced by a learners' basic ontological commitments.

2.5.3 Conceptual Change Perspective: Ontological Shift

A third cognitively focused conceptual change perspective, closely related to the idea of theory change and framework theory, views conceptual change as an ontological shift (Chi & Slotta, 1993 & 2005; Slotta, Chi, & Joram, 1995). This view looks specifically at the differences that are present between a learner's naïve ideas, and how these ideas differ from scientific ideas. It especially describes how category shifts are involved in conceptual change. This process will be described in more detail later on in this section.

Chi extends the concept of learning and conceptual change beyond the idea of a categorical shift to include the idea of belief revision and mental model transformation (Chi, 2008). Chi suggests there are three possible conditions of learning that are possible. A student may not have any prior knowledge, and the process of learning involves simply adding new knowledge. A second possible condition is that a student may have gaps, or incomplete knowledge, about a concept. Learning in this condition can be considered gap filling. In either of these two conditions either prior knowledge is missing or incomplete. Learning under these two conditions can be considered a process of enriching (Carey, 1991). Chi considers the third condition of learning, when new ideas are in conflict with previously acquired ideas, to be conceptual change kind of learning. Conceptual change kind of learning does not involve either adding new information, or gap-filling holes within a students' understanding, because there is a need to change prior misconceived knowledge in order for learning to occur. Piaget (1964) would consider this to be a process of accommodation, and Duit and Treagust (1998) would describe the resulting learning pathway as discontinuous.

Chi (2008) describes three possible grain sizes in which "… knowledge can be 'in conflict with' the to-be-learned materials, postulating for each grain size the processes by which such 'in conflict knowledge' can be changed, and speculating on the kind of instruction that might achieve such change." (p. 61). Incorrect knowledge is hard to change; making a deeper look at the kinds of knowledge that can be in conflict extremely important. This is especially important when trying to determine the kind of instruction that will be needed to bring about the needed conceptual change.

Chi's (2008) three-knowledge grain sizes are: individual beliefs, mental models, and categories. Individual beliefs that learners' hold can be represented by a single idea, such as an amphibian's heart has three chambers. If a learner who knows an amphibian's heart has chambers, but does not know how many, when taught so, would be *adding* to their prior knowledge, or beliefs. If the learner knew that an amphibian had both atria and ventricles, but did not know how many of each, their knowledge would be conceptually incomplete. Teaching the learner that an amphibian has two atria and one ventricle would amount to what Chi describes as *gap filling*. Both of these kinds of learning, *adding and gap filling* would be considered enrichment, and not be considered conceptual change. "For conceptual change to occur, prior knowledge must conflict with new information." (p. 66). When prior understanding does conflict with new information Chi (2008) considers that idea to be a *false belief*. Following the example of learning about an amphibian's heart, a false belief of a learner might be that the hearts role is to re-oxygenate blood. The false belief would *contradict* new information being presented about the heart's role in circulating blood. Instruction targeted at refuting this false belief appears to correct the false belief by revising it. Chi calls this process *belief revision*, one form of conceptual change.

Another form of conceptual change is mental model transformation, which is described by Chi (2008) as the following:

> An organized collection of individual beliefs can be viewed as forming a mental model. A mental model is an internal representation of a concept (such as the earth), or an inter-related system of concepts (such as the circulatory system) that corresponds in some way to the external structure that it represents (p. 67).

Mental models help people understand how the world works. Having mental models helps us be both critical and creative thinkers and problem solvers. Just like how our individual beliefs may be “in conflict with” scientific ideas, our personal mental models of how the world works may be “in conflict with” scientific models, in whole or part. If, however, our personal models are missing components, or the components are non-existing, learning would entail the process of *adding* and gap *filling*, just like in the process of enrichment that occurs at the level of personal belief. By Chi’s definition, this would not amount to conceptual change. For conceptual change to occur, our personal models of the world would have to contradict the corresponding scientific models of the world. Many researchers have stated that this occurs when an individual’s personal model of how some part of the world works is *flawed* (Chi, 2000; Chi et al., 1994; Vosniadou & Brewer, 1994). Flawed mental models lead to consistently incorrect predictions and explanations by learners, which help teachers uncover the flawed nature of the learner’s mental model (Chi et al., 1994; Vosniadou & Brewer, 1992, 1994). When a learner’s mental model is flawed and is successfully revised through instruction, the model is described as being *transformed.* Mental model transformation is considered conceptual change by Chi (2008). Because mental models are often built with a series of correct and incorrect personal beliefs, in order for transformation to occur, critical personal beliefs will need to be revised. Chi (2008) states “…students’ knowledge consists of an interrelated system of false beliefs and correct beliefs, forming coherent but sometimes flawed mental model” (p. 70). This coherent, but flawed, mental model is said to be in conflict with a corresponding scientific model if it consistently leads to incorrect explanations and predictions. Through a process of multiple and accumulating belief revisions, transformation of the flawed mental model is possible (Chi, 2008).

However, there are some categories of misconceptions that researchers have discovered that resist transformation based upon repeated corrections at the level of individual beliefs. This results in mental models that remain flawed even after extensive instruction aimed at correcting the flaws.

> This suggests that, for robust misconceptions, refutation at the belief or mental-model level is not the right grain size to achieve conceptual change. In such cases, we propose that instruction be designed to target conceptual change at a different grain size, at the categorical level (Chi, 2008, p. 72).

Chi (2008) believes that these robust, and difficult to change, conceptions, resist change because a learner has incorrectly assigned it to a wrong ontological category. So, in order for conceptual change to occur in these instances, Chi (2008) claims a belief or series of beliefs within a mental model will have to shift across lateral or ontological categories, or trees. For example, a learner may view a concept such as energy or photosynthesis as an 'entity', instead of as a 'process'. Within this perspective of conceptual change learning involves shifting concepts into appropriate conceptual categories. Many shifts in ontological categories are possible during learning and development. In order for this to occur, learner's misconceptions need to be confronted at the level of category. They also need to have adequate knowledge of the category to which the concept really belongs. However, learners often have a great commitment to their ontological categories that they have created, often very early in life, in order to make sense of their world. These categories seldom need to change, and in fact this occurrence is very rare (Chi, 2008). Chi claims that that this is the very reason why misconceptions are so very robust. Teachers need to help their students create new ontological categories, and build conceptual understanding as to the properties that define them.

2.6 The Classical View of Conceptual Change: The Conceptual Change Model

All of these ideas on conceptual change developed as an outgrowth of earlier research. Posner, Strike, Hewson, and Gertzog (1982) developed an historically significant model of conceptual change. Posner et. al. (1982) was highly influenced by ideas from the history and philosophy of science, especially, the *Structure of Scientific Revolutions* (Kuhn, 1970) and the Piagetian idea of accommodation. A central focus of this model is on how students change their conceptions based on information that is both new and conflicting. This relates to Kuhn's description of how "scientific revolutions" occur when paradigms are upended. Kuhn described the upending of paradigms as paradigm shifts (e.g. a major change of prevailing thought). According to Posner et al. (1982) "learning is the result of interactions between what the student is taught and his current ideas or concepts," (p. 211). The idea of *conceptual ecology*, originally described by Toulmin in 1972, and used by Posner e.t al. (1982) in their conceptual change model, referred to the epistemological and ontological commitments and beliefs that each learner holds. These commitments are used during learning to evaluate the merit of new conceptions.

In the initial conceptual change model, Posner et. al. (1982) included four conditions necessary for change. Condition number one was called *dissatisfaction*, which occurs when a learner is dissatisfied with their existing conception. This dissatisfaction results when a current conception does not engender understanding. The second condition is called *intelligibility*, which means that the learner has an understanding of a newly presented conception (e.g. it makes sense). The third condition needed for understanding by the Posner conceptual change model is called *plausibility*, and will be met if the new conception appears to be valid to the learner. The learner will most likely reject any conception that is not a good fit with an existing conception. The fourth condition set forth by the model is called *fruitfulness*, or the ability of the conception to meaningfully explain events that could not be explained before. The higher degree that a conception is able to meaningfully explain an event, while also found to be useful and credible, the higher status the conception will have. If a conception has high status it is considered to be highly developed and have coherence. Conceptual change occurs when a pre-existing conception is considered by the learner to have a lower status than the newly formed one Conceptual change may occur only after the pre-existing concept has a lower status than the newly formed one (Hewson & Hewson, 1983).

The four conditions described by Posner et. al. (1982) form a useful framework for understanding what is needed for conceptual change to occur from a cognitive perspective. Piagetian theory is useful to begin to understand the mechanisms behind the change process itself. Piaget (1964) suggested that *cognitive disequilibrium* is needed for learning to occur. There are two parts to this process, *assimilation* and *accommodation.* Assimilation occurs when new information and experience fit within the existing learner cognitive structures, while accommodation occurs when the existing cognitive structures need to be modified in order make sense of the information and experience. Posner et. al. (1982) conceptual change model placed a greater focus on the process of accommodation.

Originally, Posner et. al. (1982) limited the idea of conceptual ecology to the cognitive domain, but understood that motivational and affective dimensions of learning were also involved (Tyson, Venville, & Harrison, 1997). This limitation caused the model to be criticized (e.g. Pines & West, 1986; Solomon, 1987), which resulted in a modified version created by Strike and Posner (1992). The expanded model considered additional dimensions to exist within an individual's conceptual ecology, such as emotions, motives, and social dimensions (Strike & Posner, 1982). Alsop and Watts (1997) leveled criticism on the Strike and Posner (1992) revised model of conceptual change, charging the revisions still left the model highly cognitively focused. These researchers suggested that additional dimensions, such as self-esteem, conation, and affect be included. For Alsop and Watts (1997) the dimension of affect focused on interest, the conative dimension on how knowledge is applied in the world, and self-esteem focused on learner efficacy and perseverance during learning.

Other researchers responded to the limited nature of a socio-cultural perspective of conceptual change within the Strike and Posner (1982) model by presenting a view of conceptual change and knowledge construction as a socio-cultural process and discussing the importance of personal (individual) knowledge (Kelly & Green, 1998). Vosniadou (2007) discusses this debate where views of conceptual change sit somewhere on a continuum stretching between cognitive (personal) views of conceptual change on one end, and socio-cultural/contextual/situative views of conceptual change on the other. Vosniadou (2007) calls the space between these two extremes the cognitive-situative divide. Vosniadou (2007) argues that neither the cognitive nor the socio-cultural perspectives adequately accounts for empirical evidence on how learning occurs, and proposes a balanced perspective that acts as a bridge between the two extremes. Within this view personal conceptual change can be facilitated through participation with others in the socio-cultural learning community. Said another way, "The question of individual learning now becomes a question of how that which is inside a person might change over time as a consequence of repeated interventions with these elements of cultural structure" (Vosniadou, 2007, p. 18). The implication of a balanced perspective of conceptual change is that learning should not be viewed solely as an individual process where knowledge is transferred to the minds of students through verbal instruction, but results from a socio-cultural process of knowledge building within the classroom. This also implies that the design of learning environment interventions aimed at promoting conceptual change should embrace a balanced approach in order to successfully bridge individual and socio-cultural conceptual change perspectives. This key idea is illustrated in Figure 2.1.

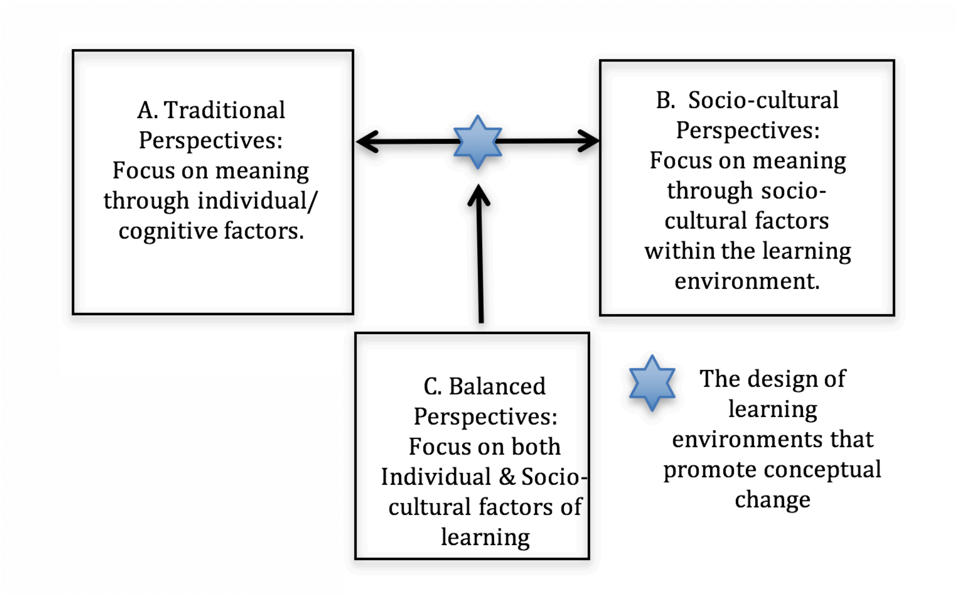


Figure 2.1. Designing learning environments that promote conceptual change

An in-depth discussion of how the personal and social perspectives of conceptual change can be linked through the design of effective learning environments is discussed in the next section.

2.7 Individual Personal and Socio-Cultural Processes of Conceptual Change and the Design of Effective Learning Environments

Vosniadou, (2001) states:

> A theory of conceptual change needs to provide a description of the internal representations and processes that go on during cognitive activity but should also try

to relate these internal representations to external, situational variables that influence them. (p. 395).

The ongoing debate between the cognitive (individual; personal) and situative (socio-cultural) research camps had a significant impact on how the researcher theorized about, and designed, an intervention aimed at supporting effective teaching and learning within this thesis.

The rich literature base on conceptual change offered images of learning that were useful during the intervention design process. During the intervention design process the researcher sought to theoretically and methodologically bridge the cognitive-situative (e.g. individual learner - social context) divide when exploring the problem of conceptual change in relation to instruction designed to bring it about. The cognitive perspective argues for a view of learning that takes place solely in individual heads, with a view of knowledge as objectified. Greeno, Collins, & Resnick (1996) describe the cognitive as an individual learning perspective that "treats knowing as having structures of information and processes that recognize and construct patterns of symbols in order to understand concepts and exhibit general abilities, such as reasoning, solving problems, and using and understanding language" (p.18). The situative perspective argues for a view of learning that takes place solely within the socio-cultural interactions, with a view of knowledge as distributed. Greeno, Collins, and Resnick (1996) describe this view as "an activity that takes place among individuals, the tools and artifacts they use, and the communities and practices in which they participate" (p. 20). With this view, knowledge would be understood as a relation between an individual and a social or physical situation" (Greeno, 1989, p. 1). This balanced view of individual cognitive perspectives working in concert with the socio-cultural and material environment provided a powerful referent for the development and implementation of the intervention described in this thesis.

2.8 Additional Perspectives on the Design of Learning Environments that Promote Conceptual Change

2.8.1 Breadth of Coverage of the Curriculum

Research findings describe how the learning of science concepts takes much longer, and is much more difficult to achieve, than was previously realized (Vosniadou, 2001). This idea suggests that an effective curriculum should offer depth over breadth with fewer topics being explored more fully (Duschl, et. al., 2008). This view is consistent with the idea of offering fewer, extended, inquiry projects focusing around important core ideas as a better approach than offering a curriculum spending much shorter time around each of a greater number of topics that are presented in the *Next Generation Science Standards* (NGSS Lead States, 2013).

2.8.2 Order of Acquisition of Concepts Involved

The order of acquisition of the concepts involved in learning is an important consideration in promoting conceptual change (Vosniadou, et. al., 2007). According to these authors concepts have a relational structure, and helping students understand this relational structure necessitates ordering the teaching in a way that facilitates student sense making. If pieces of the conceptual structure are omitted, taught out-of-order, or not taught showing how different components of the concept are related, conceptual understanding will be limited. When teachers thoroughly understand a concept, it means they have the ability to teach in a way that will facilitate conceptual understanding. Learning progressions and concept inventories are being constructed to help teachers gain a thorough understanding of their teaching domain, the order the component parts of a concept should be taught, and to what depth. This knowledge also helps to point out student misconceptions, and whether students need to modify their personal ontologies through a process of conceptual change (Vosniadou, 2001).

2.8.3 Taking into Consideration Students' Prior Knowledge and Experience

What has been discussed in the last section is directly linked to the idea that students come into classrooms, not as empty vessels, but as individuals with formed ideas about how the world works (Sinatra & Mason, 2013; Vosniadou, 2001). Consequently, the intervention designed within this thesis needed to support a shift in classroom activity to promote the activation, representation, and use of student prior knowledge and experience by both teachers and students. When teachers value and use student prior knowledge and experience instructionally proper instruction starting off points are dictated, and also potential student misconceptions are uncovered that will need to be addressed through instruction (Vosniadou, 2001).

2.8.4 Facilitation of Student Metacognitive and Metaconceptual Awareness

The researcher designed the intervention, and how it was to be implemented by the teacher, to support student metacognitive and metaconceptual awareness during learning. Developmental psychologists have stressed the significance of understanding and facilitating metacognitive awareness in educational practice (Vosniadou, 2001). Metacognition, according to Vosniadou, (2001), involves the knowledge about, and experience relating to, cognitive processes. Knowledge and experience are used to manage and promote cognitive processes during learning. Said another way, metacognition considers ideas of learner self-reflection and direction, and the awareness of, monitoring, and regulating of thinking processes during instruction. Closely related to the concept of metacognition is the concept of metaconceptual awareness. Metaconceptual awareness considers the role of thinking about one's own knowledge, theories, and metacognitive processes during the act of learning (Vosniadou, 2013). Vosniadou (2010) suggests three specific categories of metaconceptual processing: (1) metaconceptual awareness, (2) metaconceptual monitoring, and (3) metaconceptual evaluation. Reorganizing student alternative conceptions to look more like scientifically accepted conceptions is the main goal of conceptual change approaches. This suggests that instruction aimed at promoting conceptual change should explicitly support the development of both metacognitive and metaconceptual awareness and functioning in students.

2.8.5 Learner Characteristics Influencing Conceptual Change

In addition to background knowledge, Sinatra and Mason (2013) describe five learner characteristics categories deemed important factors of conceptual change: (1) achievement goals, (2) epistemic motivation and beliefs, (3) interest, (4) self-efficacy, and (5) affect and emotions.

A learner's background knowledge, which is a learner characteristic, is an important factor in the process of learning. Students may or may not have relevant personal knowledge, and this information may also be incomplete or manifest as a misconception. Students may also have a strong commitment to their prior knowledge, or conceptions, which makes their conceptions robust and hard to change (see section 2.5.3). Achievement goals refer to the personal reasons why learners involve themselves in any certain achievement task (Ames, 1992). These goals, also called intentions, have been positively linked to conceptual change in two studies exploring the relationship between conceptual change, achievement goals, and affect/motivation (Linnenbrink & Pintrich, 2002).

Another learner characteristic that was promoted within the design of the intervention was epistemic motivation and beliefs. "Epistemic motivation refers to motivations that are not focused on the self but rather on knowledge as an object" (Kruglanski, 1989). Through cognitive conflict learners may develop an understanding that their current conceptions are inadequate. In an intentional learner, having an inadequate understanding would develop the epistemic motivation to resolve the conceptual conflict through the development of understanding. Epistemic beliefs, which are beliefs about the nature of knowledge and knowing (Hofer & Pintrich, 1997), have also been shown to relate to conceptual change (Qian & Alvermann (1995). These researchers positively linked epistemic belief with the process of knowledge restructuring. Windschitl and Andre (1998) explored the relationship between epistemic beliefs and conceptual change and discovered that when students held beliefs about knowledge and knowing that correlated to epistemic beliefs that were social constructivist in nature (e.g. have both personal and social dimensions), it was more likely for conceptual change to occur in the study learning environment. They also found the opposite to be true, if students held epistemic ideas about knowledge being static and unchanging, little conceptual change occurred.

Interest has been identified as an important learner characteristic that can motivate conceptual change (Pintrich et al., 1993). Two conceptions of interest emerge from the literature (Sinatra & Mason, 2013). One conception of interest looks at the relatively stable interest individuals may have about certain objects or events, called personal or individual interest. The other conception of interest looks at situational interest, or interest that emerges through experiences within the social environment. A learner may have a topical interest, which could be both a personal interest, because it evokes positive attitudes and feeling about it, and a situational interest, because the learning environment evokes positive affective and cognitive reactions within the learner (Hidi, 2000). However, Potvin and Hasni (2014) summarize the literature about student interest in science that shows a well-documented decline in this construct starting at age eleven and continuing throughout their academic careers. This will be important to track within this thesis, because participating students are within the documented decline years.

Conceptual change researchers have increasingly investigated the roles that affect and emotions may play in the process of conceptual change (Linnenbrink & Pintrich, 2004). Sinatra and Mason (2013) infer that positive affective dimensions of learning would promote learner conceptual change, but state that there is very little empirical evidence to back up this inference. Researchers do not agree on the definitions of the concepts relating to affect and emotions. In one perspective, Rosenburg, 1998, describes the difference between mood, emotion, and affect. Rosenburg suggests that affective traits are something that humans inherently possess as part of our personalities. In this perspective affective traits stay relatively stable over a person's life, but influence how we respond with our moods and emotions, which are situational in nature. Sinatra and Mason suggest, "clearly creating a classroom environment that fostered positive activating emotions would be recommended for promoting conceptual change" (p. 572).

2.8.6 The role of Teacher in Promoting Conceptual Change

In constructivist-oriented inquiry-based science classrooms the teacher participates as a learning guide, facilitating the teaching-learning process through their decisions and actions. The intervention was designed to support the needed shift from teacher-centered to student-centered classrooms in light of this idea. There is a large body of research that suggests that the conceptual change that occurs in classrooms is tremendously influenced by both teacher-student interactions, as well as student-to-student interactions (Duit, Treagust, and Widodo, 2008). A teacher's beliefs, knowledge, and ongoing decisions and actions permeate the learning environment. A teacher's critical contribution to how individual learning interacts with and is promoted by the teacher operating within the social/contextual learning environment becomes an important factor in the promotion of student conceptual change.

2.9 A Multidimensional Theoretical Framework for Conceptual Change

To guide the evaluation of the intervention, recent research (Duit, Treagust, & Widodo, 2008) was used to update the multidimensional conceptual change model originally utilized by Venville & Treagust (1998). This information is shown in Figure 2.2.

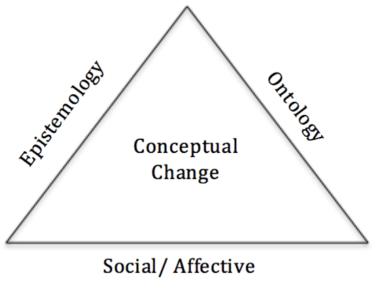


Figure 2.2. Multidimensional framework for conceptual change
(Venville & Treagust, 1998)

The Venville and Treagust (1998) model utilized three lenses, or perspectives, to analyze learning and interpret a change event—an ontological lens, a social/affective lens, and an epistemological lens. Recently, Duit et al. (2008) argued for treating the affective dimension of conceptual change as being equally important as the other dimensions. To accommodate and elaborate this view, the multidimensional model was updated by separating the affective dimension from the social/affective lens and placing it within a "new' lens category called learner characteristics (see Figure 2.3). Sinatra and Mason's (2013) review the recent empirical research on learner characteristics and conclude that in addition to affect and emotion there are four addition dimensions that have proven themselves through research to be extremely important to the process of conceptual change: achievement goals, motivation and beliefs, interest, and self-efficacy. These perspectives were included in the updated model.

The social lens of the model was also updated fundamentally drawing upon and elaborating a Vygotskian socio-cultural view of learning described earlier, where mental processing interacts with the external social and cultural environment during knowledge construction (Vygotsky, 1978). Figure 2.3 shows the updated model.

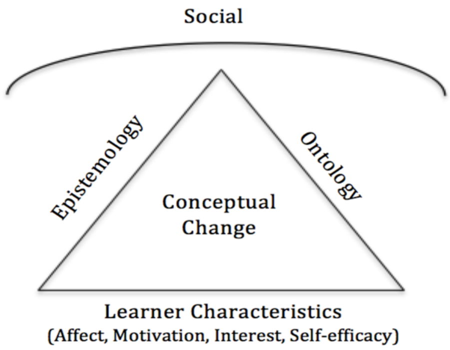


Figure 2.3. Updated Multidimensional Framework for Interpreting Conceptual Change (Adapted from Venville & Treagust, 1998)

2.10 Chapter 2 Summary

There has been a failure of recent science education reform efforts to bring about meaningful improvement to the teaching and learning of science. This failure frames the central problem that this thesis addresses.

The research base suggests a possible reason for this failure is that teachers lack a clear vision of what exemplary science education is, and how such exemplary science education might manifest itself in their classrooms. Traditional teaching, which overly focused on the transmission of knowledge, is still a dominant mode of presenting science education in classrooms. This chapter presented an argument that both an enriched vision of science education is needed, as well as, effective pedagogical tools and models of classroom instruction, to successfully help teachers implement this enriched vision.

An enriched vision of science education was presented that calls for teachers to move beyond a focus of having students memorize content, to include learning goals in epistemic (e.g. what science knowledge is and where it comes from) and social dimensions (e.g. how learning is mediated by the environment). Classrooms organized with an enriched vision in mind focus on creating a student-centered learning environment where outcomes across these multiple dimensions work together to promote powerful learning. The kind of learning promoted within an enriched vision of science aligns with a social constructivist epistemology where learning of individual students is supported through social interaction and discourse with others (e.g. social negotiation).

Educational design research was chosen as the research method for the thesis because it seeks to solve real problems teachers face through the design and testing of practical educational innovations in the context of actual classrooms. Educational design research also seeks to add to the knowledge base through the development of design principles and/or instructional design theories that function to guide the development of the innovation, as well as provide broader application in other contexts.

Conceptual change theory was chosen to guide the thesis theoretically because it also aligns well with, and supports, the enriched vision of science education. Conceptual change theory seeks to understand factors involved with the reorganization of knowledge, and how this knowledge can be promoted. Both individual and social factors of conceptual change have been promoted by some conceptual change researchers as an either/or proposition. However, a balanced perspective that promotes both individual and social perspectives of conceptual change as important to the learning process was described. This balanced perspective aligns with, and supports, the enriched view of science education where multiple dimensions of learning are promoted (e.g. cognitive, epistemic, and social/affective).

The researcher determined that the ideas of balancing individual and social factors of conceptual change (e.g. research side terminology), and ideas of enriching the vision of science education through the inclusion of multiple dimensions of learning (e.g. education side terminology), are congruent. The goal of this research, then, was to develop an intervention that would help teachers implement an enriched vision of science education by focusing on the design of a learning environment and teaching supports that balanced individual and social factors of learning to promote conceptual change.

What glues these ideas together within this thesis is research promoting a multidimensional conceptual change perspective, which suggests three lenses to analyze learning and interpret a change event - an ontological lens, a social/affective lens, and an epistemological lens (e.g. describe factors of a learning event). Educational design research uses theory in many ways, such as, to predict, describe, and prescribe learning. This allowed the researcher to use conceptual change theory to support the design of an intervention aimed at promoting conceptual change (e.g. prescribe factors of a future learning event that would promote conceptual change).

Chapter 3 Research Methods

3.0 Chapter Overview

Chapter 3 describes the educational design research methodology used to guide the thesis. Educational design research methodology has the goal of supporting the study of teaching and learning where classroom design processes and research intersect (Kelly, Lesh, & Baek, 2008). There are six sections to this chapter.

Section 3.1 introduces important educational design research ideas and also provides an overview of the sixteen-step design process (Table 3.1). An important idea discussed was how evaluation criteria changes from soundness, preferability, and appeal during the early stages of intervention design, to viability, legitimacy, and efficacy, as a design is refined. How theory was used as the intervention was developed and refined also changed. Early on theory was used to prescribe desired outcomes to be embodied within the design itself, which led to theory being used to predict and evaluate outcomes as the intervention matured. Correspondingly, the research plan dictated a specific use of data that changed over the course of intervention development.

At the earliest stages of the research no data were collected. As development progressed qualitative data was used to inform the design of the intervention (e.g. intervention soundness, preferability, and appeal). As the intervention was refined qualitative data were again collected to evaluate the intervention using additional criteria (e.g. viability, legitimacy, and efficacy). During implementation both qualitative and quantitative data were collected to describe enactment and evaluate outcomes. After implementation qualitative interview data were collected to support final evaluation and reflection. The need to specifically mix data in this way called for a mixed method research approach and data-mixing plan, which is described in section 3.2. This section will also describe the role of the researcher in mixed-method research, how the researcher determined a "best" design, how the boundaries for each research mini-cycle were determined, and how the researcher addressed the challenge of validity.

The last four sections of the chapter (sections 3.3 - 3.6) describe each of the four phases of the research and their corresponding steps. The first phase had five steps (Research Steps 1-5). The researcher conducted a needs exploration and analysis to ascertain and frame an appropriate problem manifesting in the context of a real classroom (e.g. problem of practice) (Step 1). Appropriate research questions were developed and refined (Step 2), before surveys of the literature and the field were undertaken (Step 3). The researcher used theory to prescribe desired outcomes of the intervention (Step 4). The intended audience of the intervention was described in the last step of phase 1 (Step 5). Data were also collected through the observation of the teacher's classroom prior to implementation. Data collected during these steps was used to answer the two research questions for Phase 1.

During Phase 2, which also had five steps (Research steps 6-10), the intervention was designed and refined. During the first step of this phase the researcher developed the research design (Step 6), created design principles, goals, and strategies (Step 7), which were used to design a prototype intervention (Step 8). The prototype intervention was refined over the course of three iterative design mini-cycles (Step 9), which resulted in the development of a detailed intervention design (Step 10), which concluded study #1.

Study #2 included Phase 3 and 4 of the thesis (Research Steps 11 - 16). During Phase 3 the detailed intervention design was first clarified using theory (Step 11) before data collection commenced and the intervention was implemented in a classroom (Step 12). The methods for this step will be described in detail in section 3.5. After implementation was over, the results were evaluated (Step 13) and reported on. Phase 3 concluded with the researcher conducting a final evaluation and discussion of the research (Step 14). Study #2 concluded with the completion of Phase 4, where the researcher made plans for publication (Step 15), and conducted broad impact planning to explore possible diffusion, adoption, and adaptation options, and the potential consequences of doing so (Step 16).

3.1 Introduction

This thesis includes two related studies, each of which had two research phases. The first two phases (Study #1) explored the research problem, studied the relevant literature, selected guiding theory, formalized research questions, and designed an intervention prototype aimed at solving a problem of practice (e.g. the research problem). Theory was used at this stage of the research to prescribe desired outcomes of the intervention. McKinney and Reeves (2012) describe this stage of an educational design thesis as alpha testing. During alpha testing the prototype intervention was evaluated for soundness, preferability, and appeal, rather than functionality, in order to determine if all of the original ideas for the design had been embodied within it (McKinney & Reeves, 2012). During prototype refinement, the intervention was formatively evaluated for viability (practicality, relevance, sustainability), legitimacy (research-based; coherence), and efficacy (desired results; cost benefit ratio). At this point in the research theory was used to predict outcomes of intervention implementation. In Phase 1 of the thesis no data were collected and analyzed, and during Phase 2 qualitative data only were collected, which functioned to inform the design of the intervention only.

During the next two phase (Study #2) the detailed intervention was implemented and evaluated using a multidimensional conceptual change theory. This perspective predicted that four factors of conceptual change, which were used to develop the intervention, interact positively to promote learning and conceptual change. Two very distinct categories of questions, each dealing with how the intervention functioned, were asked during Phase 3, and required very different methods to answer them: 1) Questions that evaluated the effectiveness of the intervention in meeting established goals (pre-measures/post-measures design), and 2) Questions that explored issues of intervention enactment itself. McKinney and Reeves (2012) call this stage of an educational design thesis beta testing. Following McKinney and Reeves (2012), the beta testing within this thesis sought to determine local viability of the intervention in meeting goals and whether the intervention was adopted and absorbed by the local institutional context. Questions about how the intervention was enacted called for qualitative methods, and questions about the effectiveness of the intervention called for quantitative methods. A mixed method approach was adopted for this thesis because of its ability to effectively answer the specific research questions that we were asking at different points of the design cycle (Collins et al., 2004; Herrington et al., 2007). This means that the researcher carefully matched the research approaches to the types of research questions that were being asked at different phases of the thesis. Section 3.2.0 further discusses how the data was mixed during the research.

Four main scholarly resources were used to inform the educational design process, and corresponding methods, used in this thesis: 1) A special issue of the Journal of the Learning Sciences: Design-based Research: Clarifying the Terms (Vol. 13, No. 1, 2004), 2) The book Educational Design Research, edited by Jan van den Akker et. al., 2006, 3) The Handbook of Design Research Methods in Education, edited by Kelly et al., (2008), and 4) The book Conducting Educational Design Research, written by McKenney and Reeves (2012), the latter being especially helpful during the later stages of the thesis. Using these resources, a four-phase, 16-step research model was created. This model heavily drew on a research approach developed by Bannan-Ritland (2003), called the Integrative Learning Design Framework (ILDF).

The phases of the research were: 1) Research Problem and Question Exploration, 2) Intervention Design and Refinement, 3) Intervention Implementation and Local Impact Evaluation, and 4) Broad Impact Planning and Implementation. Phases 1 and 2 were enacted during Study #1, and Phases 3 and 4 were implemented during Study #2. Table 3.1 shows the research phases and corresponding research steps for Study #1 and Study #2.

Table 3.1

R*esearch phases and corresponding steps for Study #1 and #2*

Research Phases	Research Steps
Study #1	
Phase 1: Research Problem & Question Exploration	1. Needs Exploration/Analysis 2. Research Question Exploration 3. Survey the Literature & Field 4. Theory Development 5. Audience Characterization
Phase 2: Intervention Design & Refinement	6. Research Design 7. Design Principles, Goals, & Strategies 8. Prototype Intervention 9. Iterative Design Mini-cycles 10.Detailed Design
Study #2	
Phase 3: Intervention Implementation & Local Impact Evaluation	11. Theory Refinement 12. Implementation/ Data Collection 13. Evaluation of Results 14. Reflection & Discussion
Phase 4: Broad Impact Planning & Implementation	15. Publish Results 16. Broad Impact Planning & Implementation a. Diffusion, adoption, adaptation b. Consequences

3.2 Methodological Considerations

There are methodological considerations that must be addressed in educational design research (Hogue, 2012): 1) How the data will be mixed, 2) The role of the researcher, 3) How to define better, 4) Boundaries of the iterations, and 5) How to establish validity.

3.2.0 How the Qualitative and Quantitative Data were Mixed

Mixed methods research involves collecting both qualitative and quantitative data in the same study (Tashakkori & Teddlie, 2003). The basic idea of mixed methods research is that by mixing both kinds of data sets the researcher is provided with a greater level of understanding than either set analyzed alone. The method also is able to offset any weaknesses research designs have that favor either qualitative or quantitative data (Creswell & Plano, 2007). There are many different strategies of mixing data in mixed method research, but an embedded design was chosen for this study (Creswell, Plano Clark, et al., 2003). An embedded design mixes one type of data in support of the other. Following a design used by Rogers et al. (2003) qualitative data was used in this study to inform the design of the intervention, document how the intervention was implemented by the teacher and students, and finally to help explain the results obtained by the intervention.

Quantitative data were used via pre- and post-measures to determine the impact that the intervention had on student learning outcomes. Figure 3.1 shows how the data were mixed during each of the four phases of the thesis. During research Phase 1 (Research Problem and Question Exploration) and research Phase 4 (Broad Impact Planning and Implementation), no data were collected or mixed. During research Phase 2 (Intervention Design and Refinement) qualitative data were collected and used to inform the design of the intervention.

At the start of research Phase 3, before the intervention was implemented, quantitative data were collected using pre-tests and surveys as pre-measures of student learning outcome attainment. During implementation of the intervention qualitative data were collected to determine how the intervention was actually enacted by the teachers (e.g. fidelity of implementation; alignment between the planned and enacted intervention; viability, legitimacy, and efficacy of the intervention) and how students interacted and used it during learning. After the end of the intervention implementation period, quantitative data were again collected as post-measures of student level of learning outcome attainment, which were used to produce a summative review after the implementation. One final qualitative data collection occurred after the program concluded through student and parent interviews, which were used to help explain the results achieved. The final step of Phase 3 was interpretation, which occurred when the data was mixed and results were determined based on the resulting Quan (qual) results. During Phase 4 (Broad Impact Planning and Implementation), no additional data was collected or mixed. This type of design is called an embedded mixed method design after Creswell and Plano Clark (2007).

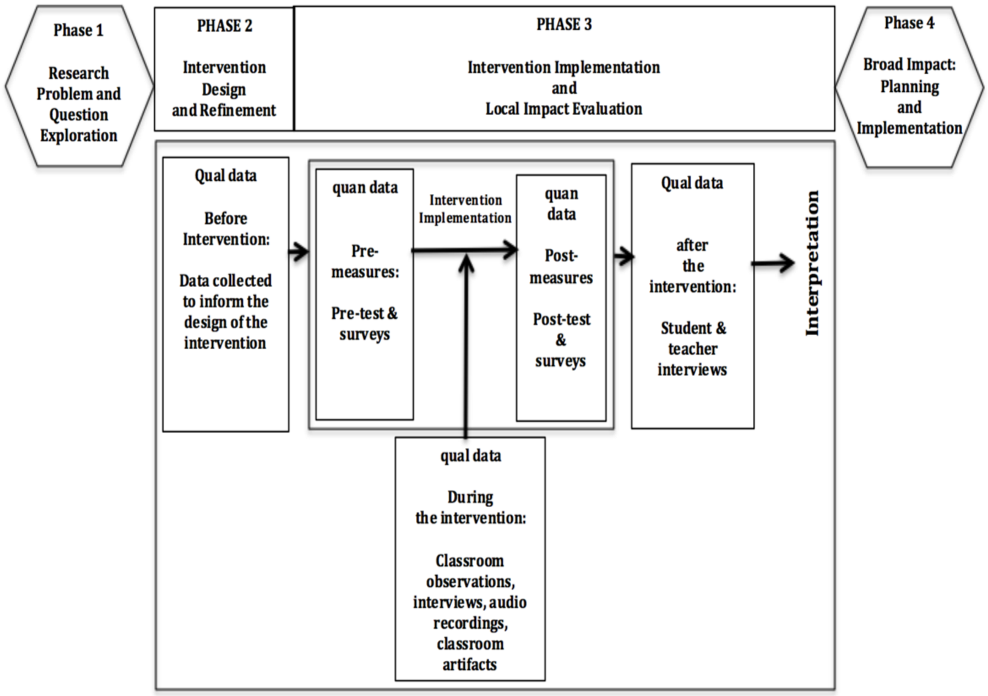


Figure 3.1. Embedded Mixed Methods Design Showing How Data were Mixed

3.2.1 The Role of the Researcher

During educational design research the researcher is often placed in multiple roles, from researcher, to designer, to developer, to teacher (implementer) and evaluator (Hoadley, 2004; Wang & Hannafin, 2005). During this thesis the researcher was the designer, developer, and evaluator of the intervention. Some scholars say that this situation creates too many opportunities for bias (Collins, 1992; The Design Based Research Collective, 2003), and argue that to prevent it, a different researcher than the one who designed it should evaluate the design. However, this is not always possible. So, as McKenney et al., 2006 suggests to minimize potential bias, a non-thesis researcher was used to help analyze the data where appropriate.

3.2.2 How it was Determined if one Iteration of a Design was Better than Another

Educational design research aims to improve upon existing designs or determine what strategies or components of an intervention work better to solve a problem of practice. But, how can researchers determine if one-design iteration is better than another? This thesis used the suggestion by Reigeluth and Frick (1999) that researchers use the concept of preferability, which they define as having the following characteristics: 1) effectiveness: how well the implemented design meets the research goals; 2) efficiency: the usability of the design in a practical sense, how well it can be scaled, and how well the intervention can continue to impact practitioners after the support of the thesis has stopped (Oh & Reeves, 2010); 3) appeal: how well and enjoyably an intervention solves problems of practice in the eyes of those who use it. To be clear, the concept of preferability was utilized to determine if one-iteration was better than another. This was a different process than the formative testing of each specific design iteration, which used the concepts of viability, legitimacy, and efficacy.

3.2.3 How the Boundaries of an Iteration were Determined

Multiple cycles of implementation, evaluation, and refinement are at the heart of iterative educational design research. Early on during development, the focus of refinement is on developing effectiveness, but as an intervention matures the focus of refinement shifts to fine tuning its efficiency (van den Akker, 1999). Throughout each of the design iterations that occurred in this thesis it was necessary for the researcher to define the boundaries, or focus, of each design implementation. This explicit thought process was followed in order to minimize a common educational design research problem described by Anderson & Shattuck (2012) as that of not knowing when one-iteration was over and another had actually started. The problem being addressed in this thesis did not lend itself to simple solutions; so, both long and short duration iterations were needed to bring about a high level of needed refinement. The researcher had to make sure that adequate time was available for the necessary iterative cycles that were planned. In addition, the iterations that unfolded throughout the research were tied to the cycle of student programs in which development occurred.

3.2.4 The Challenges of Measuring Validity

The formative evaluation process used was performed to improve the quality of the various iterations of the intervention, rather than prove the validity of it. Hogue (2012) states that the concept of "Validity is the extent to which the conclusions and interpretations of the research can be justified by the research methods employed" (p. 6), and goes on to suggest that it more useful to discuss potential challenges to validity than it is to determine whether it has occurred. Cobb et. al (2003) suggest that care must be taken when making any cause-effect relationship claims because unknown contextual factors may be having an impact on the outcomes being investigated. Martínez, Pitts, Brkich, and Lizette (2018) discuss how contextual factors, which they describe as contextual mitigating factors (CMFs), need to be recognized in support of better research designs. The intentional mixing of qualitative and quantitative data throughout the research was organized to uncover and address potential CMFs.

3.3 Methods Used for Phase 1: Research Problem and Question Exploration

3.3.0 Section Overview

This section describes the research activities, methods and questions followed to complete research Phase 1. The steps followed during this phase included: 1) Needs

Exploration and Analysis, 2) Research Question Exploration, 3) Survey the Literature and the Field, 4) Theory Development, and 5) Audience Characterization.

The purpose of first phase of the research process was to begin to explore, in broad terms, what an inquiry-based pedagogical intervention might look like in support of implementing the enriched vision of science education and promoting conceptual change. Methods in this phase included a needs analysis, survey of the literature, and an audience characterization process. The researcher began the process of integrating theory, practice, and research perspectives and generated initial models and potential solutions. The researcher also conducted a needs analysis from the perspectives of both research and practice.

Information obtained during research Phase 1 was refined and used to specify the design principles, learning goals, and strategies that served to guide the development of intervention, which occurred in Phase 2. A prototype intervention was developed through an iterative creative/critical thinking and refinement process based upon the scrutiny and social negotiation by researcher and the teacher who implemented the intervention. These design mini-cycles served to refine the intervention.

3.3.1 Research Phase 1 (Step 1): Conduct a Needs Exploration and Analysis

During this phase (Step 1) the researcher explored in broad terms the problem of practice described in section 1.0: Why the large-scale science reform initiatives aimed at solving the problem of low student performance in science have failed (TIMSS, 2008; PISA, 2012). To begin exploring the research problem broadly, the researcher asked two initial questions: 1) How does the identified problem manifest in practice? and 2) How can the problem be interpreted and clarified with existing literature and theory? To explore the practice side of problem the professional knowledge and experience of a veteran group of professional development providers was obtained and represented. Using this information, the researcher brainstormed effective teacher improvement practices based upon the collective experience of the group. The summary of this brainstorm is found in Figure 4.1. To explore how the problem could be interpreted and clarified with existing literature and theory a literature review was undertaken. This review is presented as thesis chapter 2.

Additional research activities occurred during research (Step 1). The teacher who was going to implement the intervention was given the Teacher Beliefs Inventory (TBI) to determine if epistemological beliefs held were aligned with thesis goals. Luft and Roehring (2007) developed the TBI, which is a validated semi-structured interview protocol. This semi-structured interview protocol was designed to capture and categorize teacher beliefs (see Appendix A). Based on teacher responses to a set of questions, epistemological beliefs are classified into one of five categories. These categories form a continuum from traditional to reform-based in the following order: Traditional - Instructive - Transitional - Responsive -

Reform-based. Descriptors and example teacher responses to each of the seven questions contained within the TBI are provided to support classification of responses into the appropriate category. The results of administering the TBI to the program teacher are presented in section 4.6.1.

Two additional, and related, research activities occurred during research (Step 1). Data needed to be gathered before intervention to answer the two research questions for Phase 1:

1. SLRQI: What does inquiry-based student learning look like in the teacher's classroom before intervention implementation?
2. LERQ1: How does the teacher design the classroom-learning environment to promote inquiry-based learning before intervention implementation?

To collect data to answer these questions the researcher observed the teacher teach a different group of students at the study site for eight lessons (e.g. 16 hours). Field notes were written, and transcripts created. Data was collected one year before the intervention was implemented. The reason this data was collected one-year pre-implementation was because the researcher wanted to collect data in the same program, with the same grades of students, aiming to minimize CMFs. Selection of these students followed the same protocol as the students used in the study and the focus of data collection was on the teacher, not the students. The data collection timeline was also necessary because the teacher was to begin professional development the following semester, which would negate the data as a pre-measure if it was collected during or after the training initiated. To support the answering SLRQ1, a rubric (see Appendix B) was created that corresponded to the set of eleven critical ideas necessary for effective inquiry-oriented learning gleaned from the literature review. Figure 3.2 shows an example section from the rubric relating to how student generation of questions for an inquiry was supported, which is critical idea one.

Category	0	1	2	3
Generating Questions (GQ) **A.**	**No questions were used to organize the lesson.**	**Teacher generated a question(s) that was used to organize the investigation, but it was not tested through observation.**	**Teacher generated a question(s) which was student tested through investigation.**	**Students generated their own questions, which were tested through investigation.**

Figure 3.2. Example from Critical Ideas for Inquiry-learning Rubric for Questioning

For each of the 11 critical ideas the rubric captured a range of instructional support by the teacher. This range explored a shifting of control of the item towards student regulation. If the teacher did not support the critical idea with students over the course of an intended inquiry, the component received a 0. If the critical idea was present, but was not part of an actual student inquiry, it received a 1. If the teacher controlled the thinking around the critical idea, and the students used the idea during an inquiry, the component received a score of 2. If students controlled the thinking around the critical idea, and the students also used the idea during an investigation, the component received a score of three. Through the use of this rubric the researcher could determine what critical components of inquiry were present over the course of the observed instruction, and the degree to which the teacher supported student regulation of the component. The results of this analysis are found in section 4.6.2. Classroom discourse and participation patterns, pre-intervention implementation, were also determined using the same observational data. The summary of the discourse and participation patterns found in the teacher's classroom pre-intervention implementation are presented in section 4.6.3. The Inquiry Continuum, created by Banchi & Bell (2008), was used to analyze student investigations pre/post for the level of inquiry present-confirmation, structured, guided, or open. Figure 3.3 describes each of these forms of inquiry from the Banchi & Bell (2008) continuum and the associated rubric score attached for each level. Moving from left to right across the continuum shows a shift from teacher-controlled to student-controlled inquiry.

Teacher Control			Student Control
(1) Confirmation Inquiry	(2) Structured Inquiry	(3) Guided Inquiry	(4) Open Inquiry
• Students confirm a principle through an activity when the results are known in advance	• Students investigate a teacher-presented question through a prescribed procedure	• Students investigate a teacher-presented question using student designed/ selected procedures	• Students investigate questions that are student formulated through student designed / selected procedures
Teacher Provides: - Question - Procedure - Solution/Explanation	*Teacher Provides:* - Question - Procedure	*Teacher Provides:* - Question	*Teacher Provides:* -
Student Provides: -	*Student Provides:* - Solution/Explanation	*Student Provides:* -Procedure -Solution/Explanation	*Student Provides:* -Question - Procedure - Solution/Explanation

Figure 3.3. Inquiry Continuum Rubric (Adapted from Banchi & Bell, 2008)

The pre/post analysis of inquiry levels will be presented in section 4.6.4.

3.3.2 Research Phase 1 (Step 2): Research Question Exploration

The research problem was explored to facilitate the elicitation, refinement, and evaluation of potential research questions that were used to guide the thesis (Step 2). Specific pedagogical goals and guiding theory were further conceptualized. This step also served to guide and focus the survey of the literature that occurred in research (Step 3).

3.3.3 Research Phase 1 (Step 3): Survey the Literature and the Field

The purpose of the research (Step 3) was to refine and clarify the problem and emerging research questions with both a scrutiny of how the problem was seen manifesting in the field and consideration of the theory used to interpret and clarify the problem. Potential solutions and strategies were developed and refined. After step three was completed the literature was surveyed, summarized, and analyzed. The literature review was presented as chapter 2.

Informal observations were conducted in the field to see first-hand how the perceived problem was manifesting. Insights were gleaned about potential solutions or strategies that held promise in solving the stated problem. The guiding theoretical perspectives were developed and initial models, strategies, and solutions that were developed during the needs analysis were further developed. Research questions that emerged during the needs analysis were refined, and additional questions were developed. Additional secondary information was sought out to provide insight. Through these methods of asking questions and gathering and analyzing information the problem refined and elaborated. Finally, the integration and relationship of practice and research perspectives to the theoretical perspectives were explored.

3.3.4 Research Phase 1 (Step 4): Theory Development

The purpose of research (Step 4) was to explore how theory could be used to prescribe, describe, and explain how an educational intervention could positively impact student educational outcomes. McKinney and Reeves (2012) describe how theory is used in educational design research this way: "Educational design research uses theory, along with empirical findings, craft wisdom, inspiration, and experience as inputs to create interventions that solve real problems" (p. 39). During this step the researcher also explored the contextual variables that could influence and potentially impact the local theory that was emerging out of the thesis and the design itself.

3.3.5 Research Phase 1 (Step 5): Audience Characterization / Selection

At the end of Phase 1 a characterization process occurred which involved exploring and clarifying specifics of what the intended user of the intervention would be. Even though the intervention was designed for a specific audience of middle level students who were attending a specific after-school education program, the researcher also thought about how it could be used more broadly in other contexts. A participant selection process was used, which included a parent application, student essay, letter of recommendation, and demographic profile. A stated goal of the local context was to use the demographic breakdown of the local city as a guide in selecting participants (e.g. multiracial 3%, Native American 1%, Asian 2%, Hispanic 11%, African American 20%, Caucasian 63%). Students were placed in a category based on responses given in the application. During program selection numbers were drawn from the pool of 100 applicants to determine participation.

3.4 Methods Used for Phase 2: Intervention Design and Development

3.4.0 Section Overview

This section describes research (Steps 6 through 10), which together, make up Phase 2 of the research model: Intervention Design and Refinement. During Step 6, the mixed method research design chosen for the thesis was reviewed, making sure the data-mixing plan would still be appropriate for how the intervention was manifesting. During research (Step 7), the design principles, goals and strategies were determined, which were used in (Step 8) to create the prototype intervention design. Student and teacher outcomes, presented in Table 1.3, were also drafted.

The prototype intervention was refined using formative testing during three implementation mini-cycles (Step 9), which produced the detailed intervention design after the last cycle (Step 10). The last task of Phase 2 involved the refinement of the local instructional theory based on these activities. Figure 3.4 shows where Phase 2 is located within the larger research design.

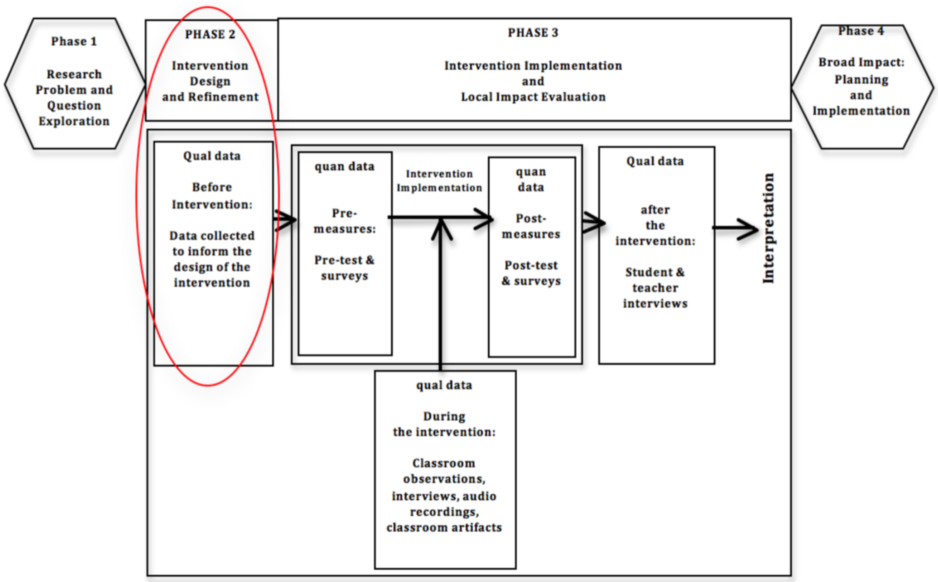


Figure 3.4. Phase 2 Located within Larger Research Design

3.4.1 Research Phase 2 (Step 6): Research Design

The research process, as envisioned in the research model, has the development of the research design as research (Step 6). However, in this thesis, the research design was chosen earlier based on a suggestion by Creswell and Plano Clark (2007). These researchers suggest an embedded mixed method research design is most appropriate for graduate students who are first learning educational design methods. Normally, the research design cannot be created until it is known what the research questions are, and in turn, what kind of data would be needed to answer them. Options include qualitative, quantitative, or mixed method designs (Creswell & Plano Clark, 2007). Even though chosen earlier, the research was refined during this step.

3.4.2 Research Phase 2 (Step 7): Design Principles, Goals, and Strategies

During research Phase 2, (Step 7), the design principles, goals, and strategies that guided the development of the intervention were formalized. A document was created during this step, in teacher language, to summarize and translate these ideas for teacher use (see Section 5.2). This document was used throughout implementation as background information for the teacher. Practical, theoretical, and research-based design principles were used in the development and refinement of the intervention. Design principles were developed, implemented, and refined, throughout three iterative design mini-cycles that are described in the next section. The researcher constantly reviewed the theory guiding the thesis, and began developing a local instruction theory based upon the work done up to this point.

3.4.3 Research Phase 2 (Step 8): Prototype Design

During research Phase 2 (Step 8), the design principles, goals, and strategies developed during research (Step 7) were used to create a final prototype intervention. The prototype intervention was refined through design mini-cycles consisting of implementation, evaluation, and refinement activities. Two longer cycles occurred, each taking place over the span of four months during the enactment of a 56-hour student program held at the study site. Within each of these longer cycles several short duration cycles also occurred. At this point the researcher evaluated the intervention formatively using the criteria described in section 3.2.2. Because of the complexity of the problem, the researcher devoted the time needed to develop an intervention with fine grain detail. This complexity arose from the need to support both the teacher in the design and enactment of the envisioned learning environment, and the students who were doing the learning within it. During research (Step 8), the researcher continually reviewed the theory guiding the thesis, and refined the local instructional theory being developed. Expected student and teacher outcomes were also refined.

3.4.4 Research Phase 2, (Steps 9 and 10): Iterative Design Mini-cycles and the Detailed Design

A final design mini-cycle occurred during research Phase 2 (Step 9) in which the prototype intervention was refined. This cycle occurred in the form of a pilot, where the teacher used the intervention with a different group of students the semester before actual implementation. This timeline was chosen to provide the researcher with adequate time for refinement activities. The researcher needed to refine the local instructional theory first, and then use it to develop the finished intervention, called the detailed intervention. The development of the detailed intervention was research (Step 10). The detailed intervention was formatively tested in terms of its preferability, which sought to determine whether the detailed design was better than the prototype. The formative testing revealed a need for additional support materials. These materials were designed, implemented, and evaluated with the same process used during prototype development. The knowledge and beliefs the implementing teacher held about teaching and learning were also determined using the Teacher Beliefs Inventory (TBI), which is described in section 4.6.1. The researcher wondered if an alignment between the personal beliefs of the implementing teacher and the philosophy underpinning the intervention was critical for the intervention to be implemented with fidelity. To support teacher alignment with the vision for how the intervention should be implemented with students a document was developed and presented to the teacher. This document is presented in section 5.2. The teacher and the researcher continually reviewed this document throughout implementation. Implementation support materials were developed, which are presented in section 5.5.7 – 5.5.9.

3.5 Methods Used for Phase 3: Intervention Implementation and Local Impact Evaluation

3.5.0 Section Overview

This section describes research (Steps 11-14), which together, make up Phase 3 of the research model: Intervention Implementation and Local Impact Evaluation. During this phase data were collected at four different points over the course of the phase. First, pre-measure data were collected before intervention implementation in the form of a pre-test, and two surveys. Second, data were collected during implementation through observations, student and teacher interviews, and collected classroom artifacts. Third, post-measure data was collected at the end of implementation using a post-test and the students once again completed the surveys. Two to four weeks after the conclusion of the implementation, a final collection of data occurred when six students and their parent were interviewed and transcripts created.

The impact of the intervention was determined through analysis of the data collected at these four points. The highlighted portion of Figure 3.5 shows these four data collection points.

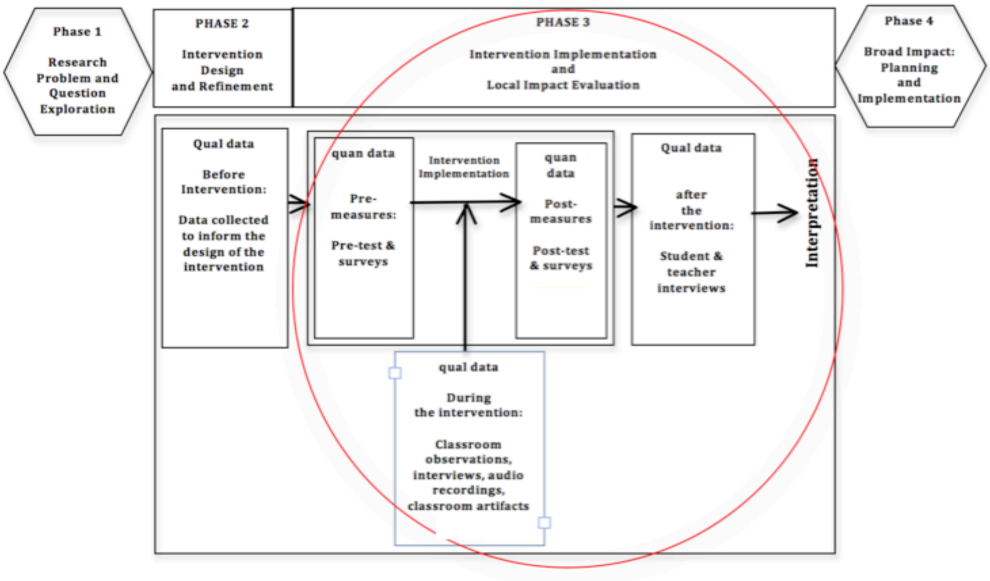


Figure 3.5. Phase 3 Located within the Larger Research Design

3.5.1 Research Phase 3 (Step 11): Theory Refinement

The research process (Step 11) was undertaken to again remind the researcher to continually ground the thesis in theory. The researcher formally revisited the local instructional theory before heading into Phase 3 of the thesis.

3.5.2 Research Phase 3 (Step 12): Intervention Implementation and Data Collection

Data were collected using the expected student and teacher-learning outcomes as a guide to develop and administer pre-measures to quantitatively assess student and teacher learning before the intervention was implemented. The pre-measures consisted of a content pre-test (see Appendix C; Appendix D = Content Test Rubric), a performance assessment (see Appendix E; Appendix F = Performance Assessment Rubric), and two questionnaires.

The first questionnaire used, *How You feel About Science and Learning Scien*ce (see Appendix G), gathered data used to determine the level of interest and engagement students had before and after experiencing the program. This survey was already being used by the local context in their student programs, was developed by an Education Professor from Calvin College. Internal consistency was examined to determine reliability of this questionnaire by calculating Cronbach’s alphas using pre-test data obtained from students who participated in the pilot program before actual implementation. The results from this analysis, presented in

Table 3.2, indicates a strong reliability coefficient among the set of items contained in the questionnaire. Reliability is considered strong if it is between .80 and .90.

Table 3.2

Cronbach's Alpha Coefficients: How you feel about Science and Learning Science

Number of Items	*Item Numbers*	*Reliability Coefficient*
21	*1-21*	*.85*

The second questionnaire administered, *Your Opinions About Science and Learning Science* (Appendix H), was also used as a pre and post-test to evaluate the impact the intervention had on student interest and confidence in science. This survey was also used by the local context, and was developed by the same professor. Internal consistency of this questionnaire was also examined to determine reliability by calculating Cronbach's alphas using pre-test data obtained from students who participated in the program the previous semester. The results from this analysis, presented in Table 3.3, also indicates a strong reliability coefficient among the set of items contained in the questionnaire.

Table 3.3

Cronbach's Alpha Coefficients: Your Opinions About Science and Learning Science

Number of Items	*Item Numbers*	*Reliability Coefficient*
11	*8-18*	*.85*

Qualitative data were collected during the implementation itself, to document how the teacher and students implemented the intervention. Data collected included classroom observations (field notes), interview and audio recordings (transcripts), and classroom artifacts (student journals, poster session photographs, and other student created class work).

At the conclusion of the intervention implementation, quantitative data were again collected using post-measures (post-test, performance assessment, and two surveys). Using this pre/post design allowed the researcher to evaluate the impact that the intervention had on student and teacher learning outcomes before and after the implementation of the intervention. Multiple raters (two for journal evaluation, three for content knowledge evaluation) used four-point scale rubrics to evaluate student outcomes for each participating student. To evaluate differences between pre and post-tests, paired t-tests were used to control for differences inherent to the individual student. When there were multiple raters, inter-rater reliability using Pearson's correlation coefficient was determined. Determining Pearson's correlation coefficient is a method used to determine the strength of two-variable relationships (Wang, 2013). Pre and post-test scores for students were arranged over these multiple raters for use in the paired t-tests. If a student did not complete one of the tests, the individual was excluded from analyses.

Two to four weeks after the conclusion of the intervention implementation, six students and their parent were selected for interview using a semi-structured interview protocol for students (see Appendix I) and for parents (see Appendix J). These interviews, which were done to help the researcher make further sense of the impact the intervention had on student learning outcomes, were audiotaped and transcribed as qualitative data and then summarized.

Figure 3.6 shows how the different data collection tools align with the four factors of the multidimensional conceptual change perspective, as well as the different conceptual ideas addressed by the thesis within each perspective.

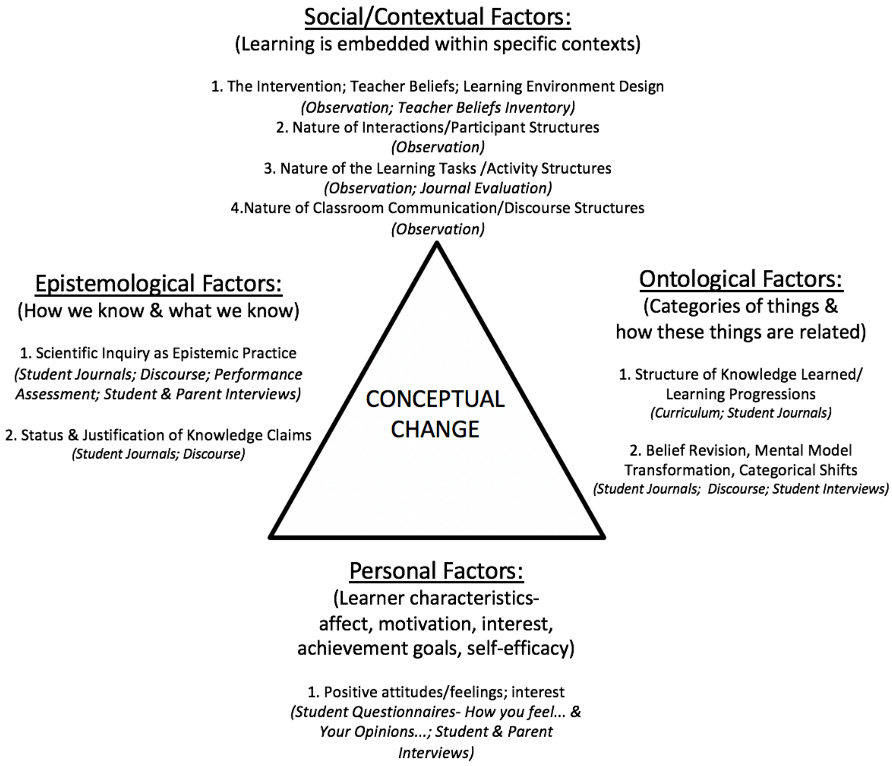


Figure 3.6. Data Collection Tools Alignment with the Multidimensional Conceptual Change Perspective (MCCP)

During Evaluation and Results (Step 13), the researcher used several strategies to make sense of the data. In addition to rubrics other evaluation tools were used to analyze the data collected using the methods and tools described, the multidimensional conceptual change perspective was used to guide an evaluation and interpretation of intervention effectiveness. This MCCP looks at an act of learning through several lens, or vantage points. Both teacher and student learning were analyzed through the lens of the four factors of the updated MCCP (e.g. social/contextual, epistemological, ontological, and Personal Factors/learner characteristics).

3.5.3 Research Phase 3 (Step 13): Evaluation/Results

During research Phase 3 (Step 13), a summary report of the results for each phase of the research was prepared, which are presented as Chapters 4-7.

3.5.4 Research Phase 3 (Step 14): Reflection and Discussion

During research Phase 3 (Step 14), the researcher completed a formal reflection about the intervention, how the intervention was implemented, and whether or not the intervention turned out to be a viable solution to the problem being addressed through this thesis. Using this reflection as a guide, plans were made to improve the intervention in preparation for research Phase 4. This reflection also supported the writing of the thesis summary, and clarified implications of the research for practice and research. These ideas were elaborated after the conclusion of Phase 4, and are presented as Chapter 8.

3.6. Methods Used for Phase 4: Broad Impact Planning and Implementation

3.6.0 Section Overview

This section describes research (Steps 15 and 16), which make up Phase 4 of the research model: Broad Impact Planning and Implementation. During this phase plans for publication and dissemination of the results occurred, as well as a final reflection of the intervention and any potential conflicts of future refinement. The local context adapted the intervention for use (see Chapter 7). The highlighted portion of Figure 3.7 shows how research Phase 4 related to the other research phases.

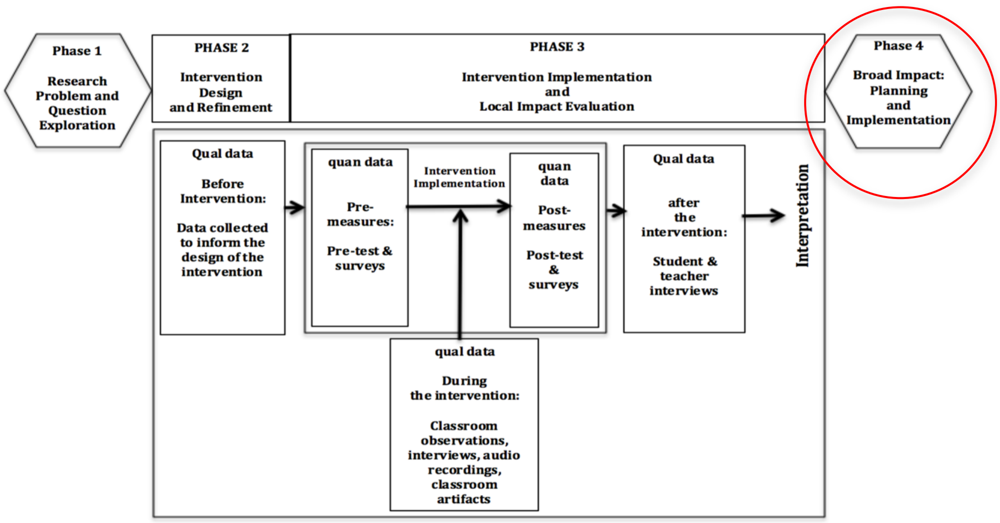


Figure 3.7. Phase 4 Located within the Larger Research Design

3.6.1 Research Phase 4 (Step 15): Plans for Publication

The publication and dissemination of results is an important part of an educational design thesis (Step 15). Additional opportunities for publication and dissemination will be pursued as well to make thesis results available to the research and practice community.

3.6.2 Research Phase 4 (Step 16): Broad Impact Planning and Implementation

Based on the outcome of the reflection and discussion of the results, the intervention was refined and planning was undertaken to determine how and when the intervention may become diffused, adopted, or adapted for use in other contexts. The plan developed had two parts. The first part planned for and initiated the adoption/adaptation of the intervention within the local context. The second part of the plan involved promoting the adoption/adaption of the intervention for use within teacher professional development and in teachers' classrooms more broadly. Consequences of such changes to the intervention were explored and used in planning and initiating potential broad impact. The intervention was refined based upon this thinking. It was determined that the research questions developed for this phase were beyond the scope of the thesis, and constituted future research.

3.7 Chapter 3 Summary

Chapter 3 described the 4-phase, 16-step, educational design research methodology used to guide the thesis. Two studies were enacted to carry out the methodology. Tables 3.4 and 3.5 summarize each study. Study #1 contained Phases 1 and 2 research (Steps 1 – 10). Study #2 contained Phases 3 and 4 research (Steps 11 – 16). Chapters 4 and 5 will summarize and discuss the results of Phase 1 and 2 (Study #1) respectively, while chapters 6 and 7 will do the same for Phases 3 and 4 Study #2.

Table 3.4

Research Questions for Study #1

Study # 1	Student Learning (SL) Focus Research Questions (RQ)	Learning Environment (LE) Focus Research Questions (RQ)
Phase 1: Research Problem and Question Exploration 1. Needs Exploration & Analysis 2. Research Question Exploration 3. Survey the Literature 4. Theory Development 5. Audience Char	What does inquiry-based student learning look like in the study teacher's classroom before intervention implementation? (SLRQ1)	How does the teacher design the classroom-learning environment to promote inquiry-based learning before intervention implementation? (LERQ1)
Phase 2: Intervention Design and Refinement 6. Research Design 7. Design Principles, Goals, & Strategies 8. Prototype Intervention Design 9. Iterative Design Mini-Cycles 10. Detailed Design	What is an optimal design for an intervention that supports student learning, especially in light of: a. What is known about factors that promote conceptual change? (SLRQ2a) b. The enriched vision of science learning? (SLRQ2b)	a. What kind of learning environment is needed to support the student learning focus? (LERQ2a) b. How can the intervention be designed to support the envisioned learning environment? (LERQ2b)

Table 3.5

Research Questions for Study #2

Study #2	Student Learning (SL) Focus Research Questions (RQ)	Learning Environment (LE) Focus Research Questions (RQ)
Phase 3: Intervention Implementation and Local Impact Evaluation: 11. Theory Refinement 12. Implementation/Data Collection 13. Evaluation of Results 14. Reflection and Discussion	What does inquiry-learning look like in the teacher's classroom because of intervention implementation? (SLRQ3a) How did the intervention impact inquiry learning in the teacher's classroom? (SLRQ3b)	How did the intervention support how the teacher designed the learning environment and taught the students? (LEFQ3)
Phase 4: Broad Impact Planning and Implementation: 15. Publish Results 16. Broad Impact Planning a. Diffusion, adoption, adaptation. b. Consequences	How has the intervention impacted student learning in other contexts? (SLRQ4)	How can the intervention that was implemented in other contexts be described? (LERQ4a) How did the intervention support how the teacher designed the learning environment in other contexts? (LERQ4b)

Chapter 4 Results of Study #1, Research Phase1: Research Problem and Question Exploration

4.0 Chapter Overview

Study #1		Study #2	
Phase 1	**Phase 2**	**Phase 3**	**Phase 4**
Research Problem & Question Exploration	Intervention Design & Refinement	Intervention Implementation & Local Impact Evaluation Pre-measures Implementation Post-Measures	Broad Impact: Planning and Implementation

This chapter presents the results of Phase 1, Research Problem and Question Exploration, which involved research (Steps 1-5) of Study #1:

1) Needs Exploration/Analysis (see section 4.1)

2) Research Question Exploration (see section 4.2)

3) Survey the Literature & the Field (see section 4.3)

4) Theory Development (see section 4.4)

5) Audience Characterization / Recruitment (see section 4.5)

In addition to completing research (Steps 1-5), the researcher accomplished four other important research tasks during Phase 1. The *Teacher Beliefs Inventory* (TBI) was administered to the teacher to determine if epistemological beliefs were in conflict with thesis goals. The results of administering the TBI to the teacher will be presented in section 4.6.1. The researcher also spent 16 hours (e.g. 8 sessions) observing the teacher one year prior to intervention implementation. Observational data were used to determine the critical ideas for inquiry present in the teacher's classroom before intervention implementation, which will be presented in section 4.6.2. This data was also used to determine the classroom discourse and participation patterns found in the teacher's classroom before implementation, which will be presented in section 4.6.3. Lastly, the data was used to determine the levels of inquiry present in the lessons observed.

Using these results the researcher was able to answer the two research questions for Phase 1:

1) What did the inquiry-based student learning look like in the teacher's classroom before intervention implementation? (SLRQ1)

2) How did the teacher design the classroom learning environment to promote inquiry-based learning before intervention implementation? (LERQ1)

The answers to these research questions will be presented in section 4.6.4.

4.1 Research Phase 1, Step 1): Needs Exploration and Analysis

Using the methods outlined in section 3.3, the researcher explored possible gaps and/or problems in theory or practice within the problem of low student performance in science. What stood out from this analysis was that researchers and educational reformers have promoted science inquiry as the solution for improvement throughout the past fifty years. Why, then, has there been little to no improvement if inquiry-based learning was indeed the solution? The researcher explored the idea that the vision of inquiry science guiding teachers has not been adequate to support meaningful improvement. Windschitl (2008) describes teacher vision of "doing science" as folk theories or mental models, and contends that most teachers are guided in this area by an inadequate vision, or misunderstanding, of how science practice is viewed. This misunderstanding is grounded in inadequate teacher understanding of what is perceived as the scientific method. Other researchers agree with this view, and promote the idea that an *enriched vision* of science inquiry and its implementation is needed to help science education realize its goal of meaningful improvement (Yerrick & Roth, 2005).

The enriched vision called for by these researchers embraces the perspectives that cognitive, social/affective, and epistemic dimensions of learning need to be explicitly supported and nurtured through inquiry-based instruction. This vision promotes learning as a process where students personally construct knowledge through meaningful engagement with the practices of scientific inquiry. The research also suggests that though personally constructed, knowledge is developed and refined through a process of social negotiation with others in the learning environment. This learning is viewed as a process of conceptual change. Yerrick and Roth (2005) view this kind of learning environment as both a discourse community, and a community of practice (Yerrick & Roth, 2005):

> An enculturation into science practices-a developed competency in tool use, language use, and interpretive stances-needed to be balanced with an enculturation in a critical reflection towards those same scientific tools. Teachers therefore need to engage students in communities of practice, which develop an understanding of the tools and concepts as well as a met-awareness of the shortcomings of those tools to explain the surrounding world. (pp. 131-132).

These ideas suggest the enriched view of science learning and conceptual change is promoted within communities of practice and is seen as having both individual and social/cultural components.

The problem being addressed and the idea that teachers need an enriched vision for science education were explored from the vantage point of both practice and theory perspectives. To explore the practice side of the problem the researcher sought out additional information from professional knowledge and experience sources. To this end, the researcher brainstormed with a group of veteran professional development providers. A summary of this brainstorm of relevant professional knowledge pertaining to effective teacher improvement practices, as shown in Table 4.1.

Table 4.1

Practice-based Professional Knowledge

Brainstorm Summary	
1.	Teacher professional development needs time, which should be built into the normal yearly schedule.
2.	Beliefs about teaching and learning should be made explicit. Connect beliefs to teacher decisions and actions within the classroom.
3.	Teachers need models of effective classroom inquiry-based practices beyond their limited view of the scientific method. Models used in the past: Learning Cycle, P-O-E Cycles, and 5 E.
4.	Teachers need significant training and support to move from predominately teacher-centered approaches we see in classrooms to the student-centered approaches needed to implement the enriched vision of inquiry science.
5.	Teachers need immersion experiences modeling how to use inquiry-based practices both as a tool to support student knowledge construction, and to improve their own content knowledge.
6.	Curricular, instructional, and assessment-based supports are needed by teachers to implement inquiry-based practices successfully in their classrooms.
7.	Teachers need an enriched vision of classroom inquiry.

In summary, from a practice-based perspective, teachers lack support tools, including an effective inquiry-based learning model, to implement the enriched vision of science education. After researching this idea further within the literature, the researcher discovered that Duschl, et. al., in *Taking Science to School* (NRC, 2007), supported this thinking through the recommendation that "State and local leaders in science education should provide teachers with models of classroom instruction that incorporates the four strands (e.g. enriched vision of science education)" p. 349. Duschl, et. al (NRC, 2007) go on to explain how such models of effective practice were not currently available for teachers to support implementation of inquiry-based teaching and learning practices.

Based on these explorations, *the researcher concluded that a lack of pedagogical tools and effective models of classroom instruction teachers need to support implementation of the enriched vision of science inquiry presented a gap in both research and practice*. It was decided that the development and testing of an intervention solution to address this gap would be investigated.

4.2 Research Phase 1 (Step 2): Research Question Exploration

The next research activity was the exploration of research questions that would guide the research. The research questions for study #1 (and also study #2 – see Chapters 6 & 7) were developed over the course of several months. The researcher decided to have both a student learning focus and a learning environment focus for research questions at each phase. Table 4.2 lists the research steps and corresponding questions for the Study #1, Phase 1.

Table 4.2

Research Steps and Corresponding Research Questions for Study #1, Phase 1

Research Phases & Associated Steps	Student Learning (SL) Focus Research Questions (RQ)	Learning Environment (LE) Focus Research Questions (RQ)
Phase 1 Research Problem and Question Exploration: 1. Needs Exploration/Analysis 2. Research Question Exploration 3. Survey the Literature 4. Theory Development 5. Audience Characterization	SLRQ1: What did inquiry-based student learning look like in the study teacher's classroom before intervention implementation?	LERQ1: How did the teacher design the classroom learning environment before intervention implementation?

The research questions for Study #1, Phase 2 are presented in section 5.0.

4.3 Research Phase 1 (Step 3): Survey the Literature and the Field

The purpose of research (Step 3) of the research process was to refine and clarify the problem and emerging research questions with both a scrutiny of how the problem was seen manifesting in the field, and with using theory to interpret and clarify. Potential solutions and strategies were developed and refined. After research (Step 3) was completed the literature was surveyed, summarized, and analyzed. This summary created for this research step is presented as thesis chapter 2.

Observations were also conducted in the field to see first-hand how the perceived problem was manifesting in other contexts. Insights were gleaned about potential solutions or strategies that held promise in solving the stated problem. The guiding theoretical perspectives were determined and initial models, strategies, and solutions that were conceptualized during the needs analysis were further developed. Research questions that emerged during this step were refined, and additional questions were developed. Additional secondary information was sought to provide insight. Through these methods of asking questions and gathering and analyzing information, the problem understanding was refined and potential solutions elaborated. Finally, the integration and relationship of practice and research perspectives to theoretical perspectives was noted.

4.4 Research Phase 1 (Step 4): Theory Development and Problem Clarification

As stated in section 3.3.4, theory is used for many different purposes in addition to the analysis and interpretation of a learning event (e.g. multidimensional conceptual change perspective) as original used by Venville and Treagust (1998). At this stage in the thesis the updated multidimensional conceptual change theory was used in conjunction with the research on effective learning (e.g. enriched vision of science education) and factors that promote conceptual change to both prescribe how the intervention would manifest, and predict how the factors of conceptual change would promote learning. Using the literature as a guide, research focus areas were determined for each area of the multidimensional conceptual change theory. The summary of the updated theoretical framework is shown in Figure 4.1, showing the research focus areas.

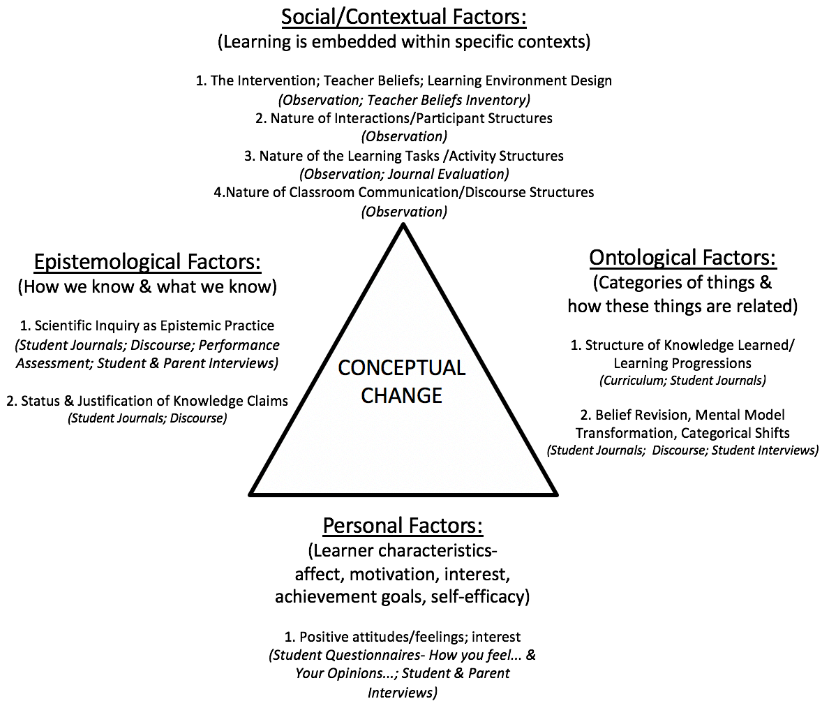


Figure 4.1. Multidimensional Conceptual Change Perspective-Research Focus Areas

4.5 Research Phase 1 (Step 5): Audience Characterization and Student Selection

Initially, the intervention was designed for students who participated in after-school (informal) science education program called the *Genetic Diversity and Human* Health program. Students participating in this program attended two times (e.g. T/T) per week from 4-6pm for a total of 56 total hours over the course of the intervention implementation. The participating students during intervention implementation were either 6^{th} or 7^{th} graders. Although the researcher hoped the intervention would eventually be adopted and/or adapted for use within the local context, the intention from the start to also design the intervention for possible use outside of these programs in other educational contexts (e.g. broader context). Exploring the transferability of interventions to broader contexts is an important consideration in educational design research.

Program applications were distributed to area community organizations and schools. In addition to completing the application students wrote an essay about why they wanted to attend the program. Selection was not based on school grades, but rather student passion for science was considered, and whether any barriers existed that would preclude attendance. Because students self-selected into the program based on their already developed positive interest for science, and also because all students also attended science classes as part of their regular schooling while also attending the after-school program, no control group was selected for comparison purposes. In addition to the student essay, socioeconomic and ethnic diversity variables were considered. Every attempt was made to match the student demographic profile to the profile of the city of Grand Rapids, Michigan demographics (e.g. multiracial 3%, Native American 1%, Asian 2%, Hispanic 11%, African American 20%, Caucasian 63%). The average family income of families of selected students was slightly higher than the median family income for the Grand Rapids area. The program was tuition free, and if students needed transportation it was provided free of charge for the duration of the program. Twenty students were initially selected out of 100 applicants. Two students transferred out of the program, to bring the total of participation students to eighteen (11 female; 7 male). The ethnic demographic profile of participating student is shown in Table 4.3.

Table 4.3

Ethnic Demographic of Participating Students

	African American	American Indian	Asian	Caucasian	Hispanic	Others	Total
Male	2	0	0	5	0	0	7
Female	2	1	0	6	1	1	11
Totals	4	1	0	11	1	1	18

4.6 Additional Research Activities of Research Phase 1

4.6.0 Section Overview

Additional research activities occurred during Phase 1, described in section 3.3.1. The teacher was given the *Teacher Beliefs Inventory* (TBI) to determine if the epistemological beliefs held were aligned with thesis goals. The result of this analysis is presented in section 4.6.1. Next, the teacher was observed teaching to gain baseline data before intervention implementation. This data was used to document the inquiry-based teaching and learning practices occurring in the teachers' classroom before intervention implementation. Section 4.6.2 summarizes rubric scores relative to critical ideas of inquiry, and section 4.6.3 summarizes the dominant themes and patterns found in the teachers' classroom. Data from these analyses were used to answer the research questions for Phase 1, which will be presented in sections 4.6.5.1 and 4.6.5.2. These research questions are:

1) What did the inquiry-based student learning look like in the teacher's classroom before intervention implementation? (SLRQ1)

2) How did the teacher design the classroom learning environment to promote inquiry-based learning before intervention implementation? (LERQ1)

The results from these pre-intervention analyses were compared to results found post-intervention implementation (section 6.2.2) to determine intervention impact on both the inquiry learning that occurred in the teachers' classroom, and how the teacher designed the classroom to promote it.

4.6.1 Teacher Beliefs Inventory

Using the Teacher Beliefs Inventory (TBI) semi-structured interview protocol (Luft & Roehrig, 2007), which is described in section 3.3.1, the researcher explored the epistemological beliefs held by the teacher. Luft and Roehrig (2007) describe how these beliefs are linked to how teachers design the classroom-learning environment to support learning. This examination led to the finding that the teacher held epistemological beliefs that were mostly consistent with the thesis goals. However, results linked to two specific questions within the interview prompted a need to probe further by the researcher. One question explored how the teacher decided what to teach and the other probed how the teacher decided it was the appropriate time to move on instructionally. In the first case the teacher voiced a common frustration often heard when working with teachers in reform activities- the decision of what to teach is out of a teachers' control, being dictated by outside forces. This idea is considered to be a traditional response (e.g. the opposite of reform-minded) within the TBI protocol. After much discussion, the teacher realized that these feelings were left over from a previous teaching context (e.g. teaching high school science within a public school) and not related, as much, to the context of the *Genetic Diversity and Human Health* program. However, time did remain an issue, based on the reality of using living organisms as models within the program. These organisms have developmental life cycles that needed to be constantly addressed. For examples, when students were culturing bacteria the teacher needed to be cognizant of the fact that five days growth was optimum. Because the students met after school on Tuesday and Thursday each week, the bacteria cultures needed to go into the incubators by the end of class Thursday for the following weeks activities. To meet such deadlines, curriculum needed to be adjusted to accommodate. However, the teacher realized that because the *Genetic Diversity and Human Health* curriculum being used within the program was not being dictated by any outside forces, and as such, there was room for the consideration of student voice and choice within curricular decisions.

The second question, which the researcher had to simultaneously consider along with the first question, involved how to know when to move on instructionally. The teacher again voiced a concern of time being an important factor involved in knowing when to move on to a new topic. The researcher explored this idea in terms of how the intervention being designed would be more reform-minded. Based on this discussion the idea of giving the learning "time to breathe" became a powerful metaphor for how to think about time within the program. By carefully scaffolding (e.g. supporting) student expertise (e.g. knowledge and skill levels) over carefully co-constructed instructional sequences, students would be better able to self-regulate the learning process, but also learn at a deeper level. To the researcher and teacher, letting the learning breathe, meant giving students the time they needed to make sense of their experiences.

The research underpinning this discussion indicates epistemological beliefs guide teachers' decisions and actions around the design of the classroom-learning environment (Jones & Carter, 2007; Pajares, 1992; Richardson, 1996). "In science education, research on beliefs has been linked to the use of inquiry, national reforms, or constructivist practice in the classroom" (Luft & Roehrig, 2007, pp. 38). The researcher viewed the thesis goals through the lens of these categories and determined that the responsive and reform-based categories strongly aligned. Based on this research, the researcher felt that teachers whose epistemological beliefs are categorized as either traditional or instructive may have a difficult time designing the kind of learning environment envisioned with an enriched view of inquiry. The TBI was administered to the teacher the semester before intervention implementation. Results can be seen in Table 4.4. Highlighted are the two questions and responses that prompted discussion, described above, and also promoted further exploration.

Table 4.4

Results of Teacher Beliefs Interview (TBI)

Question	Example Teacher Responses	Belief Categories
1. How do you maximize student learning in your classroom? (Learning)	a. "Choice is important."	Reformed
	b. "Using an inquiry model allows students to interact with the experience at their own level."	Transitional
2. How do you describe your role as a teacher? (Knowledge)	a. "We have to spend a lot of time building prior knowledge and experience."	Reformed
	b. "They need to be taught how to be in charge of their own learning."	Responsive
3. How do you know when your students understand? (Learning)	a. "I know they understand when they are able to apply their developing knowledge and skills."	Responsive
	b. "They might defend their ideas."	Reformed
4. In the school setting, how do you decide what to teach and what not to teach? (Knowledge)	a. "What I teach is often dictated by outside forces."	Traditional
	b. "But I also take student interest into account when determining what to teach."	Responsive
	c. "A critical piece is that students must feel like it is important and relevant to them."	Responsive
	d. "Within every day we give students choice and I think this is very important."	Responsive
5. How do you decide when to move on to a new topic in your classroom? (Knowledge)	a. "Time is always a constraint that I have to take into account when deciding to move on or not with my teaching"	Traditional
	b. "Depending on results of the assessments...I would let assessments dictate if extended teaching is needed"	Responsive
6. How do your students learn science best? (Learning)	a. "They have to ask their own questions and follow through to find answers to them"	Responsive
	b. "I create collaborative learning environments where they integrate meaning"	Reformed
	c. "The goal is to shift control as much as possible from the teacher"	Responsive
	d. "A collaborative environment where students are learning in teams"	Responsive
7. How do you know when learning is occurring in your classroom? (Learning)	"Have students present and offer their reflections"	Transitional
	"Sharing of ideas"	Transitional
	"Students are able to transfer or apply outside the school setting"	Reform-based

The TBI provided useful information on the epistemological beliefs that the teacher used to guide decisions and actions related to the design of the classroom learning environment. The researcher determined that the program teachers' epistemological beliefs aligned with the goals of the thesis, and would not present a barrier to intervention implementation.

4.6.2 Evaluation of Pre-intervention Critical Ideas of Inquiry

To determine the pre-intervention inquiry learning practices of the teacher, the researcher observed eight sessions of instruction (e.g. 16 hours) the year before the intervention was implemented. The methods for accomplishing this are described in section 3.3.1. In summary, a rubric was used to evaluate critical ideas of inquiry present in the teachers' classroom. This data was compared to the critical idea rubric scores post-implementation to determine how inquiry learning changed based on the intervention. The result of this evaluation is presented in section 6.2.2.

Table 4.5

Pre-intervention Inquiry Ideas Rubric Scores

Critical Ideas for Inquiry	Rubric Score
Use of Technology	2
Support/Student Self-management	2
Support/Student Habits of Mind	1
Evaluation	2
Application Experience	2
Proposing Explanations	1
Observation/Analysis	2
Investigation Design	2
Prediction/Hypothesis Use	1
Knowledge Probe	1
Generating Questions	1

4.6.3 Evaluation of Pre-intervention Discourse and Participation Patterns

The classroom observational data were also used to determine and evaluate classroom discourse and participation patterns found within the classroom pre-implementation. Table 4.6 presents the results of analyzing the classroom observational data. These results will be compared to the discourse and participation patterns found in the classroom due to the intervention. Section 6.2.2 presents this evaluation.

Table 4.6

Classroom Discourse and Participation Patterns Pre-intervention Implementation

Classroom Pattern Type	Patterns Studied	% of Classroom Time
Discourse	Teacher Talk	31%
	Student & Teacher Talk (e.g. discussion	36%
	Student to Student Talk	25%
	No Talking	8%
	Teacher / Whole Group (TWG)	31%
Participation	Teacher/Student (SHARED)	36%
	Student/Small Group (SSG)	21%
	Student/Whole Group (SWG)	4%
	Student/Individual (SI)	8%

These themes and ideas found pre-implementation will be compared to those found post-implementation to determine the interventions impact is presented in section 6.2.2.

4.6.4 Inquiry Levels Present Pre-implementation

Section 3.3.1 discusses four basic inquiry forms (e.g. confirmation, structured, guided, and open) and presents a rubric to support analysis of classroom inquiry lessons. During the classroom observation the researcher observed eight lessons considered a form of inquiry. Table 4.7 shows the results of attaching the rubric score to each of the lessons.

Table 4.7

Inquiry Forms Present in Classroom Pre-implementation

Confirmation	Structured	Guided	Open
0%	63%	37%	0%

This data indicates that for the majority of the inquiry lessons experienced by students' pre-implementation were in the form of structured investigations. In a structured investigation the teacher presents both the question students will investigate, and the procedure they will follow to answer it. In a structured inquiry, students construct an explanation rather than being presented one by the teacher. In a minority of lessons students experienced a guided inquiry form, which means that the teacher provided the question, and the students developed the procedure and explanation themselves. In zero of the lessons did the teacher have the students confirm a principle when they already knew the answer in advance (e.g. confirmation lesson), or formulate their own investigation questions, procedures, explanations during an inquiry (e.g. open inquiry). These results will be compared to the form of inquiry students experience as a result of intervention implementation, which will be presented in 6.2.2.

4.6.5 Answers to Phase 1 Research Questions

4.6.5.0 Section Overview

Section 4.6.5 contains two sub-sections. Section 4.6.5.1 contains the answer to research question SLRQ1, and section 4.6.5.2 contains the answer to research question LERQ1.

4.6.5.1 Answer to Research Question SLRQ1

What did the inquiry-based student learning look like in the teacher's classroom before intervention implementation? (SLRQ1)

Each of the eight inquiry lessons (e.g. 16 hours) observed started with snacks and the teacher telling a content story or students having an interactive media experience (i.e. How jellyfish are adapted for survival in their environment). These stories were designed to develop student interest in, and motivation for, the study of particular content. Active engagement of the students was interpreted as high by the researcher. Students were also observed working individually, in small groups, and in whole group arrangements. The dominant discourse pattern found was class discussion (36%) followed by teacher-dominated talk (31%). This indicates that the students were arranged with the teacher up front of the classroom, with the students attending in a whole group manner 67% of the observed class time. Consequently, student sense-making occurred whole group led by the teacher. During investigations students were observed placing various tape-ins (i.e. teacher provided copies of investigation plans) into their journals as lessons proceeded. This occurred under the direct guidance of the teacher. Students were observed using laptops, various probes (i.e. temperature, humidity, light), document cameras, and an interactive whiteboard at various times during class time.

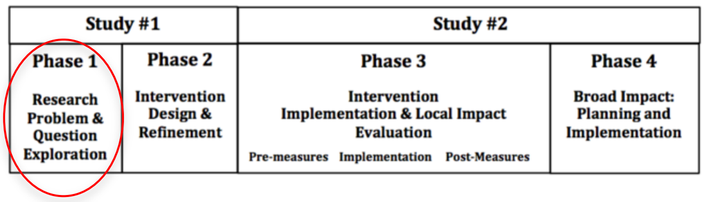
4.6.5.2 Answer to Research Question LERQ1

How did the teacher design the classroom-learning environment to promote inquiry-based learning before intervention implementation? (LERQ1)

The teacher organized the physical space for all activities in two rooms (e.g. laboratory and classroom), which had a variety of tables for the students to sit. The teacher also had the students sit on the floor occasionally. This arrangement allowed for separate investigation and discussion spaces within the learning environment. The teacher could physically move the students out of the investigation spaces for focused discussions. This was important because the investigation spaces, interesting in their own right, also contained a large number of living organisms in cages and tanks, which excited the students greatly.

The rubric scores for the eleven critical ideas for inquiry were analyzed to determine how the teacher designed the learning environment to support student engagement. The results indicate that the teacher effectively designed the learning environment to support student use of technology. The teacher was also skilled at supporting student ability to self-manage inquiry activity within the learning environment and designed the learning environment to support application experiences. The teacher also supported students in the designing of investigations, making quality observations, and evaluating the outcomes of inquiry activities. However, the teacher did not design the learning environment to support students asking their own questions, activating and using their prior knowledge during instruction, making predictions of future outcomes, or proposing explanations to answer investigation questions. The teacher did not intentionally design the learning environment support student use of productive habits of mind, such as creative or critical thinking.

4.7 Chapter 4 Summary



This chapter presented the results of Phase 1, Research Problem and Question Exploration, which involved research (Steps 1-5) of Study #1. In addition to completing research (Steps 1-5), the researcher accomplished four other important research tasks during Phase 1. The *Teacher Beliefs Inventory* (TBI) was administered to the teacher and it was determined that epistemological beliefs were not in conflict with thesis goals. These results were presented in section 4.6.1. The researcher spent 16 hours (e.g. 8 2-hours sessions) observing the teacher one year prior to intervention implementation. Observational data were used to determine the critical ideas for inquiry present in the teacher's classroom before intervention implementation, which were presented in section 4.6.2. This data was also used to determine the classroom discourse and participation patterns found in the teacher's classroom before implementation, which were presented in section 4.6.3. Lastly, the data was used to determine the levels of inquiry present in the lessons observed. Using these results the researcher was able to answer the two research questions for Phase 1:

> *1) What did the inquiry-based student learning look like in the teacher's classroom before intervention implementation? (SLRQ1)*

> *2) How did the teacher design the classroom learning environment to promote inquiry-based learning before intervention implementation? (LERQ1)*

The answers to these research questions were presented in sections 4.6.5.1 and 4.6.5.2.

Chapter 5 Results of Study #1, Research Phase 2: Intervention Design and Refinement

5.0 Chapter Overview

Study #1		Study #2	
Phase 1 Research Problem & Question Exploration	Phase 2 Intervention Design & Refinement	Phase 3 Intervention Implementation & Local Impact Evaluation Pre-measures Implementation Post-Measures	Phase 4 Broad Impact: Planning and Implementation

This chapter presents the results of Phase 2, Intervention Design and Refinement, which involved research (Steps 6-10) of study # 1:

6) Research Design (see section 5.1)

7) Design Principles, Goals, and Strategies (see section 5.2)

8) Prototype Intervention Design (see section 5.3)

9) Iterative Design Mini-cycles (see section 5.3)

10) Development of the Detailed Design. (see section 5.5).

The first research activity of Phase 2 was to review and finalize the research design (section 5.1), which was accomplished as research (Step 6). During research (Step 7) the researcher started developing the design principles, goals, and strategies that would guide the development of the intervention. Section 5.2 presents an instructional goals and pedagogical strategies statement that functioned as informal design principles, goals, and strategies early on during the development of the intervention. These informal constructs evolved into more formal ones as the intervention matured. During research (Step 8) a prototype intervention was developed and then iteratively refined during research (Step 9). After the prototype intervention was developed, the researcher used a questioning process based on conceptual change theory and the enriched vision of science education to clarify it (see section 5.4). During research (Step 10) the prototype intervention was refined into the finished detailed design (e.g. the completed intervention). This process started with the development of overarching design goals based on the three broad dimensions of the prototype intervention (e.g. habits of mind, inquiry-based learning process, and a socially and language rich learning environment). Using the overarching design goals a local instructional theory was developed. After constructing the student and teacher learning outcomes, the researcher used the local instructional theory to develop formal design principles that were used to refine the Q-POE2 Process of Scientific Inquiry and the Community of Scientific Practice Model. A suite of student and teacher supports was also developed (see sections 5.5.7- 5.5.9; 5.5.11) as part of the intervention. At this point in the research, the researcher also refined the curriculum that would be used with the intervention (section 5.6). During the last activity of Phase 2 the researcher answered the research questions for this phase. The research steps and corresponding research questions for Study #2, Phase 2 are presented in Table 5.1. The answers to these questions will be presented in section 5.7.

Table 5.1

Research Steps and Corresponding Research Questions for Study #1, Phase 2

Research Phases & Associated Steps	Student Learning (SL) Focus Research Questions (RQ)	Learning Environment (LE) Focus Research Questions (RQ)
Phase 2:		
Intervention Design And Refinement	What is an optimal design for an intervention that supports student learning, especially in light of:	What is an optimal design for an inquiry learning environment, especially in light of:
6. Research Design 7. Design Principles, Goals, & Strategies 8. Prototype Intervention Design 9. Iterative Design Mini-Cycles 10. Detailed Design	a. What is known about factors that promote conceptual change? (SLRQ2a) b. The enriched vision of science learning? (SLRQ2b)	a. What kind of learning environment is needed to support the student learning focus? (LERQ2a) b. How can the intervention be designed to support the envisioned learning environment? (LERQ2b)

5.1 Research Phase 2 (Step 6): Research Design

The four-phase, 16-step, research design guiding the thesis is discussed in Section 3.1, and summarized in Tables 3.1 and 3.3, was refined during Phase 2 (Step 6): Research Design. It was determined during this phase that two studies would be undertaken to complete the research design. Study #1 would include research Phases 1 and 2, and Study #2 would include research Phases 3 and 4. The detailed research design is presented as thesis chapter 3.

5.2 Research Phase 2 (Step 7): Design Principles, Goals, and Strategies

An instructional goals/ pedagogical strategies statement was written by the researcher to describe the enriched vision of science education. From a research perspective this statement functioned as an informal version of the design principals, goals, and strategies for the intervention and was written in teacher language. Formal design goals, principles, and strategies developed out of this informal version, and were used throughout to guide the design of the detailed intervention (see section 5.5).

The goals/pedagogical statement was given to the teacher as a first step in getting ready to implement the intervention. It was revisited several times before the intervention was implemented, and also reviewed daily by the teacher and researcher throughout implementation to promote discussion and insight. This document, named *Instructional Goals and Strategies*, was key to understanding how the enriched vision of science was used to support the teacher while implementing the intervention. Even though this document is long, it is presented in its entirety because of its importance:

Instructional Goals and Strategies:

The overarching vision for students experiencing the Genetic Diversity and Human Health curriculum is:

Students will learn how to think, act, and talk like scientists within a compelling inquiry-based community of practice. The result of student learning will be the construction and application of scientific knowledge, the understanding and using science as a way of knowing, and an increase in science engagement. Students will learn about and explore biodiversity at the level and DNA/genes (e.g. genetic diversity).

To achieve this vision the learning activities have been designed using the following learning outcomes. Students will:

1. *Develop, and/or maintain positive attitudes and interest in science*
2. *Design, conduct, and communicate the results of scientific investigations*
3. *Engage in scientific reasoning*
4. *Explain how health depends on genetic diversity found in species & habitats*
5. *Explain why certain organisms are used as models to learn about and improve human health*
6. *Describe how plant and animal cells are alike and different*
7. *Explain how DNA causes biodiversity*

How the Genetic Diversity and Human Health Curriculum Supports these Goals:

The curriculum has been designed as an extended inquiry project that incorporates the outcomes listed above. Each lesson builds on the previous one as the instructional sequence unfolds. As a culminating experience, groups of students work in teams to design and conduct an independent research project that applies previous learning within a *compelling context where students develop their own research labs in teams. Not only is the culminating project intended to promote student interest in science, it also is designed to support students as they independently collect and evaluate evidence, develop language and reasoning skills, and participate in a community of scientific practice. As students gain confidence in their ability within this community they also develop a positive identity as science learners and perhaps as potential scientists as well.*

In order to meet these goals, the teacher needs to engage a set of pedagogical strategies within a classroom environment explicitly designed to support learning through scientific inquiry. Students need to think, act, and talk like scientists as they construct new scientific knowledge and experience the nature of science. Pedagogical strategies to support scientific learning by students emerge from a set of critical ideas from educational literature on the implementation of scientific inquiry in the classroom. The critical ideas of a scientific inquiry pedagogy are:

***Generating Questions**: Instruction should be organized around questions, problems, and a sense of wonder. Students should develop and use an investigation question to frame the design, carrying out, and communication of the results of a science investigation.*

***Knowledge Probe:** There are two sources of knowledge to focus on instructionally.*

1. *Student personal knowledge*
   A. The activation and use of student prior knowledge & experience should be an instructional focus.
2. *Secondary knowledge*
   B. Obtaining and integrating secondary information will occur as knowledge probes as needed throughout an investigation.

***Prediction / Investigation Design / Explanation / Evaluation:** There should also be a focus on student sense making and knowledge construction practices, including, but not limited to, the proposing of explanations based on data transformed in evidence by students.*

***Observation & Data Analysis**: Instruction will be designed with active student engagement in the gathering, organization, and analysis of data.*

***Application Experience**: Student "taking action" through meaningful application of newly constructed knowledge will be a part of the learning process. Examples: artifact construction, public demonstrations, field experiences, model development, etc.*

***Habits of Mind & Student Self-regulation**: Intentional teaching and student development of, "Productive Habits of Mind", focusing on critical and creative thinking, student self-regulation and engagement, and REFLECTION will be part of every lesson.*

***Discourse**: Student-centered scientific discourse and communication practices will support student sense-making.*

***Socially & Language Rich Learning Environment**: The learning environment will be designed as a "Community of Scientific Practice", with collaborative student participation, discourse, and social negotiation of meaning.*

***Use of Technology**: A technology rich learning environment will support the learning process.*

These key ideas of a scientific inquiry-based pedagogy will be our focus when implementing the Genetic Diversity and Human Health program. What follows is more detail about each idea.

<u>Generating Questions</u>… Science learning will be initiated or framed by questions. Scientific inquiry is organized around questions! Sometimes the investigation question originates from the teacher. Other times the teacher and students develop the question together, but ultimately, we want students to learn how to develop their own investigation questions. Moving from teacher-initiated questions to student generated ones will be intentionally designed into instruction. As students develop their knowledge and experience within an instructional sequence, we will shift more control to them. By the time students design an independent research project we will help them use their expanded knowledge and experience to develop high quality investigation questions. A question evaluation tool has been developed to support this process. Students will use this high-quality investigation question to frame the design, carrying out, and communication of the results of an independent science investigation.

<u>Knowledge Probes</u>… We will focus on student prior knowledge and experience, and the careful use of secondary information in a supporting role. New information gathered from both primary and secondary sources will be filtered through students' prior personal knowledge and experience during learning. It is very important, then, to help students activate, use, and represent their prior knowledge and experience throughout a learning experience. This is an important idea in helping students construct knowledge through a process of conceptual change and is built into the instructional model developed for this program. Scientific inquiry relies on the collection both primary (multi-sensory based observation) and secondary (books, internet, data bases, etc.) sources of data/information. It is the integration

of both of these sources of knowledge that forms to basis of inquiry idea number three, observation and data analysis. In a scientific inquiry pedagogy, teachers actively support their students in the acquisition, organization, and processing of data/information. This is in stark contrast to a more traditional pedagogy where students are given information to be memorized. Specific instructional tools have been developed to support this process.

Transforming Data into Evidence…The analysis and transformation of data into evidence, which will be used to support the construction of student knowledge claims (answers to investigation questions) will be written as part of explanations. Students will be taught that claims should answer the investigation question, if possible, and should be supported with evidence and reasoning. Evidence is generated during data analysis, and reasoning provides an argument or justification of how the evidence selected actually counts as evidence. Teaching support posters have been designed as scaffolds to support the students in accomplishing this task.

Meaningful Application… We will have students meaningfully use their newly constructed knowledge through applying, refining, or elaborating activities. Application examples are the generation of a new question to pursue, presenting and defending arguments to peers, or taking a trip to a local hospital.

Habits of Mind… An import idea within the pedagogy is the intentional teaching and student application of selected habits of mind. Example habits of mind from our model are curiosity, critical/ creative thinking, and self-regulation. We are going to teach students how these habits of mind support them during an investigation. We will ask students to select a habit of mind that they think will help them the most during an upcoming investigation, and then afterwards ask them if it did, or whether they would now select a different habit of mind that helped them the most. Through whole class discussions habits of mind will be explored in terms of specific behaviors of our students.

Scientific Discourse and Communication… We will teach students how to use discourse/communication strategies to support their sense making. Two specific strategies, with associated instruction tools, have been developed to support oral communication, named Research in Progress (RIP) and Present and Defend. Both of these strategies have scaffolds to support their use in the classroom. Written communication will be promoted using both paper and electronic student journaling approaches.

Interaction Patterns… We will pay careful attention to how students are grouped for instruction. Sometimes we will group students individually for personal reflection and activation of prior knowledge activities. Sometimes we will group students in small groups for investigation, clarification and elaboration activities, while other times instruction will focus on whole group discussion and sense making. It is through the purposeful planning of *individual, small group, and whole group activities that we will help students construct knowledge through the negotiation of ideas within the broader learning community.*

Promoting a Technology Rich Learning Environment... The classroom learning environment will be developed to be technologically rich. We will use computers and probe ware, document cameras, and interactive whiteboards throughout the project. Students will use technology to analyze and present data to their classmates, and a final presentation to parents, scientists, and community members.

This pedagogical statement was used as a guide for discussion and professional development for the teacher by the researcher. During implementation a coaching cycle was used where the researcher met with the teacher for the following activities: 1) Pre-planning, 2) Observation, and 3) Reflection. During the pre-planning meeting specific student and teacher outcomes were established using the guide for the upcoming lessons and any needed learning discussed and practiced. Student learning scaffolds were discussed and plans made for how students should interact with the scaffolds. During the observation part of the cycle the researcher observed the teacher teach, field notes were written, and pertinent artifacts collected. The coaching cycle was completed when the researcher met with the teacher for a post reflection meeting. At this meeting the teacher and researcher would compare the established outcomes for the lesson with the actual lesson data collected by the researcher. This meeting concluded with the creation of plan for what the teacher was going to focus on going forward, as well as items that the researcher needed to address.

5.3 Research Phase 2 (Steps 8 & 9): Prototype Intervention Development and Iterative Refinement Cycles

This section describes how the prototype intervention was developed and refined during research (Steps 8 and 9). The researcher first engaged a creative thinking process (e.g. brainstorm) that explored the conceptual possibilities for the intervention as presented in the research literature (e.g. enriched vision of science education and conceptual change research literature). This brainstorm sought to integrate ideas from both research and practice perspectives. Ideas from the literature were written on a poster with a loose attention to conceptual grouping. This initial list is shown in Figure 5.1.

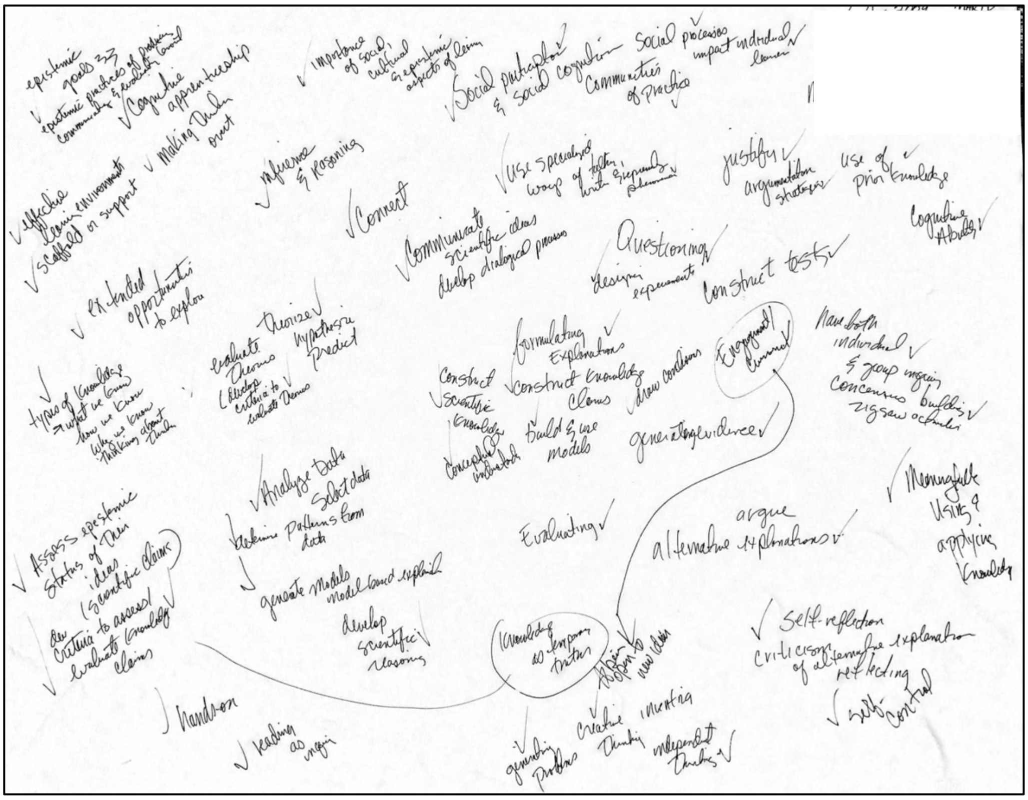


Figure 5.1. Poster Brainstorm- Initial Conceptual Themes for Prototype Intervention Design

During a first design mini-cycle this list was classified, using a process of critical thinking, into broader themes. These themes were then appropriately named according to the ideas they contained. Eight categories emerged:

1) Nature of Science (cultural)
2) Effective Learning Environments
3) Interplay of Social and Individual Processes
4) Metacognition
5) Meaningful Use of Knowledge
6) Knowledge
7) Communication
8) Scientific Processes.

Supportive relationships between categories were also explored and documented. For example, ideas contained within the *Nature of Science* category, such as curiosity, would enhance the process of *Constructing Knowledge* (i.e. curiosity drives the questioning process). Likewise, ideas contained within the *Effective Learning Environment* category, such as the social negotiation of knowledge, supports *Knowledge Construction* (e.g. knowledge is negotiated with members of the discourse community). This first of four design mini-cycles resulted in a series of regrouped categories. These categories and their relationships are shown in Figure 5.2.

Figure 5.2. Initial 8 Themes with Relationships for Prototype Intervention Design

During design mini-cycle number two the themes were further refined. Three broader categories emerged: A) The Nature of Science, B) Scientific Processes/Science as Epistemic Practice, and C) Effective Learning Environments (Social Processes). These three broader categories, and how they are related, became the first conceptual model of the developing intervention. This model is shown in Figure 5.3.

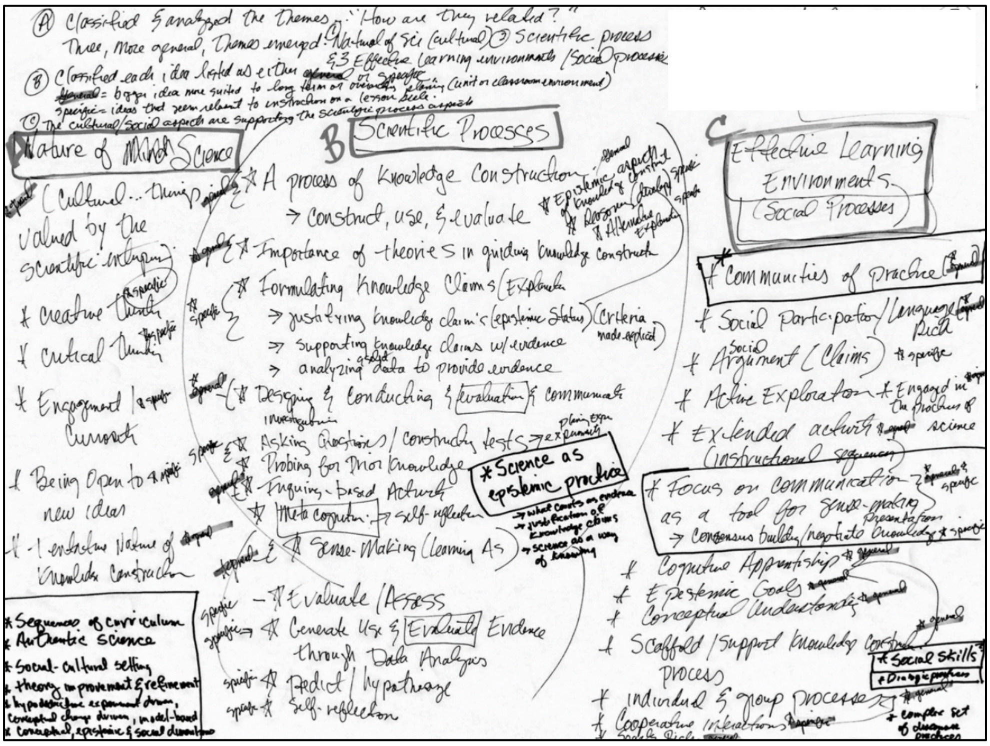


Figure 5.3. Conceptual Model for Prototype Intervention Design

During design mini-cycle number three the developing intervention was clarified and refined into a broader conceptual model, which resulted in a prototype intervention draft, which is shown in Figure 5.4.

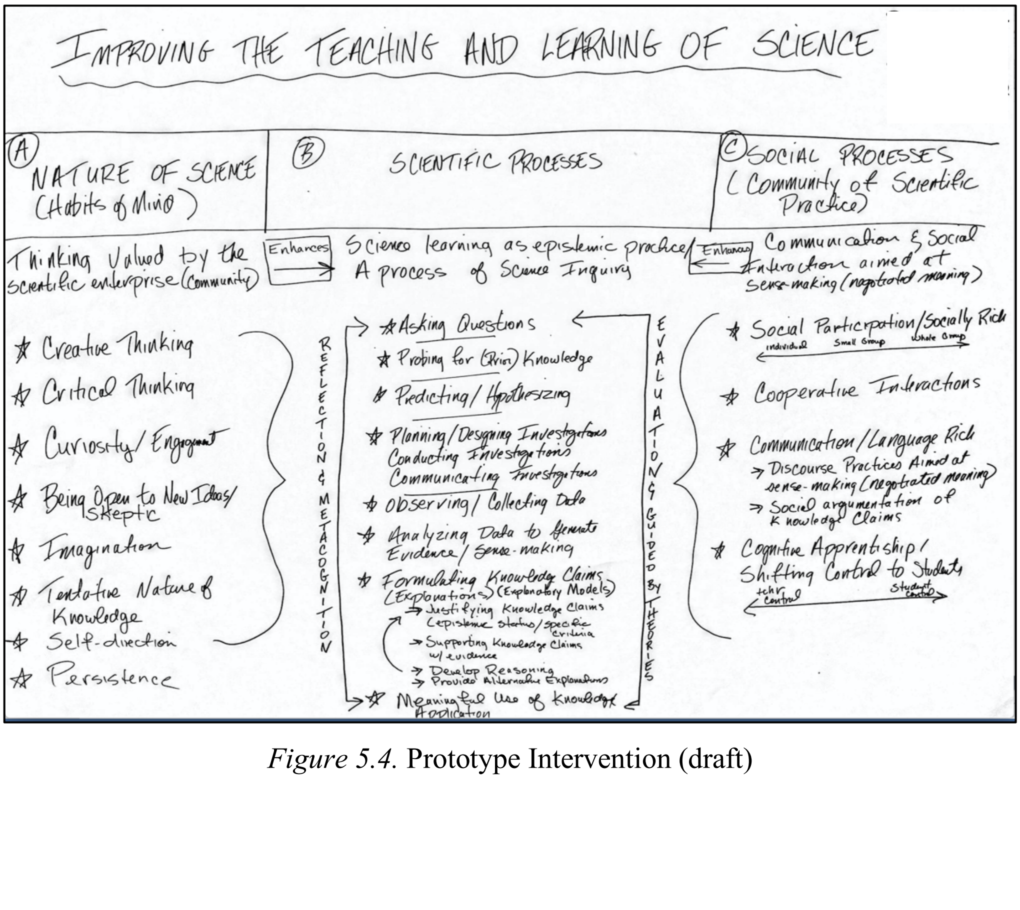


Figure 5.4. Prototype Intervention (draft)

The prototype intervention draft was alpha tested with students during a fourth design mini-cycle by using the criteria of soundness, preferability, and appeal (see section 3.2.2). The prototype intervention draft was determined to be sound because it embodied the intended design goals. However, in this design it lacked preferability, as it was not as useful as needed for teacher and student use in its current form. The design also lacked appeal. It was determined that the center dimension of the model especially needed further work and development. Based on this evaluation the prototype intervention draft was refined. First, the researcher simplified the headings of the dimensions, named each of the components of the intervention (Q-POE2 Process of Scientific Inquiry and Community of Scientific Practice Model), and clarified them. The biggest refinement came with the development of the Q-POE2 Process of Scientific Inquiry. This refinement came by determining the main components from the draft model that were important within the enriched vision of science. These components were: Question, Prediction. Observation. Explanation, and Evaluation. To show relationships they were placed on the model graphically and connected with arrows. This was also done to show the non-linear nature of scientific inquiry. More arrows could have been included, but the model became messy and lacked appeal when doing so. Four supporting components emerged based on importance to science as inquiry and the promotion of conceptual change. These components were: Prior Knowledge Probe, Investigation Planning, Data Analysis, and Meaningful Application. There was considerable thinking about where to put the ideas of metacognition/self-regulation of thinking and reflection. For a while these ideas were placed in the center of the model (evaluation was placed with meaningful application). However, in the end these ideas were removed from the model and left for later reconsideration. This refinement resulted in the prototype intervention, which is shown in Figure 5.5.

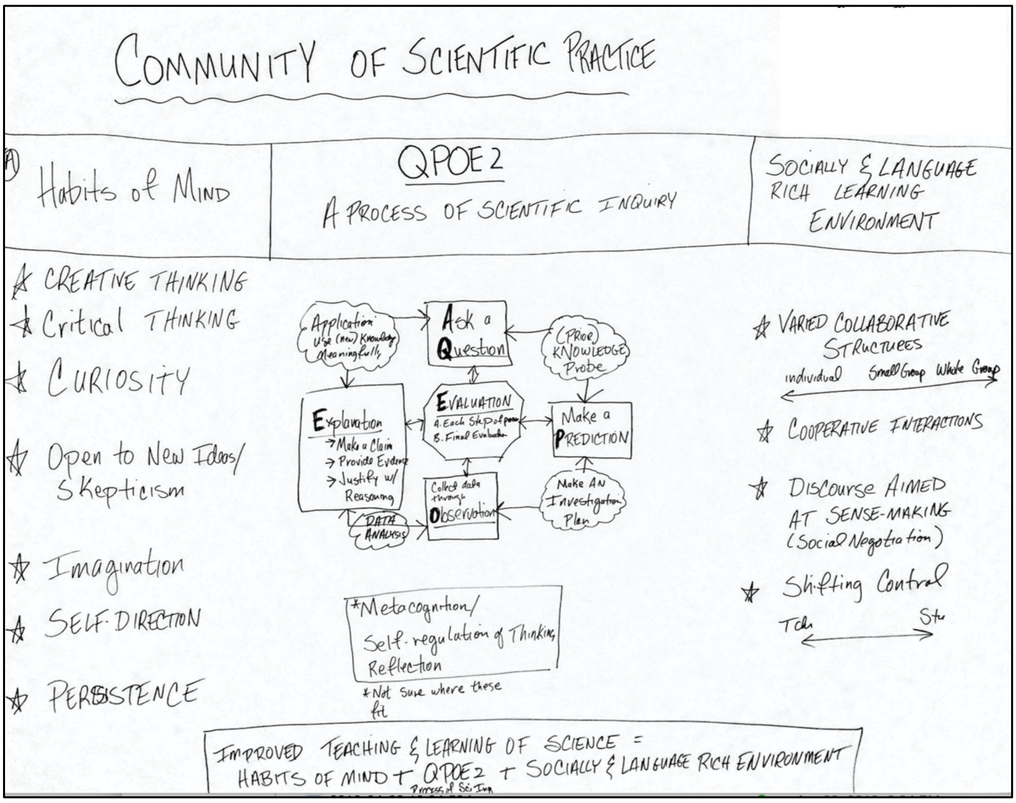


Figure 5.5. Prototype Intervention

5.4 Clarifying the Prototype Intervention with Conceptual Change Theory and the Enriched Vision for Science Education

Next, the researcher explored the developing intervention through a series of statements, based on the multidimensional conceptual change framework (see section 2.9), and the enriched vision for science education (see section 1.0) in a clarification process. This work also functioned to explore how factors that promote conceptual change and the enriched vision for science instruction are embodied within the intervention. The statements explored were:

1. How the intervention supports epistemological understanding and development.
2. How the intervention supports knowledge construction. How the intervention supports the process of conceptual change and the enriched vision for science education. Knowledge students constructed using the intervention.
3. How learner characteristics informed (i.e. interest and motivation) the design of the intervention.
4. How the intervention helped the teacher design an environment that supported multiple dimensions of learning.

A second exploration occurred using this process after the detailed intervention was implemented and evaluated. The results of these explorations are important outcomes of the thesis, and are presented in section 8.8.

5.5 Research (Step 10): Detailed Intervention Design

5.5.1 Three Broad Dimensions of the Prototype Intervention

The prototype intervention had three broad dimensions: A) Habits of Mind, B) A Process of Scientific Inquiry/QPOE2, and C) Socially and Language Rich Learning Environment. Taken together, these three broad dimensions are conceptualized as a community of scientific practice. These three dimensions of the prototype intervention are highlighted in Figure 5.6.

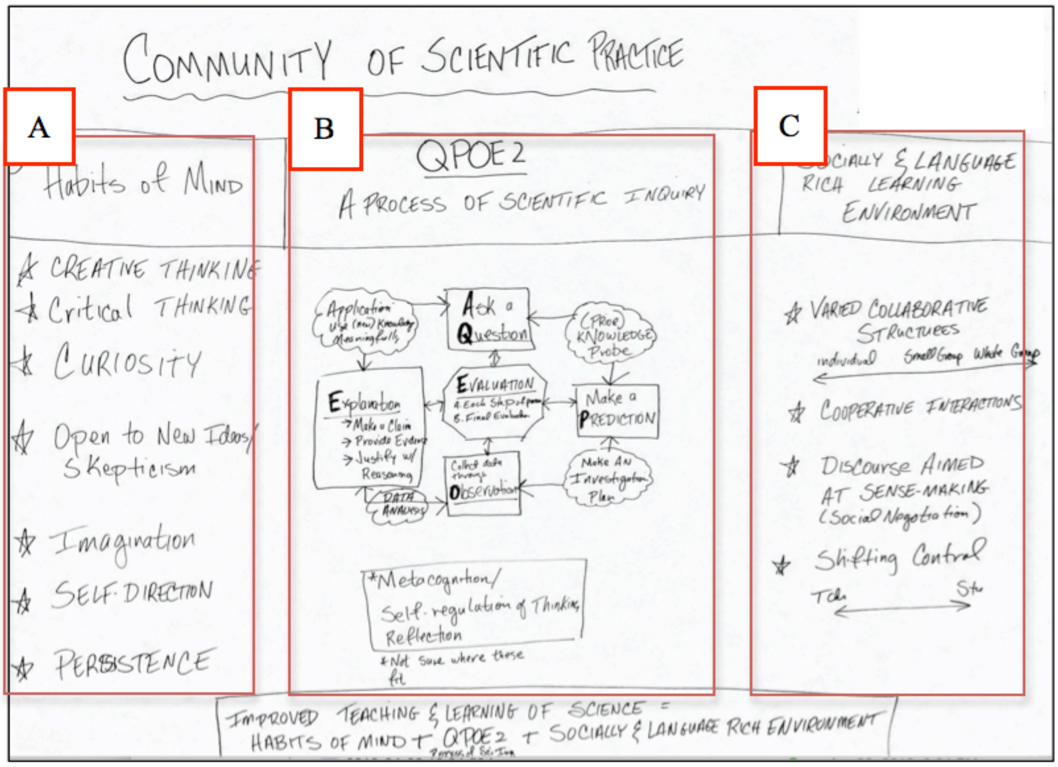


Figure 5.6. Three Broad Dimensions of the Prototype Intervention

5.5.2 Overarching Design Goals

As a first activity of research (Step 10), the researcher stated the three broad dimensions (Figure 5.6) of prototype intervention as design goals, which became:

A) Surround learners with a culture that nurtures the productive habits of mind that are valued by the community,

B) Support the learning of science as epistemic practice & conceptual change through the ritualized use (e.g. as a thinking routine) of the Q-POE2 process, and

C) Surround learners with a socially and language rich learning environment: a community of scientific practice where varied and purposeful discourse is used by members to negotiate meaning.

A graphic representation of the three overarching design goals intervention was developed and is shown in Figure 5.7.

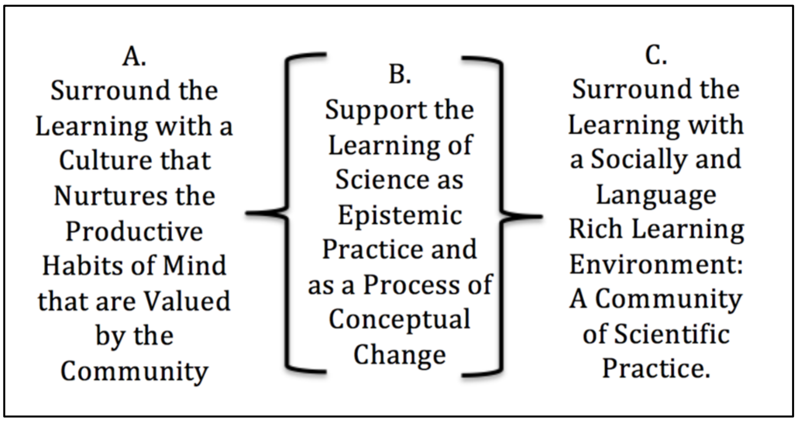


Figure 5.7. Graphic of the Three Overarching Design Goals for Prototype Refinement

5.5.3 Local Instructional Theory

The overarching design goals were used to develop a local instruction theory. Local instructional theories are a refinement and elaboration of overarching goals. Gravemeijer and Cobb (2004) state: "Such a local instructional theory consists of conjectures about a possible learning process, together with conjectures about possible means of supporting that process." p. 21 The local instructional theory developed predicted that learning could be maximized when:

A. Productive scientific habits of mind are purposefully valued and taught within the learning environment; AND,

B. Students actively construct knowledge through a process of scientific inquiry. This process promotes science learning as epistemic practice, and as a process of conceptual change; AND,

C. The learning environment is socially and language rich.

Part A of the local instructional theory says that learning will be promoted when scientific habits of minds are promoted in the classroom. Scientific habits of mind are shared values, attitudes, and skills operating within the culture the learning environment. From a science education perspective curiosity, persistence, imagination, creative thinking, critical thinking, openness to new ideas, and skepticism are good examples of scientific habits of mind.

From the conceptual change perspective self-motivation, maintaining positive attitudes and feelings, and intentionality are examples of productive habits of mind that have shown to promote learning.

Part B of the local instructional theory says that learning will be promoted when students experience science learning as epistemic practice, and as a process of theory and/or conceptual change. Within a learning environment that embraces these ideas teachers effectively scaffold inquiry-based activity so as to ritualize thinking and promote expertise. An inquiry-based thinking ritual should not be a linear enactment, but should highlight how the different kinds of scientific thinking used to construct knowledge are connected to, and support each other. The scientific inquiry promoted by the local instructional theory should embrace the critical ideas for inquiry discussed in section 5.2.

Part C of the local instructional theory says that learning will be promoted when the learning environment is socially and language rich. Within this kind learning environment students experience a culture where personal knowledge is constructed through a process of social negotiation. Designed as "a community of practice," students actively participate within varied collaboration structures, cooperative interactions, and purposeful discourse. Control within this learning environment is shared between the students and teacher, with the teacher acting as a guide. The teacher actively plans for the purposeful shifting of control to the students.

The local instructional theory conjectures that learning will be maximized when all three parts, A, B, and C interact with each other with intentionality during learning.

5.5.4 Student and Teacher Learning Outcomes

With the intervention conceptualized, and the local instructional theory developed, student and teacher learning outcomes were developed. From the student perspective the intervention was designed to promote learning within social, epistemological, conceptual, and affective dimensions as discussed in section 1.1. A key goal of the intervention was to have students learn science concepts through a process of scientific inquiry experienced as an epistemic practice. Epistemic practice was further conceptualized as students designing, carrying-out, and communicating scientific investigations within a supportive socio-cultural environment. Conceptual learning outcomes for students addressed four life science concepts:

1. Human health depends on genetic diversity within species and habitats.
2. Organisms are used as models to learn about and improve human health.
3. Plant and animal cells have similarities and differences.
4. DNA causes biodiversity.

From the teacher perspective the intervention is intended to help design the supportive social/cultural learning environment needed to implement the enhanced vision of science education. Teacher learning outcomes for the thesis focused on teacher understanding of how to use the intervention with fidelity with the students. The teacher outcomes also addressed the understanding of how to develop appropriate classroom norms to promote the social epistemology of science. To accomplish this goal teachers must know how to assist learners with both the construction and evaluation of knowledge claims, and how student attitudes and feeling affect science learning.

Outcomes were created to view learning from the vantage point of both teachers and students. First, the researcher wanted to determine if the teacher was able to use the intervention as intended to support student learning. For example, was the teacher able to effectively use the intervention to support student design of investigations? The specific learning outcomes developed for both the teacher and students are listed in Table 5.2.

Table 5.2

Student and Teacher Learning Outcomes

Student Learning Outcomes	Teacher Learning Outcomes
The student will know or be able to:	The teacher will know and be able to:
1. Develop, and/or maintain a positive attitudes and feelings toward science.	1. Use the intervention to teach students how to design, carryout, and communicate the results of science investigations.
2. Design, carryout, and communicate the results of science investigations.	2. Use the intervention to guide the design of a socially and language rich learning environment.
3. Evaluate and confront the epistemic status of their personal knowledge claims.	3. Use the intervention to guide the design of a learning environment that nurtures the habits of mind of their students.
4. Explain how health depends on genetic diversity found in species and habitats.	
5. Explain why certain organisms are used as models to learn about and improve human health.	
6. Describe how plant and animal cells are alike and different.	
7. Explain how DNA causes biodiversity.	

5.5.5 The Refined Detailed Intervention Design

Using the local instructional theory, the prototype intervention was refined into a detailed design through an iterative design mini-cycle. The center dimension, the Q-POE2

Process of Scientific Inquiry, was refined first. The Q-POE2 process was envisioned to be a ritualized activity structure that would support the science as process (e.g. epistemic practice) and conceptual change dimension of inquiry-based learning. Focusing on the ideas of Lemke (1990), Polman (2004) and Krajcik, Blumenfelf, Marx, & Soloway (2000), the researcher viewed the design principles for the inquiry process as functional elements in need of support if they were to become classroom rituals that students could do on their own. Pedagogical design principles for Q-POE2 process were developed to support the learning of science as epistemic practice and as a process of conceptual change. To accomplish this goal pedagogical design principles were developed, which are listed in Table 5.3.

Table 5.3.

Pedagogical Design Principles for the Q-POE2 Process of Scientific Inquiry

Principle #	Design Principle
B1	The intervention should provide support for developing and evaluating investigation questions
B2	The intervention should support the: a) Activation, representation, and use of prior knowledge and experience, b) Integration of scientific knowledge, models, and theories into the learning process, c) Student evaluation of knowledge sources.
B3	The intervention should support students in the use and evaluation of predictions and hypotheses.
B4	The intervention should support the development and evaluation of fair test investigations plans. In addition, students should be supported as they gather/retrieve, organize, and analyze, and explain both primary data and secondary information.
B5	The intervention should support students as they propose and evaluate explanations, including the writing of a claim and providing evidence and reasoning in support.
B6	The intervention should support students to refine, extend, and apply knowledge. Examples: artifact construction; test, generate, & revise theory; build, test, & revise theories or models; defend knowledge claims through argument; design an additional investigation; extended student research.
B7	The intervention should help student evaluation of the specific steps of the inquiry, as well as a final evaluation at the end of the investigation.
B8	The intervention should help students understand how the different design principle concepts relate, and support each other.

5.5.6 The Design and Refinement of Q-POE2

Using these design principles, the Q-POE2 process was further developed through a design mini-cycle. The refined version of the Q-POE2 process (detailed intervention, component B) is shown in Figure 5.8.

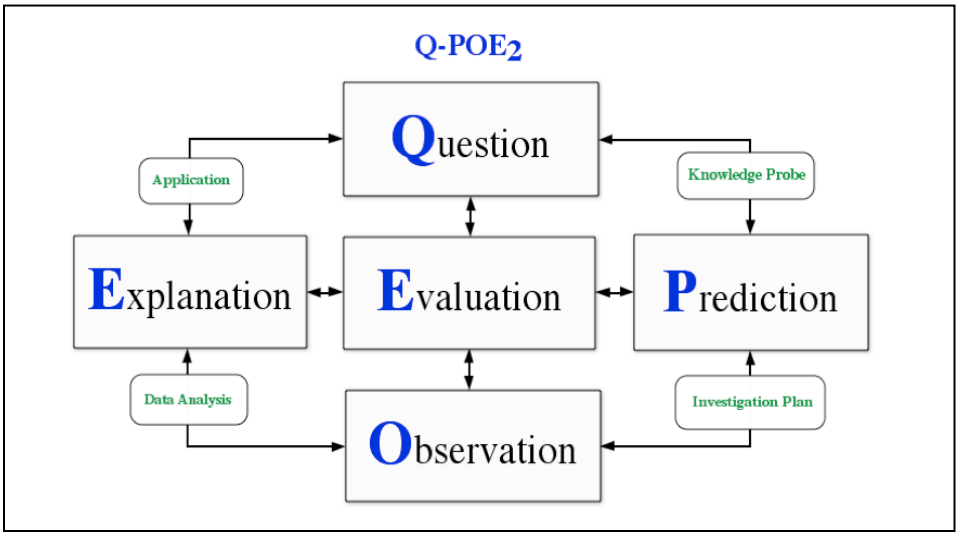


Figure 5.8. Q-POE2 Process of Scientific Inquiry (Detailed Intervention Component B)

5.5.7 The Development of Student Support Materials: Stickers

Student support materials to aide in Q-POE2 process implementation were also designed and tested. To support students in using and ritualizing the model, color-coded stickers of each part of the model were developed for student journal use. These stickers were collated into a packet and given to students. An additional sticker was added to the packet, which was reflection. This decision was made to support student metacognitive thinking, and also give teachers the reminder to have students reflect over any or all component parts of the inquiry process within the journal format. A photo of a sticker packet, as well as photos of example pages of student journals where the stickers were used, is shown in Figure 5.9.

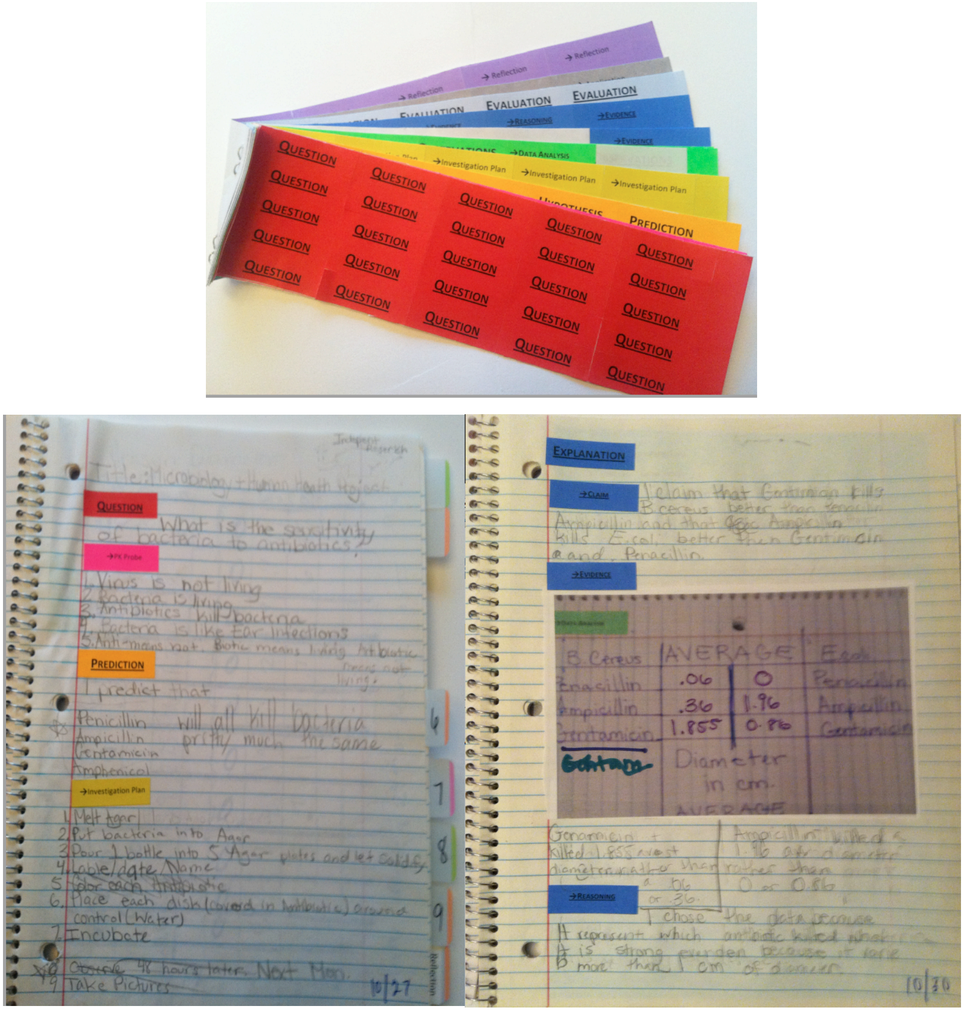


Figure 5.9. Student sticker packet and example student journal pages showing stickers being used to organize an investigation using Q-POE2 Process of Scientific Inquiry

5.5.8 The Development of Student Support Materials: Journal Evaluation Protocol

A journal evaluation tool was also developed using the design principles to support student self-evaluation of any Q-POE2 process components throughout and inquiry, or used as teacher a feedback tool. It included the idea of points for each of the areas and a place for feedback. It was expected that the students would complete three investigation evaluations over the fifteen weeks of the program. The journal evaluation protocol is shown in Figure 5.10.

Student ____________________ **Eval 1/2/3** **FCA**_____

Investigation Name ____

Journal Evaluation Protocol

QPOE$_2$ Process	Student Self-evaluation	Teacher Evaluation
Question (0-3pts) • Interesting • Doable • Important		
Knowledge Probe (0-2 pts) • Prior Knowledge & Theories • Scientific Knowledge & Theories		
Prediction (0-2pts) • Connected to question • Forecast of future observation • and/or **Hypothesis** (0-2pts) • Variables listed • If/then /because statement		
Plan/ Invest Design (0-3 pts) • Numbered steps • Makes sense • A "fair test"		
Observations (0-2 pts) • Qualitative/Quantitative data collected & organized as per plan • No opinions/prior knowledge listed		
Data Analysis (0-2 pts) • Use of at least 1 strategy evident • Evidence produced		
Explanation (0-6 pts) • Claim (answers the question) • Evidence (listed in support) • Reasoning (justification provided)		
Evaluation (0-6 pts) • All evaluation points (a -f)		
Application (0 or 3 pts)		
Totals:		

Figure 5.10. Q-POE2 Process Implementation Support Tool for Journal Evaluation

5.5.9 The Development of Teaching Support Posters

A set of teaching support posters, including one evaluation poster each for each Q-POE2 process component, as well as data analysis, explanation, confidence and fair test posters, were designed to aid in the teaching process and to support the development of student reasoning. It was not intended for these posters to be used at the same time, but rather used individually as appropriate throughout instruction. The data analysis poster was designed to support the development of high-quality evidence, and the explanation poster was developed to support the use of the evidence in constructing quality explanations. The confidence poster was designed to support students as they determine the confidence status, and the reasoning supporting their knowledge claims, based on the results of their investigation. The confidence categories were intended to correspond to Posner's (1984) status categories (see section 2.6). The fair test poster was designed as a teaching support that could be used when teaching students how to design high quality investigations. Teaching support posters can be seen in Figure 5.11.

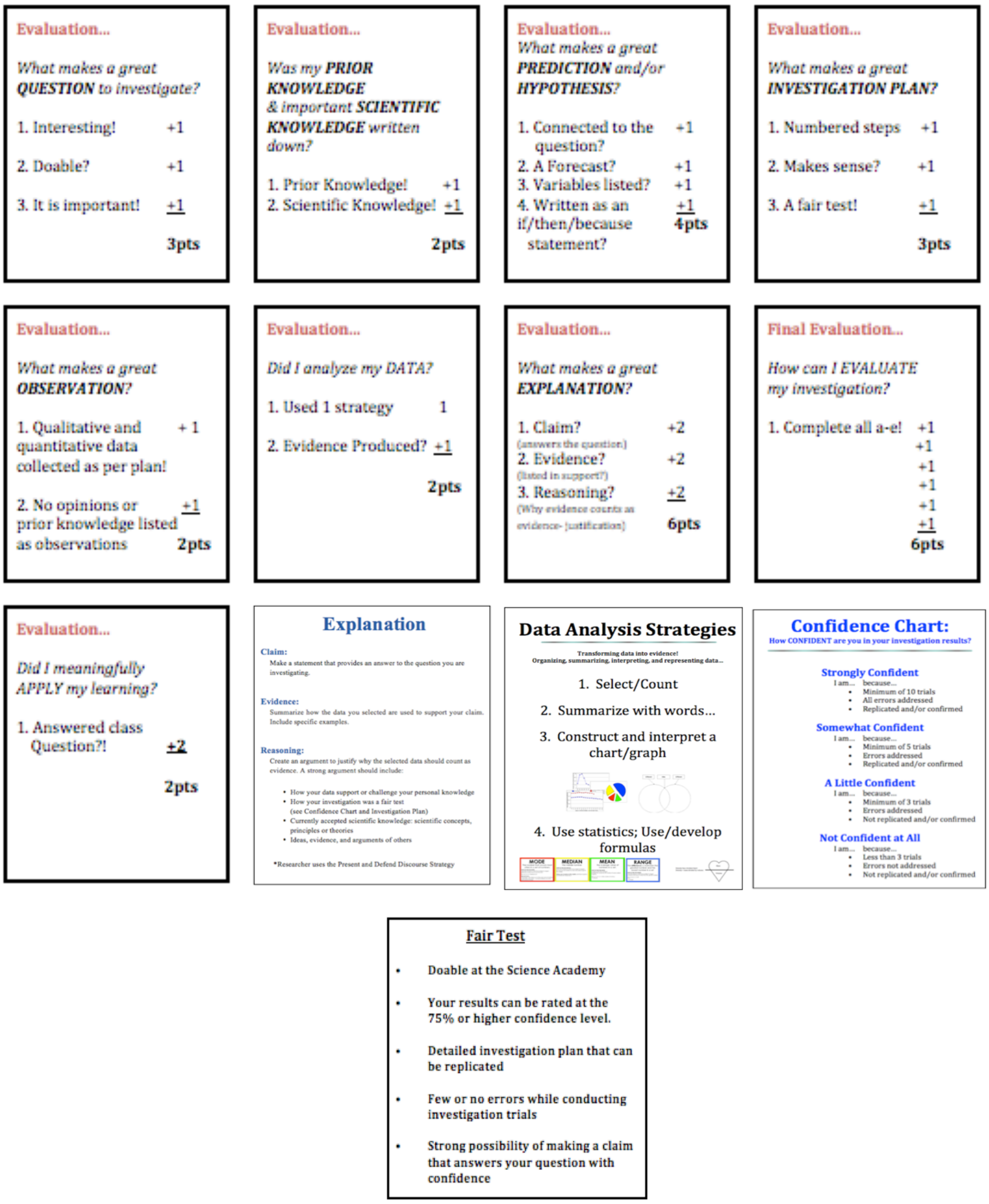


Figure 5.11. Teaching Support Posters

5.5.10 The Development of the Finished Detailed Intervention

The Q-POE2 Process of Scientific Inquiry was component B of the detailed intervention. It was developed as a stand-alone instructional model to support the enriched vision of scientific practice. However, the finished detailed intervention also included an additional model. This section describes the development of this additional model, which includes part A and C of the overarching design goals. The three design goals are shown once again in Figure 5.12 to remind the reader that two more broad areas needed to be developed in order to meet development goals dictated by our local instructional theory (e.g. Area A & C).

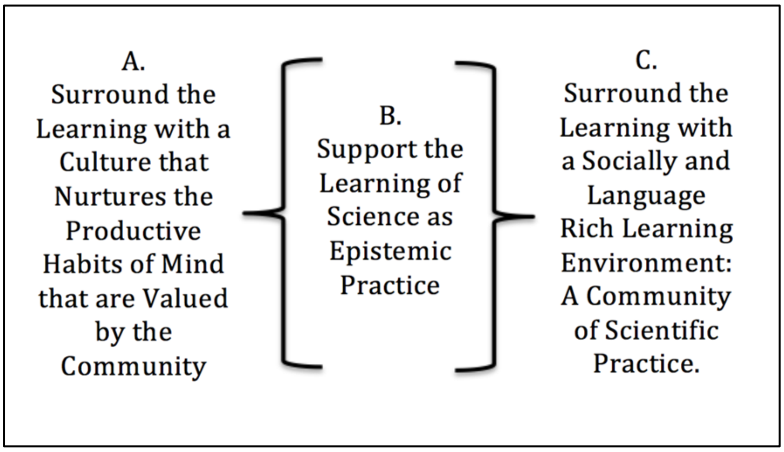


Figure 5.12. Overarching Design Goals

Goal A States: Surround the learning with the productive habits of mind that are valued by the community. The researcher decided that the teaching of habits of mind should occur within the intervention in two distinct ways:

1) Opportunities to discuss and model habits of mind should occur as they "bubble up" during instruction. The teaching of habits of mind in these circumstances would be considered emergent.

2) Specific habits of mind can be planned for and taught as they naturally fit within instruction. Teaching habits of mind in these circumstances would be considered explicit. Within explicit instruction of habits of mind, students should be asked to reflect over, and demonstrate, how they used habit of mind thinking to support their investigations.

Table 5.4 lists the pedagogical design principles developed to support Goal A.

Table 5.4.

Pedagogical Design Principles Supporting Goal A

Principle #	Design Principle
A1	Design the intervention to support teacher & student use of curiosity/interest as a habit of mind.
A2	Design the intervention to support teacher & student use of openness to new ideas/ skepticism as a habit of mind.
A3	Design the intervention to support student use of critical and creative thinking as a habit.
A4	Design the intervention to support teacher and student use of persistence as a habit of mind.
A5	Design the intervention to support teacher and student use of self-direction as a habit of mind.
A6	Design the intervention to support teacher and student use of imagination as a habit of mind

Goal C States: Surround the Learning with a Socially and Language Rich Learning Environment: A Community of Scientific Practice. The intervention should support the development of discourse communities (Community of Scientific Practice), where members purposefully interact to negotiate meaning. Table 5.5 shows the pedagogical design principles developed to support goal C.

Table 5.5

Pedagogical Design Principles Supporting Goal C

Principle #	Design Principle
C1	Use varied collaboration structures in support of cooperative interactions & social negotiation.
C2	a. Vary the interaction patterns (individual, small group, whole group) to facilitate cooperation, discourse, and social negotiation of meaning. b. Promote components of cooperative learning.
C3	Scaffold activity (e.g. experience) to actively promote student self-direction and independence (e.g. expertise)
C4	Design specific discourse scaffolds that promote social negotiation of meaning.
C5	Value and promote a culture of social negotiation of meaning.

Using these two sets of design principles, and the stand-alone Q-POE2 Process of Scientific Inquiry, a finished detailed intervention was developed, implemented, evaluated and refined during a design mini-cycle. A summarized version of the local instructional theory was placed in a bottom box on the model (e.g. Intentional Teaching of Habits of Mind + Q-POE2 Process of Scientific Inquiry + Learning within a Socially and Language Rich Environment = Improved Teaching and Learning of Science). The detailed intervention was designed primarily as a teacher tool to support the design of the supportive classroom-learning environment, but could also be used with students. This detailed intervention was formally named *The Community of Scientific Practice Model* by the researcher, and is shown in Figure 5.13.

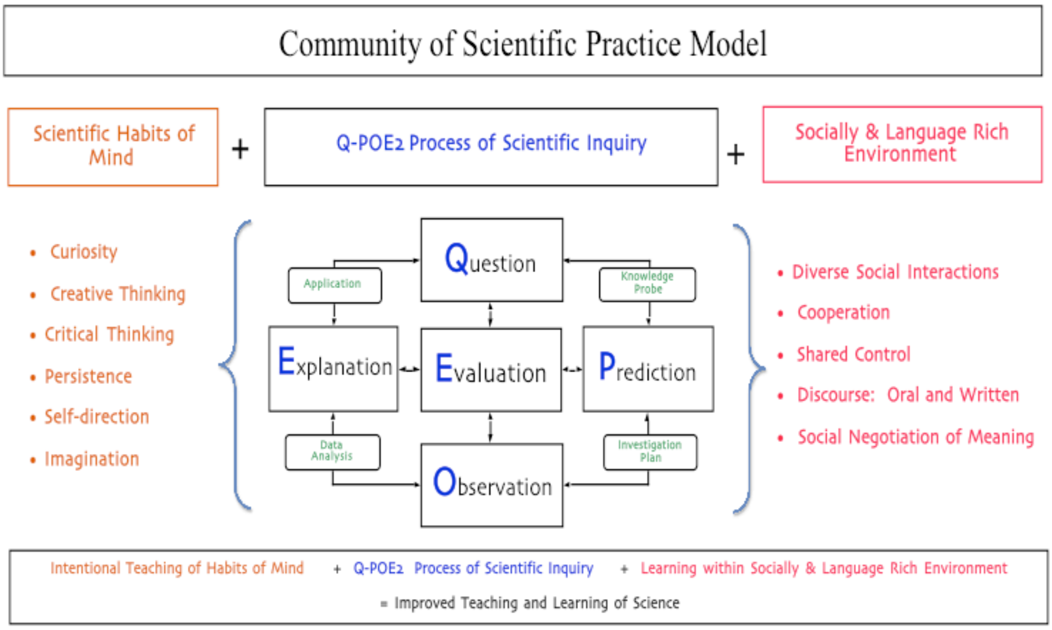


Figure 5.13. Detailed Intervention: *Community of Scientific Practice Model*

5.5.11 The Development of Student Support Materials for the Community of Scientific Practice Model: Discourse Strategies

To support the Community of Scientific Practice model, the researcher developed two discourse strategies, which were displayed on teacher posters for classroom use. The *Research In Progress* discourse strategy was specifically developed for use at any point during an investigation up to the point where students had written an explanation. This strategy, at times, could be used at the beginning of class as a review of what transpired the day before. One or more student groups could present. The strategy could also be used at the end of a class session to pull the lesson together, show exemplary student work, and to facilitate a social support system within the classroom. The audience should be taught that they have a role to play within the strategy and are expected participate. The strategy could also be used any time during an investigation to bring clarity and support to the inquiry process. The steps to *Research and Progress* discourse strategy can be seen, as a poster graphic, in Figure 5.14.

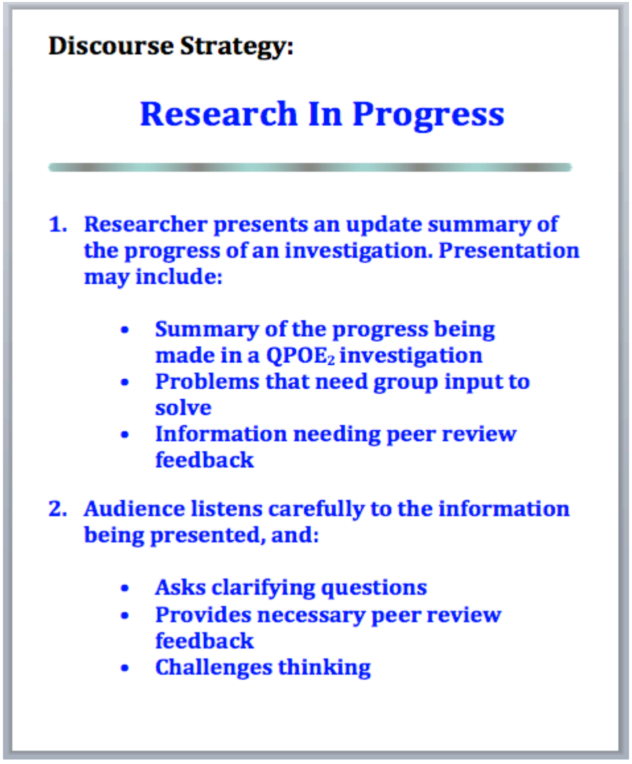


Figure 5.14. Research In Progress Discourse Strategy Poster

The second discourse strategy that was designed was named the *Present and Defend* discourse strategy by the researcher. This discourse strategy was designed as a public presentation and defense of a written explanation by students, individually or in teams. It has three basic steps: 1) the researcher(s) present the question and explanation, 2) an opportunity for an audience rebuttal, where alternative explanations may be offered, and 3) researcher(s) defend through argument the merits of their explanation. The teacher could utilize this strategy in several different ways. All investigation teams could present the results to the whole class using the strategy at the conclusion of an investigation. This would be an appropriate strategy to use while the students are first learning the strategy. The teacher would be able to guide the discussion and model appropriate responses. As the students gain in their understanding and ability to self-direct the process, the strategy could be used in teams. In this instance the whole class would be divided up into discussion teams and each has a conversation, using the strategy steps. The teacher would float between groups to monitor and give feedback as needed. This implementation of the strategy would be the most powerful if a variety of questions were pursued by the different teams, so that they didn't know what the others had done. The teacher may need to train discussion leaders who act as group discussion facilitators. The steps to *Present and Defend discourse* strategy can be seen, as a poster graphic, in Figure 5.15.

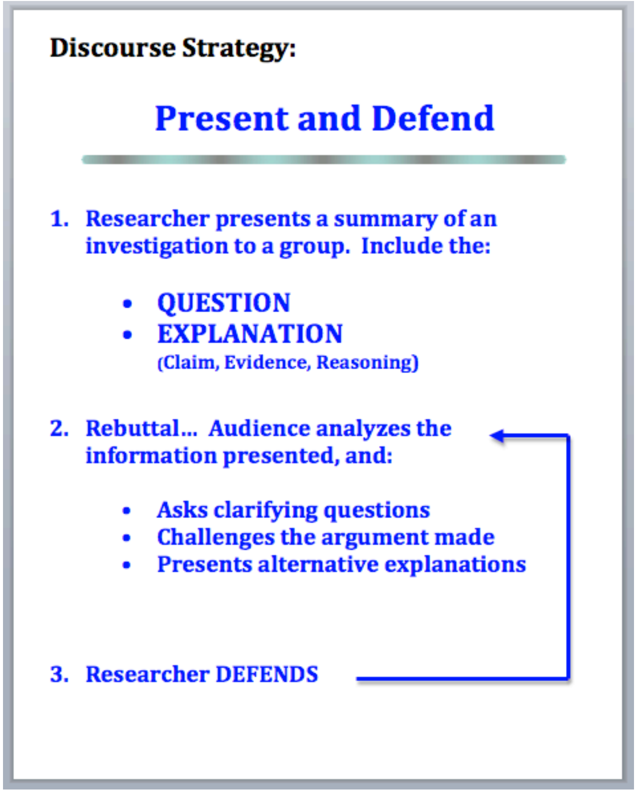


Figure 5.15. Present and Defend Discourse Strategy Poster

5.6 Summary of the Curriculum

In a parallel development cycle to the instructional model components of the intervention just described, the researcher also developed the curriculum. The researcher wrote the curriculum as a learning progression, carefully designing linked and ever more sophisticated sequences of learning throughout the progression. Conceptual knowledge was organized around core ideas, which provided a knowledge framework for the project. To make the curriculum researched-based it is designed using a learning progression on evolution created by a design team of science educators, scientists, and children learning experts (Catley, Lehrer & Reiser, 2005). Based on this research key "big ideas" deemed accessible for children to investigate were integrated into the curriculum. These key content ideas were: 1) variation, 2) structure/function (adaptation), 3) ecology/interrelationships, and 4) biodiversity.

The curriculum had thirteen lessons that were developed using the key content ideas, organized into four learning sets (Figure 5.16). A driving question, "How does our health depend on genetic diversity?" framed the curriculum. Key concepts within the curriculum were "for all organisms there is an inward similarity to outward diversity" and "model organisms are used to learn about and improve human health". The first learning set had the students explore the question "What is diversity?" In a series of investigations, students examined the phenotypical differences (e.g. genetic differences within a species) among their classmates. The investigations were designed to develop the foundational concept that individuals within a sexually reproducing population are not exact copies. Next, students examined differences and similarities between species by observing a variety of both plants and animals. As students looked inwardly, they are able to observe that organisms were more alike at the cellular and DNA levels (e.g. all living things are constructed of the same materials). These similarities enabled the students to use organism models to learn about themselves, and about potential medical therapies for the improvement of human health in general.

In the second learning set, students used model organisms to explore how changes in DNA promote biodiversity. Students explored the growth and development of a living fern named *Ceratopteris* (C-fern) as a model plant system. As part of their investigations they observed male gametes (sperm) swim toward the female gamete (egg), which resulted in fertilization. The students also used the model plant system called *Wisconsin Fast Plants*. These plants are a rapid cycling form of the species *Brassica rapa,* a member of the cabbage family. Students learned that genes are passed from parent to offspring, and how genes are expressed through inheritance through investigations using *Wisconsin Fast Plants.*

During the third learning set students explored the question, "Why are certain organisms used as models to learn about and improve human health?" These investigations used selected model organisms to help students begin to understand the different ways in which a scientist might use a model organism. Students gained insight into the importance of preserving biodiversity in order to maintain the variety of potential model organisms available for research. For example, students studied the growth and development of a zebrafish in order to understand how easily the developing embryo could be observed. Students investigated *Xenopus* (African clawed frogs) tadpoles and daphnia to test drugs on physiological responses such as heart rate. Students also investigated bacteria to experience how chemicals could be tested to see how they control bacterial growth. Through second-hand research, students learned how investigations using different species could bring about potential treatments for human disease. Examples of this included denning bears and their ability to resist osteoporosis and renal disease despite months of inactivity during hibernation; the cone snail, which carries a venom used to paralyze its prey, and in humans, relieves pain; and the now extinct gastric brooding frog, which was used in acid inhibition studies in an effort to find therapies for peptic ulcers.

Learning set four culminated in an independent research project and two field experiences designed to answer the question "How are model organisms used to learn about and improve human health?" For their independent research project, student groups choose from five possible project areas: organism physiology, organism growth and development, organism genetics, microbiology, and DNA extraction. These projects allowed students to deepen their understanding in an area of their choosing, as well as reinforce the concept that all organisms, including humans, are more alike than different at the level of DNA. The independent research project also served as a performance assessment of student ability to self-direct a research project using the intervention as a guide. Field experiences also occurred where students visited a biomedical research lab and a local hospital that used cutting edge technology. During their visit to the research lab, students talked to a scientist to learn about research as a career, and how laboratory work may lead to treatments of human disease. At the hospital, students talked with staff about cutting edge medical technology as well as the path from research to viable medical therapy, and how that path included the use of various organism models. An organizational question structure for the curriculum is shown in Figure 5.16.

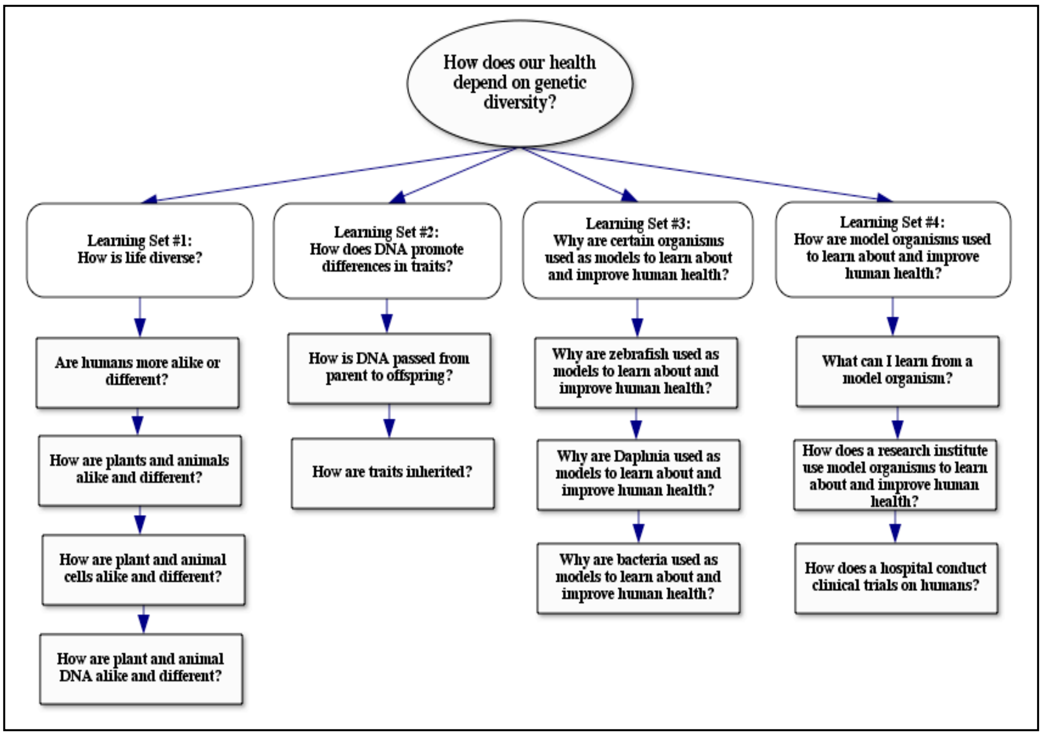


Figure 5.16. Learning Sets for Genetic Diversity & Human Health Curriculum

5.7 Answers to Phase 2 Research Questions

5.7.0 Section Overview

Section 5.7 contains two sub-sections. Section 5.7.1 contains the answer to the student learning focused research question for Phase 2 (SLRQ2a/b), and section 5.72 contains the answer to the learning environment focused research question for Phase 2 (LERQ2a/b). These two research questions are highly interrelated, and parts of each help answer the other. In chapter 8 (see section 8.8) both of these research questions will be explored further.

5.7.1 Answer to Research Question SLRQ2a/b

What is an optimal design for an intervention that supports student learning, especially in light of:

a) What are known about factors that promote conceptual change? (SLRQ2a)

b) The enriched vision of science learning? (SLRQ2b)

The Q-POE2 Process of Scientific Inquiry (see Figure 5.8), together with the sticker packets students used to implement the model in their journals (see Figure 5.9), and other supports (see Figures 5.10 & 5.11) were designed to support student learning in light of factors that promote conceptual change and the enriched vision of science learning. For example, one important factor promoted with the Q-POE2 process was knowledge construction as an inquiry-based epistemic practice (see section 8.8.1) that intentionally built upon and used student prior knowledge and experience. Also, critically important inquiry practice components identified were meaningfully linked within the Q-POE2 process (e.g. Question-Prediction-Observation-Explanation-Evaluation), which presented learning as an outgrowth of the inquiry process itself (see section 8.8.2). Another important factor of learning promoted by the intervention was the intentional inclusion of learner characteristics within the model (see section 8.8.3). Students were given choice within the curriculum, and the activities were designed to share control between the teacher and students. Also, students were taught in a way that promoted confidence through intentional scaffolding of activity in ways that promoted success. Examples of how this occurred will be presented next.

The teaching posters were printed on heavy museum board and displayed on easels in both the lab and discussion area as needed. The Q-POE2 poster was placed in the front of the room, and referred to throughout lessons by the teacher and students. The teacher introduced the Q-POE2 process slowly, and it took about two weeks (or 8 hours of instruction) for the students to become comfortable using it. The teacher modelled how to use the Q-POE2 sticker packets when first learning Q-POE2 process, which greatly supported students in its use. Four other supports were used heavily, the two discourse posters (Present and Defend & Research in Progress) and the data analysis and explanation teaching posters. These scaffolds were introduced slowly to students, with heavy teacher modelling occurring when they were first introduced. For example, when a poster was first introduced the teacher would use a single poster/support to organize an investigation or lead a discussion. Sections of the posters would often be covered up at first, and then slowly revealed throughout a lesson as needed. After students became comfortable with the poster and/or other support, they could be used independently by them.

5.7.2 Answer to Research Question LERQ2a/b

What is an optimal design for inquiry learning environments, especially in light of:

a) What kind of learning environment is needed to support the student learning focus? (LERQ2a)

b) How can the intervention be designed to support teachers as they work to create the envisioned learning environment in their classroom? (LERQ2b)

The researcher determined that by itself the Q-POE2 Process of Scientific Inquiry was not adequate to ensure that teachers create the kind of classroom learning environment prescribed by the enriched vision of science learning and the factors that promote conceptual change. *The Community of Scientific Practice Mod*el (see figure 5.13), together with implementation supports, were developed to alleviate these deficiencies. To create *The Community of Scientific Practice Mod*el the researcher added two additional dimensions to the Q-POE2 Process, *Scientific Habits of Mind* and *Socially* and *Language Rich Learning Environment* (see Section 5.5.10). Specific teaching strategies, teaching posters and a curriculum were developed to support the teacher during implementation of these additional dimensions of the completed intervention (see Sections 5.5.11 and 5.6).

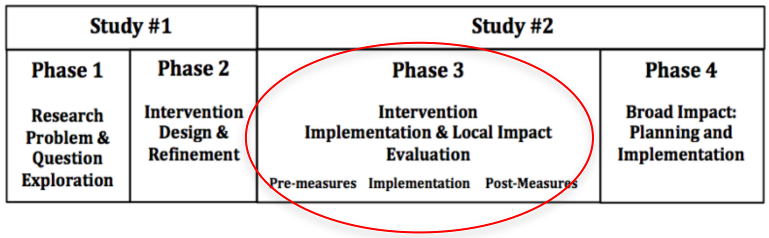
5.8 Chapter 5 Summary

Study #1		Study #2	
Phase 1 Research Problem & Question Exploration	**Phase 2** Intervention Design & Refinement	**Phase 3** Intervention Implementation & Local Impact Evaluation Pre-measures Implementation Post-Measures	**Phase 4** Broad Impact: Planning and Implementation

This chapter presented the results of Phase 2, Intervention Design and Refinement, which involved research (Steps 6-10) of study # 1.During this phase the research design was finalized (section 5.1) and design principles, goals and strategies, were developed and used to develop and then refine the intervention. Early on during the phase an instructional goals and pedagogical strategies statement was developed that functioned as informal design principles, goals, and strategies (section 5.2). Using these ideas, a prototype intervention was developed (Steps 8-10), and then clarified using conceptual change theory and the enriched vision of science education. The results of this clarification activity are presented in section 8.8. During research (Step 10) the finished detailed design was completed. This process started with the development of overarching design goals based on three broad dimensions of the prototype intervention (e.g. habits of mind, inquiry-based learning process, and a socially and language rich learning environment). Using the overarching design goals a local instructional theory was developed. After constructing the student and teacher learning outcomes, the researcher used the local instructional theory to develop formal design principles that were used to refine the Q-POE2 Inquiry Process and the Community of Scientific Practice Model, as well as, to develop a suite of student and teacher supports (see sections 5.5.7- 5.5.9; 5.5.11). At this point in the research, the researcher also refined the curriculum that would be used with the intervention (section 5.6). To complete research Phase 2 the researcher answered the research questions for this phase, which were presented in section 5.7.

Chapter 6 Results of Study #2, Research Phase 3: Local Impact Evaluation

6.0 Chapter Overview



This chapter presents the results of research Phase 3, Intervention Implementation and Local Impact Evaluation. Research Phase 3 was described in section 3.5. Phase 3 involved research (Steps 11-14) of Study #2:

11) Theory Refinement (section 6.1)

12) Implementation/Data Collection (section 6.2)

13) Evaluation of Results and (section 6.3)

14) Reflection and Discussion (section 6.4)

The goal of chapter six is evaluate the impact the intervention had on both how the teacher designed the learning environment, and the actual learning that occurred there. To accomplish this goal the researcher studied how students learned through inquiry in the teachers' classroom both before and after the intervention was implemented. The students were also given content and performance pre and post-tests, as their interests and feelings toward science were surveyed.

The results from research Phase 3 were used to answer the research questions for this phase (Table 6.1). The answers to the research questions will be presented in section 6.5. The last section of this chapter, section 6.6, will provide a chapter summary.

Table 6.1

Research Steps and Corresponding Research Questions for Study #2, Phase 3

Research Phases & Associated Steps	Student Learning (SL) Focus Research Questions (RQ)	Learning Environment (LE) Focus Research Questions (RQ)
Phase 3: Intervention Implementation and Local Impact Evaluation: 11. Theory Refinement 12. Implementation/Data Collection 13. Evaluation of Results 14. Reflection and Discussion	What does inquiry-learning look like in the teacher's classroom because of intervention implementation? (SLRQ3a) How did the intervention impact inquiry learning in the teacher's classroom? (SLRQ3b)	How did the intervention support how the teacher designed the learning environment and taught the students? (LERQ3)

6.1 Research (Step 11): Theory Refinement

Before intervention implementation, the researcher reviewed the local instructional theory (see section 5.5.3) through the lens of the multidimensional conceptual change theory to determine if the local instructional theory needed refinement. This step is an important iterative activity of educational design research. The researcher decided that no refinement was needed at this point in the research.

6.2 Research Phase 3 (Step 12): Implementation & Data Collection

Data were collected at four points during Phase 3, research (Step 12), of the thesis:

- Pre-measure data were collected before implementation (section 6.2.1)
- Data were collected during the intervention implementation (section 6.2.2)
- Post-measure data were collected at the end of implementation (section 6.2.3)
- Post-implementation data were collected one month after implementation (section 6.2.4)

6.2.1 Pre-measure Data

To determine assessment baselines at the start of implementation, pre-measure data were collected from the students using the following data gathering tools:

1) Content Pre-Test

2) Performance Pre-test;

3) Student Questionnaire: How You Feel About Science and Learning Science, and Student Questionnaire: Your Opinions About Science and Learning Science.

These data gathering tools were administered again at the end of implementation as post-measures. Pre-measure data were then compared with the post-measure data to determine impact of the intervention.

The first pre-measure data were collected in the form of a content pre-test. All 18 participating students were given the content pre-test before implementation, and then the post-test after implementation. Each student individually answered the four content questions:

- How does our health depend on genetic diversity?
- Why are certain organisms (Zebrafish, African Clawed Frog, bacteria) used as models to learn about and improve human health?
- How does DNA cause biodiversity? and,
- How are plant and animal cells alike and different?

A rubric was used by three-raters to assess student content knowledge attainment for both the pre-test and post-test. The pre-test scores were then compared to the post-test scores to determine if statistically significant increases occurred in student content knowledge. The results of this comparison are presented in section 6.2.3.1.

Immediately following the content pre-test, the students were given a performance task, which was also used as a pre-measure. The students were given an organism to observe for ten minutes. After the conclusion of the ten minutes the students were asked to design and conduct an investigation based on their observations and given as much time as they needed to complete the investigation. During the last week of the program the students were again asked to design and conduct an investigation following the exact protocol for a post-test. The following five components of an investigation were evaluated through the performance assessment:

- Confidence and conclusion were congruent
- New question or variable was proposed.
- Revision of the investigation plan occurred.
- Data was analyzed and summarized.
- Explanation was supported by evidence.

A rubric was used by three-raters to determine pre/post performance assessment scores. The scores were compared to determine if significant increases occurred in student ability to design and conduct an investigation (i.e. the performance task). The results of this comparison are also presented in section 6.2.3.2.

Immediately after the students completed the performance assessment, they went into another room to complete the two questionnaires - *How Do You Feel about Science and Learning Science,* and *Your Opinions About Science and Learning Science* - to determine if student feelings, opinions, and interest regarding science changed pre/post intervention implementation. For each question, as shown in Figure 6.1, students had a range of six choices, from definitely false (1) to definitely true (6)

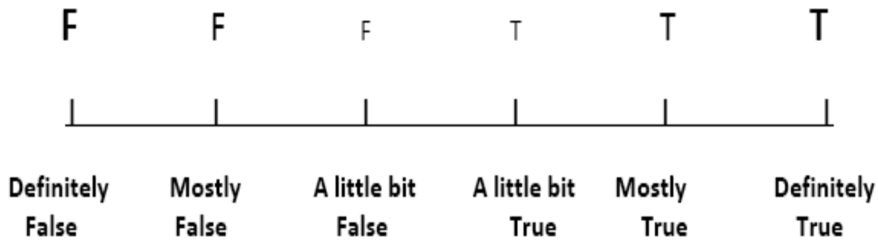


Figure 6.1. Range of choices for each survey question

The pre/post data were analyzed, and the results of this analysis for each survey is presented in section 6.2.3.3.

6.2.2 Data Collected During the Intervention Implementation

Data collected during implementation of the intervention included classroom observation field notes, student interviews, and classroom artifacts (e.g. student journals, poster session photographs, and other student created class work). The researcher observed classroom activity over the course of eight sessions (e.g. 16 hours). The researcher analyzed this data to determine the classroom patterns (e.g. activity, participation, & discourse) that occurred during implementation. These patterns were compared to those found the semester before in the teacher's classroom to evaluate how the classroom-learning environment possibly changed due to intervention implementation (see section 4.6.2). Table 6.2 shows a summary comparing classroom patterns pre/post implementation.

Table 6.2

Classroom Discourse and Participation Patterns Pre-intervention Implementation

Classroom Pattern Type	Patterns Studied	Pre	Post	% Change
Discourse	Teacher Talk	31%	13%	-58%
	Student/Teacher Talk (e.g. discussion)	36%	41%	+14%
	Student to Student Talk	25%	40%	+60%
	No Talking	8%	6%	-25%
Participation	Teacher / Whole Group (TWG)	31%	13%	-58%
	Teacher/Student (SHARED)	36%	41%	+14%
	Student/Small Group (SSG)	21%	34%	+38%
	Student/Whole Group (SWG)	4%	6%	+33%
	Student/Individual (SI)	8%	6%	-25%

Some dramatic changes were seen in both discourse and activity patterns likely as a result of the intervention. Teacher talk occupied 31% of classroom time before implementation and 13% of time during implementation, a +60% change. Discussion, which was defined as an exchange of ideas between students and the teacher, had a change of +14% pre/ post. The amount of talk shifted to students talking to each other, which increased 60% of the time because of implementation. This shift appears to do due to the teacher using two new discourse strategies developed to support the intervention, *Research In Progress and Present and Defend*, the teaching strategy posters of which, are shown in Figure 6.2.

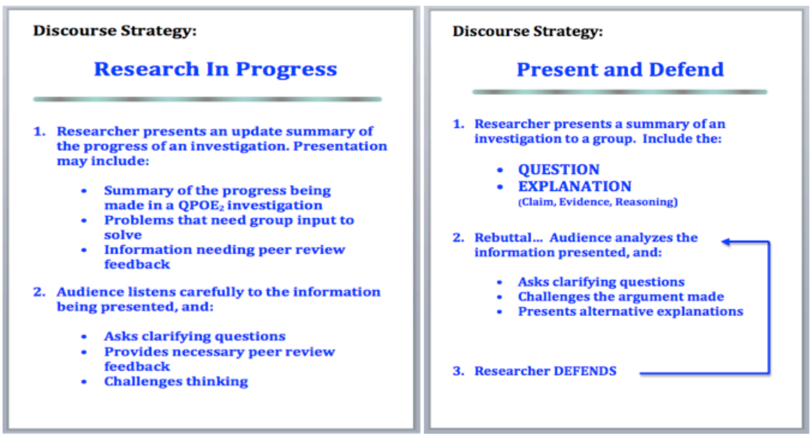


Figure 6.2. Research In Progress & Present & Defend Discourse Strategy Posters

The *Research In Progress* strategy was often used by the teacher throughout student investigations to support clarification and sense-making discourse. A teaching poster was placed where all students could see, which acted as an effective guide for discourse. Over time it was observed that the students needed the teaching poster less and less, as they had internalized the strategy. This *Research In Progress* discourse strategy also functioned as an important formative feedback tool, which was observed being used between students, and between the teacher and students within the classroom.

The strategy called *Present and Defend* was also used, often at the end of investigations, where students were observed constructing and defending claims with evidence and reasoning in a more formal sense. The poster for Present and Defend discourse sessions was placed where all students could see it. Students were observed eagerly reviewing the teaching posters and engaging in these discourse strategies, even when the teacher was not present. Two additional teaching posters were a focus during the discourse sense-making activities, the *Confidence and Fair Test posters* (Figure 6.3).

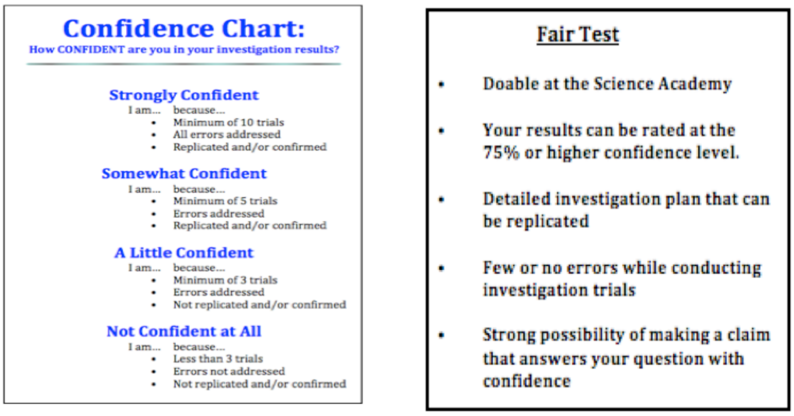


Figure 6.3. Confidence and Fair Test Teaching Posters

The research was clear that in order for students to confront misconceptions they needed to construct explanations based on data they collect, and have confidence in. Within the intervention design, this process started with an evaluation of the investigation question by students to determine if a rich set of data could be collected to answer the investigation question within the classroom environment. The students were taught that without rich data important patterns and trends could not be found through analysis. An important strategy to help student gain confidence in their data was having them evaluate investigation plans with the support of the Fair Test teaching poster. Students were also asked to evaluate their investigation plans and data analysis process for confidence during discourse sessions using these teaching posters.

By the time students constructed explanations, they had evidence that they were confident in (or not), and could provide reasoning in support. For the first month of the intervention the teacher guided the *Present and Defend* discourse sessions whole group, but by the middle of implementation students were put in small groups for *Present and Defend* discourse sessions. These moments were especially powerful, and the students were the most interested, when each student within the small group had a different investigation to share which the group needed to complete a larger project. The teacher remarked that he felt during these moments like he could leave the room and the students would not even notice or miss him.

Table 6.1 also shows that when discourse patterns shifted to more student-to- student a corresponding change naturally occurred within the participation patterns observed. That is, when students talked more to each other, it occurred because they were productively organized in small groups. There was a 38% increase of students participating within small groups likely because of the intervention. It was also noted that students spent more time presenting to each other in whole group arrangements (+33%). The teacher and students spent more time in discussions, which increased 14% with the intervention. The time for these increases came from a decrease of 58% of the time the teacher previously had spent talking to all the students in a whole group arrangement.

Section 4.2.2 describes the set of critical ideas of a scientific inquiry pedagogy that was used to develop the intervention. These critical ideas were envisioned to support the implementation of an enriched vision of science learning, and to promote conceptual change. An important question pursued was whether or not the intervention helped the teacher implement these critical ideas within the classroom. To find out, the researcher developed a rubric (see Appendix B), which was used to evaluate the teachers' classroom pre and post implementation. For example, one critical idea was the promotion of student self-direction within the classroom-learning environment. The rubric for the student self-direction component was: 0 – Teacher controlled all aspects of lessons; 1- Teacher and students shared control during lessons; 2 – Students primarily self-controlled an investigation with teacher supplied supports, 3- Students self-directed an independent investigation. Pre-implementation data collection occurred during research Phase 1 (see section 4.6.2). The researcher compared all 11 critical inquiry ideas pre/post in this manner. The results of this comparison are shown in Figure 6.4.

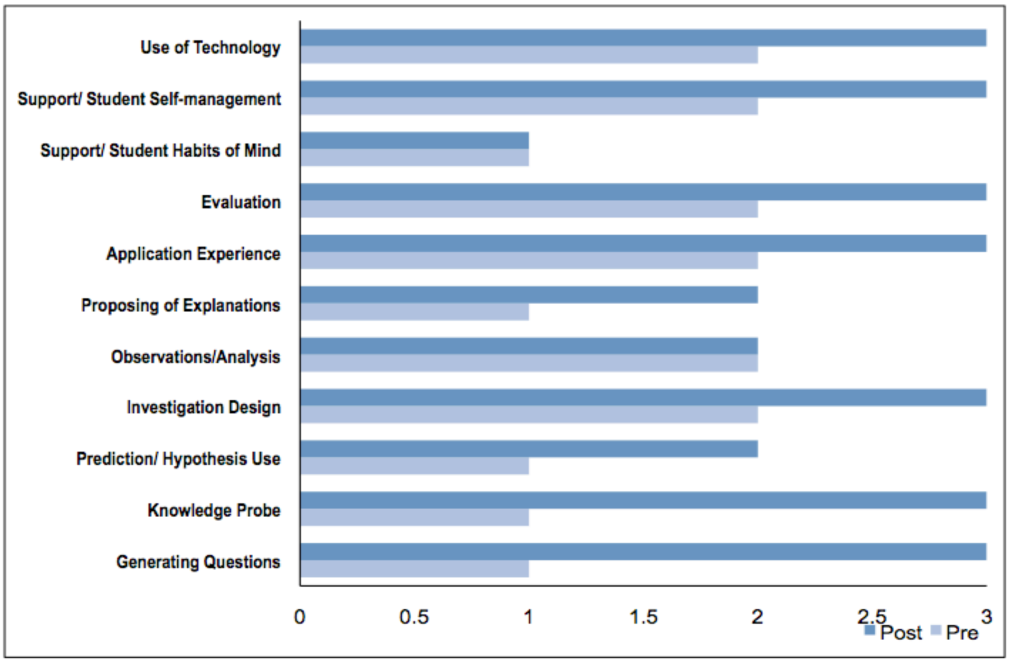


Figure 6.4. Scores for critical ideas for inquiry found within classroom teachers' classroom pre- and post-implementation for comparison.

For 10 out 11 of these ideas an increase in score of at least one rubric level occurred. For 7 out of 11 of these ideas post data indicated the highest score possible (Use of Tech; Student Self-regulation; Evaluation; Application Experience; Investigation Design; Knowledge Probe, and Generating Questions). The largest improvements came in student ability to independently generate investigation questions, and in the integration of personal and secondary knowledge during knowledge probe. It appears that the intervention was responsible for these increases. Key areas that did improve, but not as much as the researcher had hoped, occurred within the proposing explanations and supporting student habits of mind use and development. These two areas were the hardest for the teacher to support with the intervention, and indicate areas of future development needed.

Data were also used to determine post inquiry levels present in the classroom (e.g. confirmation, structured, guided, or open), which were then compared to pre-levels found. We first presented the pre-assessment inquiry levels present in the classroom in section 4.6.4, and section 3.3.1 provides details on these various forms of inquiry. In summary, a shift right along the continuum means students have more control during their investigations, while the teacher is exerting less control. Table 6.3 shows the pre/post evaluation of inquiry levels present in the classroom.

Table 6.3

Pre/Post Evaluation of Inquiry Levels Present

	Confirmation	Structured	Guided	Open
Pre-assessment	0%	63%	37%	0%
Post-assessment	0%	26%	57%	23%
% Change	No change	-57%	+54%	undefined

The data likely indicate that control shifted towards the students as a result of the intervention. The shift occurred as a result of fewer structured investigations (-57%) and a corresponding increase in both guided (+53%) and open (value of 23%) investigations. The percentage change is listed as undefined for open investigations because you can't calculate a percent change with a starting value of zero. These results also reflect how the lessons within the curriculum intentionally built upon one another in a sequence. Structured investigations were presented, when necessary, to develop student knowledge and experience needed to be successful in guided investigations, and guided investigations were used to prepare students for success in open investigations. The teacher was also challenged to look for opportunities to shift control to students during implementation, and these results appear to indicate that this was successfully accomplished.

6.2.3 Post-measure Data

The content test, performance test, and the two surveys were evaluated by comparing the pre and post data sets. These data were used to evaluate student attainment of learning outcomes, and in so doing determine the local impact the intervention had on students. For these tests the researcher used paired t-tests to control for differences inherent to the individual student. Multiple raters were used (two for performance assessment, three for content knowledge assessment except for one question where there was a rubric error. For that one there was only one rater for both pre and post measures). When there were multiple raters, the researcher analyzed inter-rater reliability using Pearson's correlation coefficient. Correlation coefficient formulas are used to determine strength of relationships between variables. Pearson's correlation coefficient measures strength of relationship between sets of data, and results +0.70 or higher indicating a strong positive relationship between the data sets. Results between +0.50 and +0.70 indicate a moderate positive relationship. Pre and post scores for students were averaged over these multiple raters for use in the paired t-tests. If a student did not complete one of the tests, the researcher excluded them from analyses. Rubrics used in analyses were based on a four-point scale for the content knowledge and performance assessments (1=beginning; 2=developing; 3=meeting; 4=exceeding). The scale for the surveys was based on a six-point scale as described in section 6.1.

6.2.3.1 Evaluating the Content Pre/Post Tests

Students were given the content pre-test before the implementation of the intervention, and the post-test after the implementation had concluded. Each student individually answered the four content questions (Table 6.4 & Figure 6.5).

Table 6.4

Results from a paired t-test comparing student content scores. Both individual questions and total scores are shown

Item	t-value	df	Sig. (2-tailed)
How does our health depend on genetic diversity?	3.62	14	0.003
Why are certain organisms used as models to learn about and improve human health?	8.86	15	<0.0001
How are plant and animal cells alike and how are they different?	4.34	14	0.0007
How does DNA cause biodiversity?	8.59	15	<0.0001
Total Score	9.49	15	<0.0001

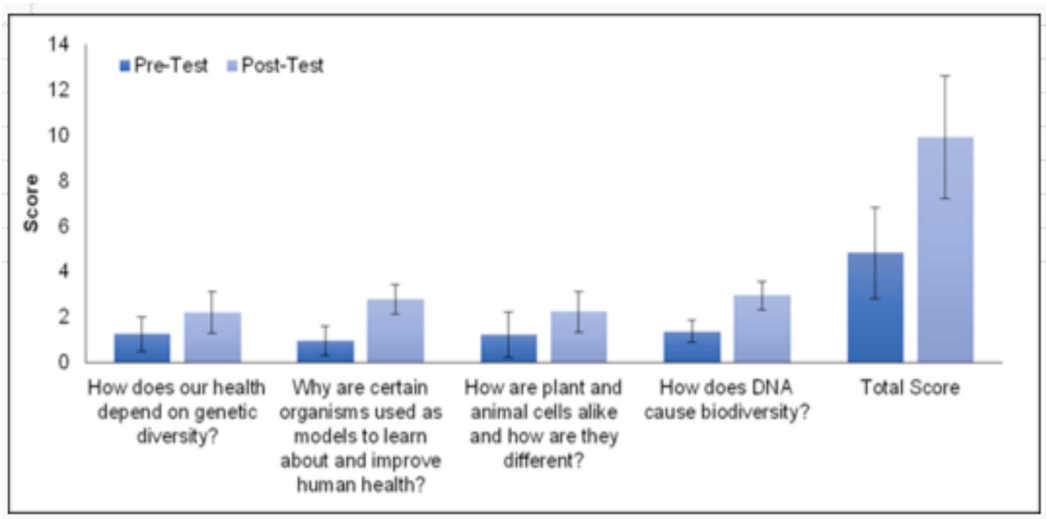


Figure 6.5. Scores for individual content questions and average total scores with standard deviations for pre- and post-test comparison. Individual questions were scored from 1-4, and the maximum total score was 16.

Comparing the pre-test scores to the post-test scores showed statistically significant increases for all four of the science content questions. Inter-rater reliability for the questions ranged from 0.706 to 0.940 (average 0.821), showing a high correlation between all raters. For all four content questions and the total scores, student scores increased significantly ($p<0.05$ in all cases; Table 6.4). This indicates that the chances the growth in the students' scores was simply due to chance would occur in less than one out of one hundred thousand cases. It appears likely that the intervention was responsible for this increase in knowledge. The fourth question, "How does DNA cause biodiversity?" increased the most, with a 1.37 pre and 2.9 post result.

6.2.3.2 Evaluating the Performance Task Pre/Post Test

To evaluate student ability to design and conduct scientific investigations a performance task was created where students were asked to design an investigation (e.g. perform a scientific investigation) after observing a living organism (i.e. frogs, turtles, spiders, crayfish) pre/post intervention implementation. Students documented investigations within a journal with Q-POE2 stickers format. Student performance was evaluated by comparing pre/post responses using a four-point rubric across five components (Figure 6.6).

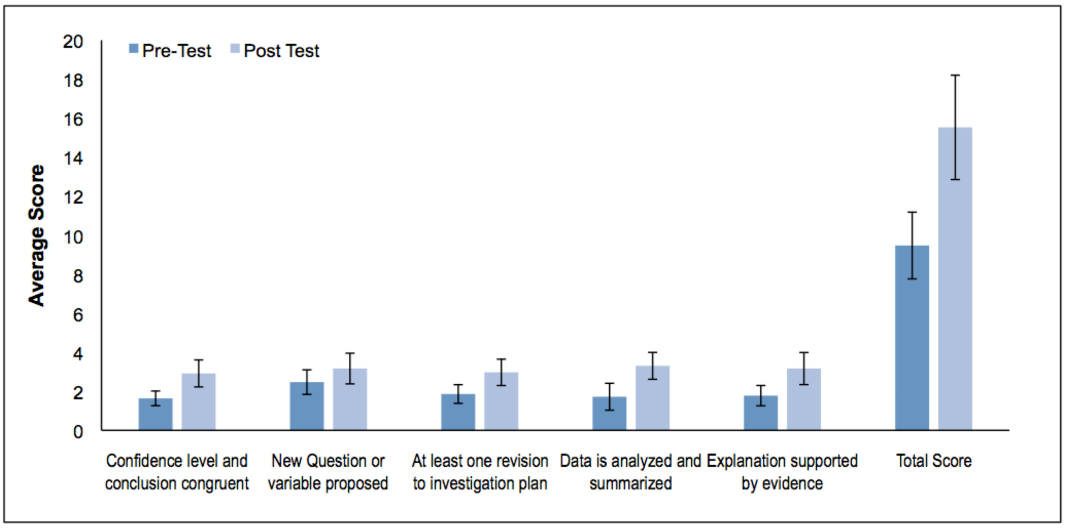


Figure 6.6. Scores for individual performance task scores and average total scores with standard deviations for pre- and post-test comparison. Individual questions were scored from 1-4, and the maximum total score was 20.

Paired t-tests were conducted for each component and it was determined that statistically significant increases ($p<0.05$) occurred for each of the five investigation components. Using Pearson's Coefficient, it was determined that inter-rater reliability ranged from 0.528 (moderate positive relationship) to 0.708 (strong positive relationship), with an average of 0.618 across all five components. Based on these results it appears likely that the intervention was responsible for this increase in student ability to independently perform science investigations. Figure 6.6 shows the significant increases from pre-test to post-test for each performance task component.

The researcher had intended on using ideas from Posner et al. (1982) to evaluate student ability to evaluate the status of their conceptions (e.g. dissatisfaction, intelligibility, plausibility, and fruitfulness) using the performance assessment data. However, the researcher was not able to translate these concepts into language the sixth and seventh graders could understand. In lieu of this, the researcher used the pre/post performance task data to do a simple evaluation of student ability to confront the status of their knowledge claims. To accomplish this task the researcher looked specifically at whether or not student confidence in a claim was congruent with the conclusion and explanation offered. It was conjectured that a student was not able to confront the status of their knowledge claims if they had high confidence, but this confidence was not justifiable based on a low quality of explanation and/or supporting evidence offered. Analysis of the pre-data indicated that 16 out of the 18 students were not able to confront the status of their knowledge claims, while 9 out of the 18 students were able to do so post. The researcher is not entirely confident in whether this simple evaluation actually showed what it was intended, or whether the results obtained were actually based on an increase in student ability to develop and link high quality evidence to the construction of explanations in general.

6.2.3.3 Evaluating the Two Questionnaires Pre/Post

To determine changes to student feelings and opinions regarding science, students were given the following questionnaire: *Your Opinions About Science and Learning Scien*ce. The researcher used paired t-tests, and found that in 20/22 questions there was no significant decrease in feelings/attitudes toward science, indicating that in general feelings about science were high when entering the program and remained high when students left the program. Significant results were found in that students were less likely to ask for help and were less likely to work as long as possible. This may be caused by an increase in student confidence in independently conducting science investigations. The results of this evaluation are represented in Figure 6.7.

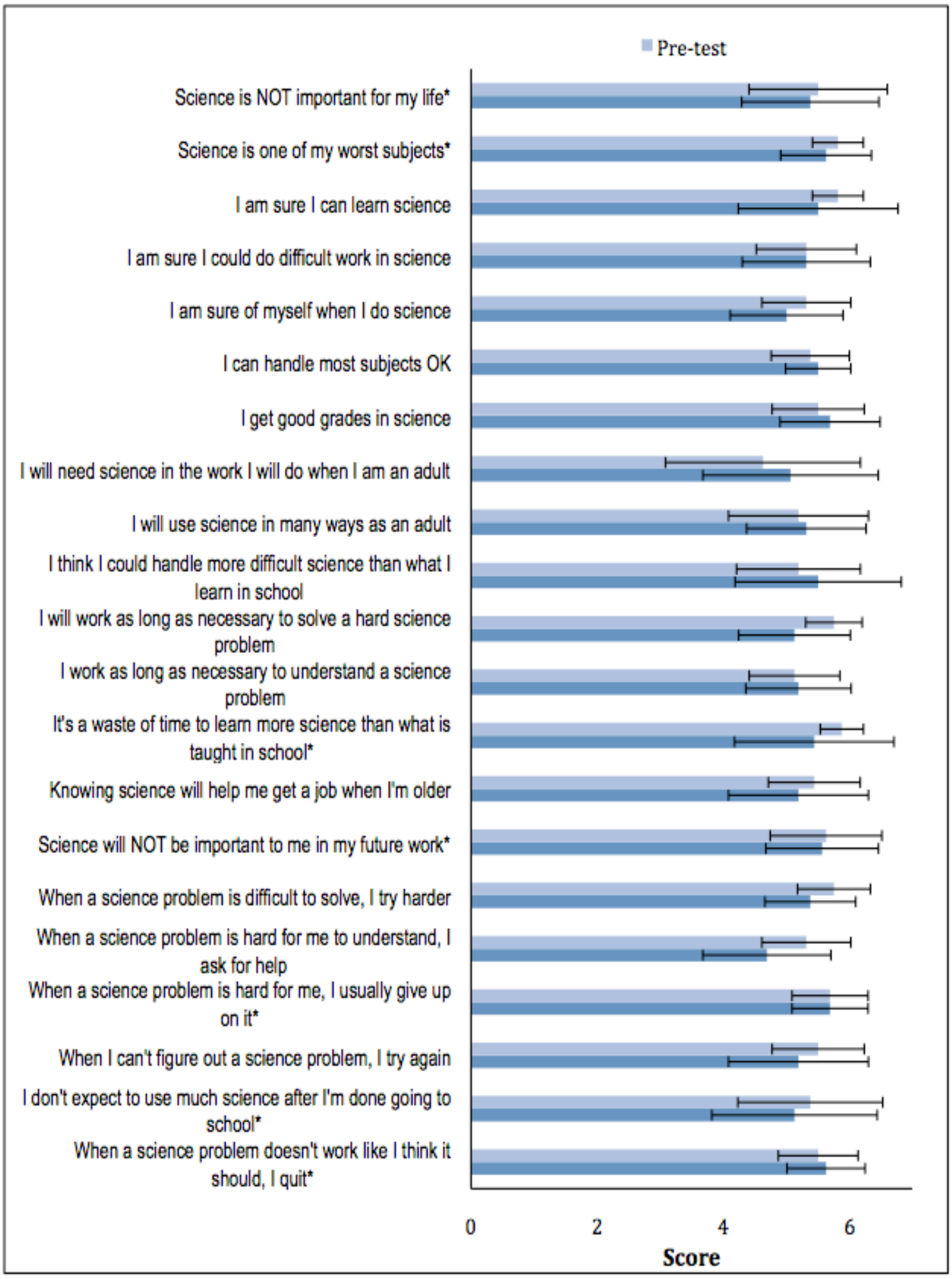


Figure 6.7. Averages for responses to *Your Opinions About Science and Learning Scien*ce, with standard deviations for pre/post comparison.

Note: Individual questions were scored from 1-6. Asterisks indicate negatively worded items that have been reverse coded for easier comparison with positive items. For all items, a higher score indicates a more positive opinion about science.

To determine changes to student interest regarding science, students were given the following questionnaire: *How You Feel about Science and Learning Science*. The researcher used paired t-tests, and found that in 10/10 questions there was no significant decrease in interest toward science, indicating that in general interest about science was high when entering the program and remained high when students left the program). The results from this evaluation are represented in Figure 6.8.

Section 2.8.5 summarizes the literature about student interest in science, showing a well-documented decline in this construct starting at age eleven and continuing throughout their academic careers. The goal for this thesis was to improve or maintain student interest because of intervention implementation. The results show this goal was reached, as no significant negative change of student interest occurred from pre to post.

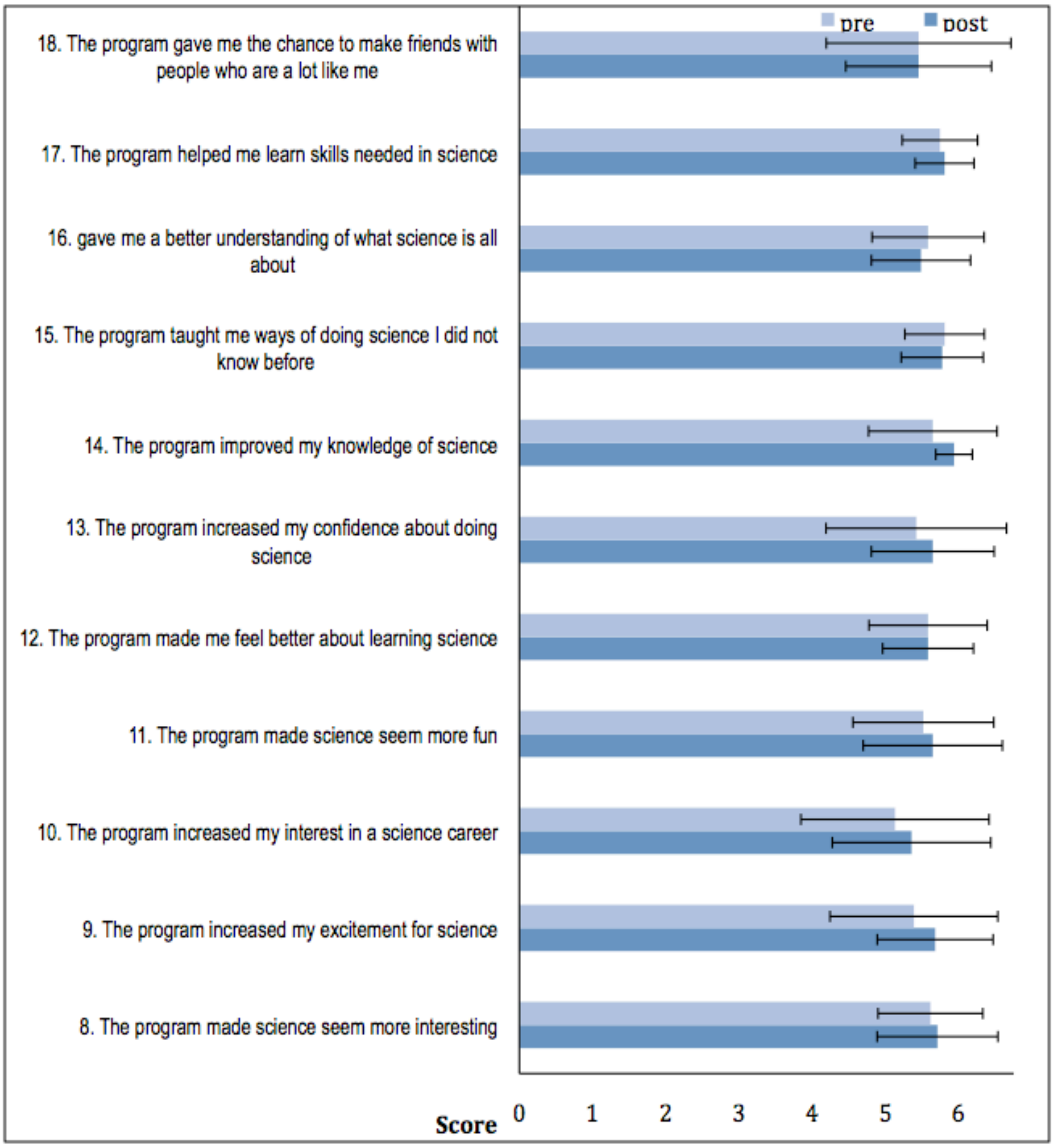


Figure 6.8. Survey Results from *How do you Feel About Science...*

Note: For all items, higher scores indicate more positive feelings about science. Averages for responses with standard deviations for pre- and post- comparison shown. Individual questions were scored from 1-6. For all items, higher scores indicate more positive feelings about science.

6.2.4 Post-implementation Data

To gain insight into any possible broader impacts the intervention had on participating students, six students, and their parents, were randomly selected to be interviewed, using a semi-structured interview protocol (see Appendices I & J). These interviews were recorded and transcripts made. The researcher analyzed the transcripts and four dominant themes emerged: 1) Thinking and Acting Scientifically, 2) Making Emotional Connections, 3) Experiencing Personal Growth, 4) Impact on Interest and Career Choice. These results are summarized next.

6.2.4.1 Theme #1: The Ability to Think and Act Scientifically

The intervention aimed to teach science as both epistemic practice, and as a process of conceptual change. The analysis of the transcripts indicates that for four out of the six students their ability to think and act scientifically changed.

Sandy's parent describes how "She's (Sandy) become more analytical in things" and "She's (Sandy) found logic".

Margaret's mom suggests, "(this program) gave her (Margaret) the tools so that she could find an answer thinking on her own." Margaret's mom also suggests, "Likewise, she's (Margaret) still interested in the science aspect, but differently now, she's more apt-acting like a scientist when it comes to finding the end of something. She (Margaret) didn't really know how to take those initial steps to testing something like she does now."

Luke's mother said, "I think, in some way, it was really a perfect thing for him, (Luke) because now he knows what a scientist actually does... and he's actually done it himself." Luke talks about his own changed understanding this way: "...this program has given me a great practical understanding of science... um, the scientific method; designing experiments that are practical and that will work, that will answer the question". Luke goes on to say, "Using (my) intelligence as opposed to just raw knowledge to solve problems."

Lisa's father describes how Lisa's thinking process changed because of participation, "I guess I see her looking at and viewing things differently; the questioning where the knowledge came from, where the assumption came from... a (new) way of thinking." Lisa's father goes further, suggesting that the parents also came away with a new kind of thinking, "And that's where VAI and the education part of the institute has been so strong; it's questioning the way you think-your student, and also in the parents. You, as a parent, come away with a better way of thinking."

6.2.4.2 Theme #2: Making Emotional Connections

Five of the six students described a strong emotional connection to the program itself, to fellow participants, and to staff members teaching the program. Tom states, "I felt I got a great experience from it..." and "it made me a lot more interested in science."

Lisa describes her experience this way: "I like coming" and "I don't think anybody else could have provided this experience. I loved it; it was awesome!"

Luke's mom talks about how "He (Luke) was sad he can't continue" and "It's the highlight of his week and he would spend more time here if he had the opportunity". She also describes how "...this program has been a dream come true for him, okay, since the beginning." She also says, "It's a privilege--and a great opportunity to be part of a program that not everyone gets to participate in and we understand that."

Margaret's mom talks about how Margaret experienced the program by saying, "And she really enjoyed it. Margaret will normally be up for a skip day, usually whenever, but she won't, she wouldn't skip on a program day."

Sandy was both sad and relieved by the ending of her program experience. Sandy's mom sums up her daughter's experience by saying "...she is going to miss being here" but is also "relieved it is over," because of how busy her life became during the third year of the program.

6.2.4.3 Theme #3: Experiencing Personal Growth

Throughout the interview process comments continually arose that indicated the participating students experienced personal growth. All six students and/or their parent indicated personal growth as an outcome of participating in the program.

Sandy stated, "I have more confidence in whatever. (In school there is…) Nothing you'll have to figure out by yourself and it's right there in your notebook and it's hard to understand how people get a bad grade in it, cause it's all right there. Well, I mean, we did, like one or two experiments, but it was like planned, it was like, so you don't get to do it yourself?"

Like Sandy, Lisa also talked a lot about how her experience within the program was different than her school experience, "We usually just get up and do things by ourselves here- and that's what I wanted. So, I had more freedom and I felt like, you know, this is a good place to be..." She suggested, "...when I'm in school I already know the stuff before they even teach it to me, cause like, I learned it at Science Academy..." and "...the Science Academy helps me with my grades at school."

Luke's mom described how her son connects his Science Academy learning with his school learning. "And Luke takes whatever he learning here into his science classroom and that's been really fun to watch. To know that whatever he does here is more advanced than the advanced science class at school, yeah." Luke himself compares his school and Science Academy experience this way: "Well, that is, again, it's a lot of memorization in school, um, and if we had a problem we had to solve through scientific method, it was extremely straight forward. Um, with not much thinking involved. Well here (at the Science Academy) it great because like I said, a lot of time it's developing your problems to solve, which is very interesting. Like phrasing the question yourself, which is very helpful, and developing your plan yourself, and it works here, because you have the resources, as opposed to school where you can only do one thing." Luke's mom stated that they are having trouble finding other science learning opportunities for Luke outside of school. Luke has only participated in a "Day of genetics seminar at Grand Valley," the only opportunity they could find.

Ana's mother talked about how the program was hard for her, in part, because of how introverted she is. However, she believes that these hard experiences benefited Ana outside of school. She says "...even the presentations, you know she's so introverted and to have the kids, have that experience to get up in front of peers, and public speaking, let alone on such an intellectual level. You know, really, I think that's just a huge advantage that they have going forward. Definitely, in communication... She has more confidence in her knowledge." Ana's mother echoed Luke's mother in saying it was hard to find similar science experiences for Ana to participate in after the program finished. Margaret summed up the differences between her school science and Science Academy science this way: "It's (school science) not like it (Science Academy Science), because you let us go off by ourselves and learn by ourselves not teach them-this is how you do that and this is how you do that. It's more of a free, free roaming thing, and I like it more than regular science."

Margaret's mom talks to how Margaret applies her science learning this way: "...she's more apt to acting like a scientist when it comes to finding the end of something. You know, like before, if she would just ask something, now she'll go on the internet, or further her things herself, which, she didn't really know how to take those initial steps to testing something like she does now." When asked by the interviewer if she thinks this is important, she says, "I do, because they don't teach these kinds of things in school."

6.2.4.4 Theme #4: Impact on Student Interest in Science and a Science Career

Interest is an important variable in promoting conceptual change. Analyzing the transcript data showed that all six students described how the program either maintained or expanded their interest in science. Margaret's mom describes how "She (Margaret) either wants to be a scientist or a veterinarian. She's changed her mind over the course of the program - at first she wanted to be a dentist." Margaret echoes this sentiment; "It (the program) got me really motivated to do science. I might not be a scientist, but I want to be a veterinarian cause I love animals, and I learned I like to interact with them and see if I can improve their health or stop diseases for them."

When Lisa's dad was asked to describe the impact the program has had on his daughter's interest in science, he suggested, "I would say it's probably an eight or nine... out of ten."

Sandy describes how "(because of the program) I know I wanna be a pediatrician. But then I also learned there's like a hundred other things I can do."

Luke's mom talks about how he has always had a tremendous interest in science: "Yes, since before he was three. It is his life. It's what he lives and breathes. It's on every shirt he wears, it's what he reads- I mean, Stephan Hawking at 12? It is who he is." Luke himself suggested, “Well, I was already very motivated. I mean I've been planning on going into a scientific career since I was three years old. But, um, definitely, felt more prepared, um, this program has given me a great practical understanding of science...".

Ana says, "Yeah, I guess I want to be a scientist of some sort."

Even Tom's mother, who did not believe the program had a big impact on her son, describes how "...sometimes he talks about, um, he wants to be a doctor. Yeah, and he never said that before." Tom describes how he has changed because of the program: "It made me a lot more interested in science. Like, before, I was like more interested in, like astronomy. But I think it's like, health, I like more."

6.3 Research (Step 13): Evaluation of Results

A detailed intervention was iteratively developed during study #1. The data collected were used to inform the design itself (e.g. soundness, preferability, and appeal). The intervention was designed to help the teacher and students implement the enriched vision of science and promote conceptual change.

Classroom observations appear to determine that the teachers and students used the intervention with fidelity. Pre and post-test comparisons showed significant increases in student content knowledge ($p<0.001$ in all cases) that likely arose from the intervention. Science performance (e.g. epistemic practice), which was evaluated within student journals, showed increases for each of five content knowledge areas ($p<0.01$ in all cases) likely as a result of the intervention.

Questionnaires designed to measure student attitudes and interest in science determined that student interest remained high throughout the program, in contrast to well-documented reports of normal student decline of interest within this age group. Through interviews with six students and parents it was determined that the implementation was personally meaningful to the students and that their learning transferred to outside settings.

The ability of students to transfer knowledge beyond the learning context is an important finding for conceptual change research. A full evaluation of the results will be presented in chapter 7.

6.4 Research (Step 14): Reflection and Discussion

Study #1 successfully developed an educational intervention aimed at promoting conceptual change in support of an enhanced vision of inquiry-based science. Study #2 demonstrated that the intervention promoted the attainment of learning outcomes by supporting both the teaching of, and learning through, inquiry-based science. It was determined that the intervention was responsible for significant increases in student content and performance (e.g. science as epistemic practice). It was also determined that students entered the study with a high level of interest and positive attitudes toward science, which did not decrease over the course of implementation. Based on the outcome of the evaluation the intervention was refined and plans for broad dissemination of the intervention explored. A multidimensional conceptual change perspective proved to be an effective referent in support of the design and evaluation of the intervention. A detailed discussion and reflection will be presented in chapter 7.

6.5 Answers to Phase 3 Research Questions

6.5.1 Answers to Student Learning Focus Research Questions for Phase 3

What does inquiry-learning look like in the teacher's classroom because of intervention implementation? (SLRQ3a)

The researcher explored this research question through the lens of activity (e.g. what the students were doing), discourse (e.g. the nature of classroom talk), and participation (e.g. how members of the classroom interacted with each other). Observations were made both before and after the intervention was implemented, and comparisons made. The *Teacher Beliefs Interview* (TBI- see section 4.6.1) indicated that the teacher held progressive (e.g. aligned with the enriched vision of science education) views on how students should learn science. However, some dramatic changes to the teacher's teaching practice were observed likely as a result of intervention implementation. Section 6.2.2 provides an in-depth evaluation of these changes. In summary, teacher talk dramatically reduced (-58% change), while student-to-student talk dramatically increased (+60% change). These changes corresponded to similar changes in how the students were grouped for interaction. For, example the amount of time the teacher spent in front of the class addressing the whole group reduced dramatically (-58% change), which provided more class time for discussions (+14% change), and for students to spend more time working together in small investigation teams (+38% change).

Section 6.2.2 discusses the role of two intervention discourse strategies and teaching posters in supporting these changes. The Q-POE2 Process of Scientific Inquiry, as implemented with stickers and student journals, also supported the increased time student spent working on investigations (e.g. change in activity).

How did the intervention impact inquiry-learning in the teacher's classroom? (SLRQ3b)

There were seven learning outcomes developed for students to determine the impact the intervention had on student learning. Table 6.5 shows attainment of the student learning outcomes.

Table 6.5

Student Attainment of Learning Outcomes

Student Learning Outcome	Attainment
1) Develop, and/or maintain positive attitudes and feelings toward science	Students maintained positive attitudes and feelings as a result of the intervention (see section 6.2.3.3)
2) Design, carryout, and communicate the results of science investigations	Students significantly increased in their ability to design, carry out, and communicate the results of a science investigation (see section 6.2.3.2)
3) Evaluate and confront the epistemic status of personal knowledge claims	Students ability to provide and evaluate evidence for knowledge claims increased significantly, but evidence of confronting epistemic status of such claim was inconclusive (see section 6.2.3.2)
(4-7 are Content Outcomes)	
4) Explain how health depends on genetic diversity found in species and habits	Significant increases in student content knowledge pre/post were found for all content questions (see section 6.2.3.1; Table 6.3; Figure 6.6)
5) Explain why certain organisms are used as models to learn about and improve human health	
6) Describe how plant and animal cells are alike and different	
7) Explain how plant and animal cells are alike and different	

6.5.2 Answers to Learning Environment Focus Research Questions for Phase 3

How did the intervention support how the teacher designed the learning environment and taught the students?

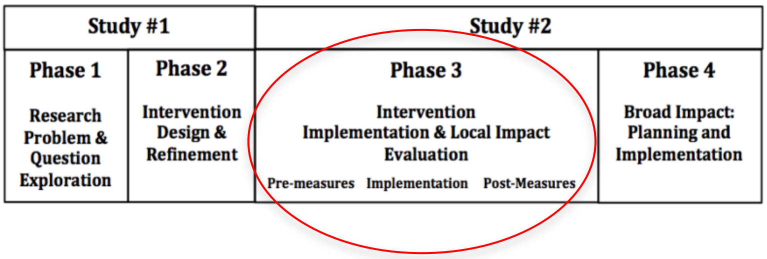
Section 6.2.2 summarizes how the teacher designed the learning environment changed based on implementing the intervention. Table 6.2 shows how discourse and participation patterns shifted likely due to the intervention before and after implementation. Figure 6.4 summarizes how the teacher supported critical ideas for inquiry within the learning environment. For 10 out 11 of these ideas an increase in score of at least one rubric level occurred. For 7 out of 11 of these ideas post data indicated the highest score possible (Use of Tech; Student Self-regulation; Evaluation; Application Experience; Investigation Design; Knowledge Probe, and Generating Questions). The largest improvements came in student ability to independently generate investigation questions, and in the integration of personal and secondary knowledge during knowledge probe. The intervention appears to be responsible for these increases. Key areas that did not improve as much as the researcher had hoped occurred within the proposing explanations and supporting student habits of mind use and development. These two areas were the hardest for the teacher to support with the intervention, and indicate areas of future development needed. Table 6.6 summarized teacher attainment of learning outcomes.

Table 6.6

Teacher Attainment of Learning Outcomes

Teacher Learning Outcomes	Attainment
1. Use the intervention to teach students how to design, carry out, and communicate the results of science investigations.	How the teacher taught the students significantly improved likely as a result of the intervention (see section 6.2.3. Figures 6.5 & 6.7). Students were able to independently design, carry out, and communicate the results of science investigations based on how the teacher designed the learning environment and taught students. Intervention components best supporting these results: QPOE2 Model & Stickers; Discourse & Evaluation Teaching Posters.
2. Use the intervention to guide the design of a socially and language rich learning environment.	The teacher was able to use the intervention to guide the design of a socially and language rich learning environment. Students worked and talked together more often in small teams. Overall, the teacher talked less and the students talked more pre/post likely based on the intervention (see section 6.22; tables 6.1 & 6.2; Figure 6.5). Intervention components best supporting these results: Community of Scientific Practice Model; Discourse Teaching Posters
3. Use the intervention to guide the design of a learning environment that nurtures the habits of mind of their students.	The intervention successfully supported the teacher in being aware of the role habits of mind have in enhancing inquiry-based instruction. However, the teacher did not intentionally nurture the habits of mind of the students using the intervention. The intervention will need to better support the intentionally teaching of habits of mind to the with specific strategy development and use.

6.6 Chapter 6 Summary



This chapter presented the results of research Phase 3, Intervention Implementation and Local Impact Evaluation. Research Phase 3 was described in section 3.5. Phase 3 involved research (Steps 11-14) of Study #2. The goal of chapter six was to evaluate the impact the intervention had on both how the teacher designed the learning environment, and the actual learning that occurred there. To accomplish this goal the researcher studied how students learned through inquiry in the teachers' classroom both before and after the intervention was implemented. The students were also given content and performance pre and post-tests, as their interests and feelings toward science were surveyed. The results from research Phase 3 were used to answer the research questions for this phase, which are shown in Table 6.9. The results of Phase 4, and the answering of Phase 4 research questions will occur in chapter 7.

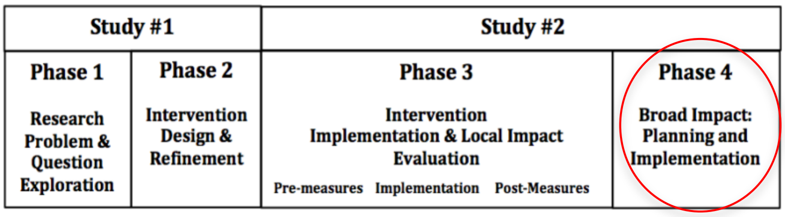
Table 6.7

Research Steps and Corresponding Research Questions for Study #2, Phase 3

Research Phases & Associated Steps	Student Learning (SL) Focus Research Questions (RQ)	Learning Environment (LE) Focus Research Questions (RQ)
Phase 3: Intervention Implementation and Local Impact Evaluation: 11. Theory Refinement 12. Implementation/Data Collection 13. Evaluation of Results 14. Reflection and Discussion	What does inquiry-learning look like in the teacher's classroom because of intervention implementation? (SLRQ3a) How did the intervention impact inquiry learning in the teacher's classroom? (SLRQ3b)	How did the intervention support how the teacher designed the learning environment and taught the students? (LERQ3)

Chapter 7 Results of Study #2, Phase 4: Broad Impact Planning and Implementation

7.0 Chapter Overview



This chapter presents the results of research Phase 4, Broad Impact Planning and Implementation. Research Phase 4 was described in section 3.6. Phase 4 involved research (Steps 15 -16) of Study #2:

15) Publish Results (section 7.1)

16) Broad Impact Planning & Implementation (7.2)

Even though this research unfolded within the context of one classroom within the local context of an education institute, the intervention was developed with the intention of having an impact on student learning, and teacher practice, within a broader context. The goal of this chapter is to begin planning for and implementing this possibility.

The four sections of this chapter will present the results of Phase 4, Broad Impact Planning and Implementation. There are three main sections plus a summary section. Section 7.1 will present research (Step 15), and section 7.2 research (Step 16). The results from this chapter will be used to answer the research questions for Phase 4 (see Table 7.1).

Table 7.1

Research Steps and Corresponding Research Questions for Study #2, Phase 4

Research Phases & Associated Steps	Student Learning (SL) Focus Research Questions (RQ)	Learning Environment (LE) Focus Research Questions (RQ)
Phase 4: Broad Impact Planning and Implementation 15. Publish Results 16. Broad Impact Planning a. Diffusion, adoption, adaptation. b. Consequences	How has the intervention impacted student learning in other contexts? (SLRQ4)	How can the intervention that was implemented in other contexts be described? (LERQ4a) How did the intervention support how the teacher designed the learning environment in other contexts? (LERQ4b)

7.1 Research (Step 15): Publish Results

For educational design research to have broad impact, research results should be disseminated to both practice and research venues. Plans are currently underway for publishing thesis results. Disseminating results to the practice-based community is integrated tightly with plans for broad impact planning.

7.2 Research (Step 16): Broad Impact Planning and Implementation

Even though educational design research occurs within the context of a classroom/program, interventions are developed with an eye towards a possible broader impact. By the time Phase 4 was initiated the researcher realized that the research questions developed for this phase were beyond the scope of the thesis. However, what was within the scope of the research was a narrower exploration of how the intervention was adopted/adaption for use by the local context post implementation. To that end, immediately after implementation ended the researcher started developing a plan to promote broad impact of the intervention. The plan developed had two parts. The first part planned for the adoption /adaptation of the intervention within the local context of the education institute student programs where the research took place. The second part of the plan involved promoting the adoption/adaptation of the intervention for use within the teacher professional development presented by the education institute within school districts. Within several months of the completion of the implementation, the researcher reviewed the main components of the intervention (e.g. Q-POE2 Process; Community of Scientific Practice Model; Instructional Supports/Teaching Posters, Journals, Sticker Books, Critical Ideas of an Inquiry-based Pedagogy) with the two-part plan in mind. The researcher decided that the two models within the intervention were strong and worked as intended to support an enriched vision of science learning. The researcher also decided that the two discourse strategies (e.g. Research In Progress; Present and Defend) were powerful tools within the developed pedagogy and would not need any refinement, at least right away. However, the researcher determined that four of the teaching posters would benefit from a refinement cycle: 1) Evaluation Poster, 2) Confidence Chart Poster, 3) Explanation Poster, and 4) Data Analysis Poster. The researcher developed refined versions of these posters, which will be presented in section 7.2.1.

7.2.1 Adoption/Adaption of the Intervention within the Local Context

After the refinements were completed the researcher presented them, along with the rest of the intervention, to the education institute staff (e.g. associate director, curriculum specialist, technology specialist, and an education specialist). The staff was aware that the intervention was being used and evaluated in one of their programs, but only the actual teacher of the program worked with it closely. After a very positive discussion, the team explored the intervention and supporting materials for possible refinement. The QPOE-2 and Community of Scientific models were explored at meetings throughout the following year. The staff loved the models and suggested a few minor adaptations. Figure 7.1 shows the adapted version of the Q-POE2 Process of Scientific Inquiry and Figure 7.2 shows the refined Community of Scientific Practice model that was created.

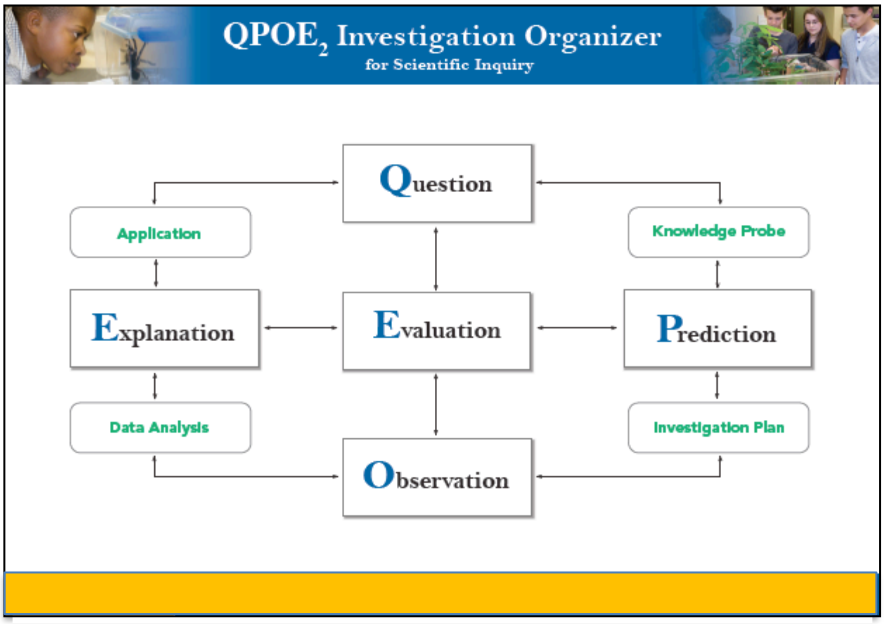


Figure 7.1. Local Adaptation of the Q-POE2 Process

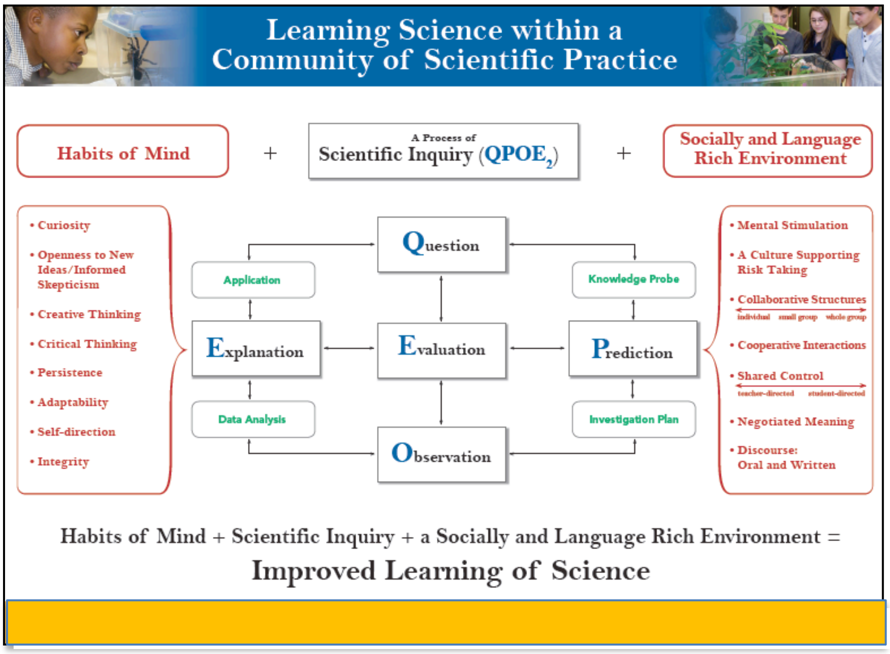


Figure 7.2. Local Adaption of the Community of Scientific Practice Model

For the Q-POE2 process, the changes made by the local context were minor. The name of the adapted version of the model was changed to the $QPOE_2$ Investigation Organizer for Scientific Inquiry. The institute decided to adapt the Community of Scientific Practice Model slightly to create their version. Two habits of mind were added to the model, adaptability and integrity. Additionally, two ideas were added to the socially and language rich component, mental stimulation and a culture supporting risk taking. When exploring the possibility of modifying an intervention an educational design researcher needs to consider the consequences of the changes. In this instance, the researcher felt that the changes made by the local context staff would not negatively affect the outcomes of using the model with students and teachers. The cosmetic changes of adding color, photographs, and top and bottom headers added to the appeal of the model.

Next, the team explored the adaptation of the six teaching posters that the researcher had presented, which included the two discourse strategy posters and the four additional posters presented at the end of section 5.2.2. Adapted versions were created for all six posters. Each poster will be presented in pairs. The first graphic in each pair shows the refined teaching poster as designed by the researcher, and the second graphic shows how the local context team adapted the poster to create their version. Reviewing each pair will show that most of the teaching posters developed by the researcher were changed very little by the staff for use within the local context. The data analysis teaching poster had the most changes. How the two discourse strategies were adapted will be presented first in Figures 7.3 and 7.4.

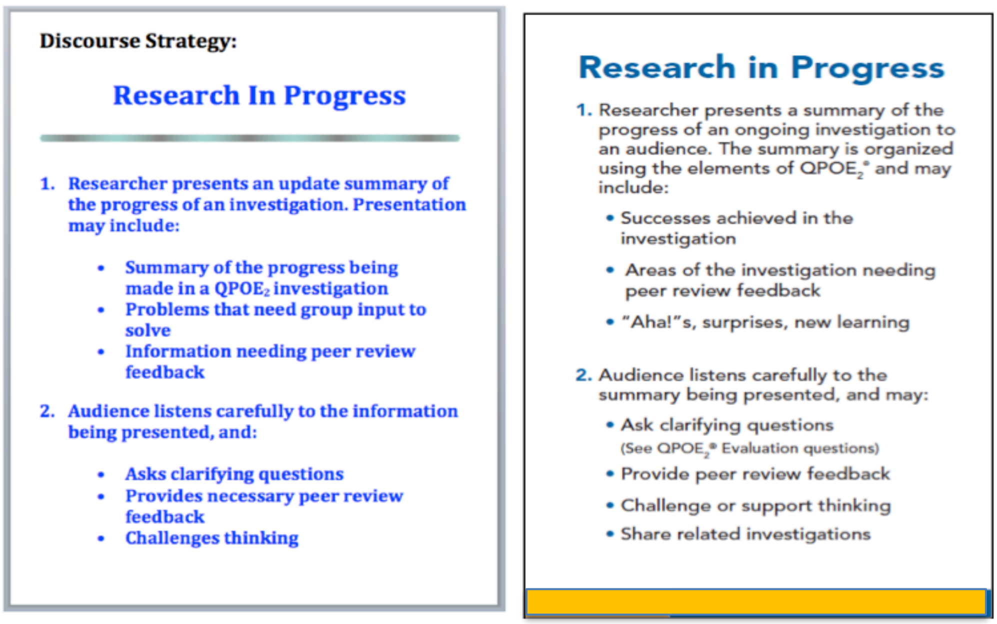


Figure 7.3. Local Adaptation of the Research In Progress Discourse Strategy

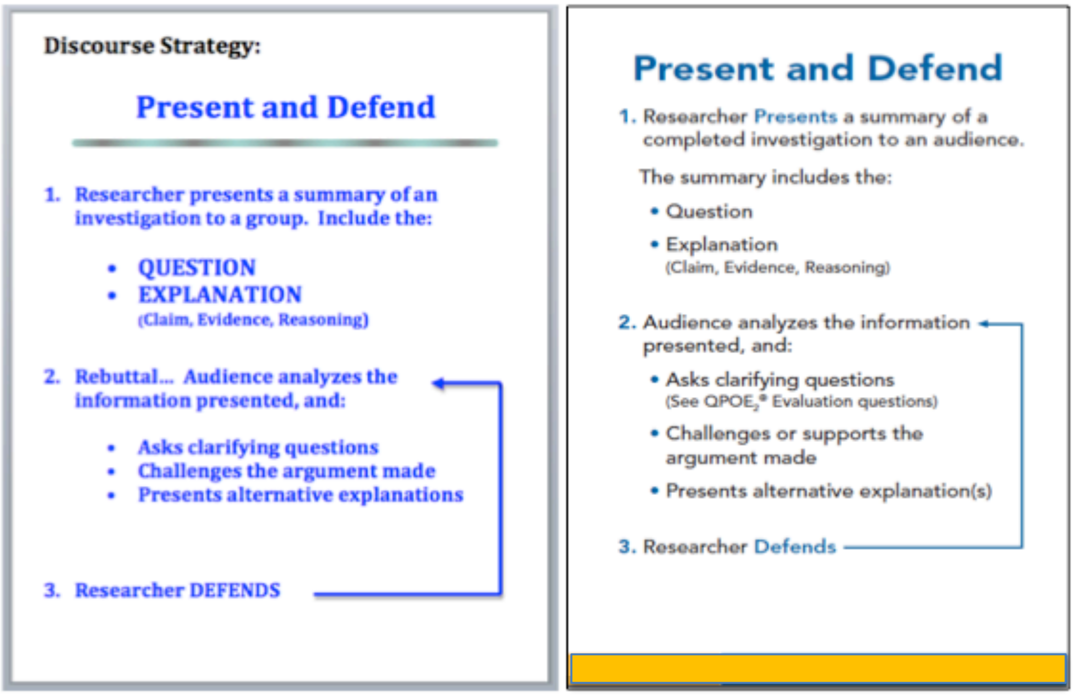


Figure 7.4. Local Adaptation of the Present and Defend Discourse Strategy

The local team also decided to adapt the Evaluation and Confidence Chart teaching posters for use within the local context. Figures 7.5 and 7.6 show the result of this adaptation.

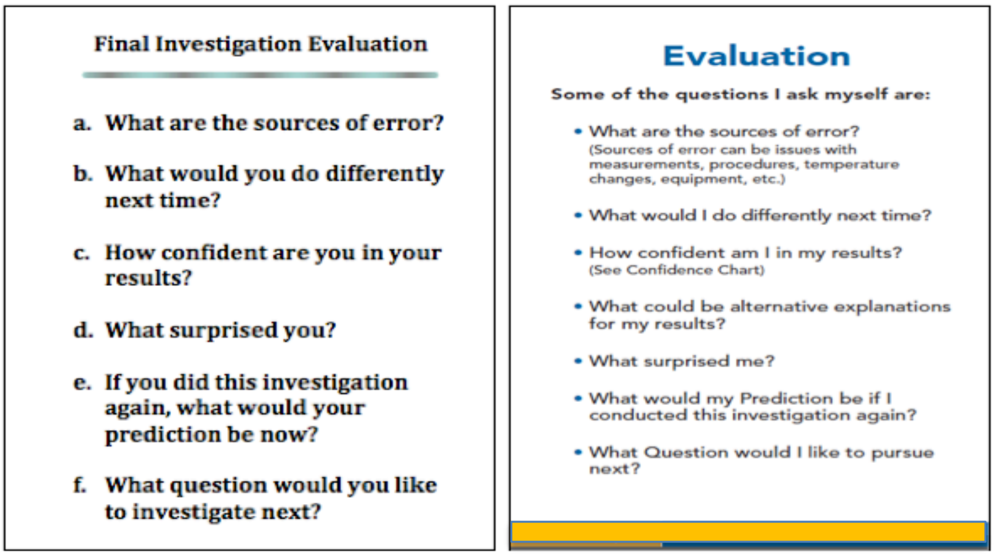


Figure 7.5. Local Adaptation of the Evaluation Teaching Poster

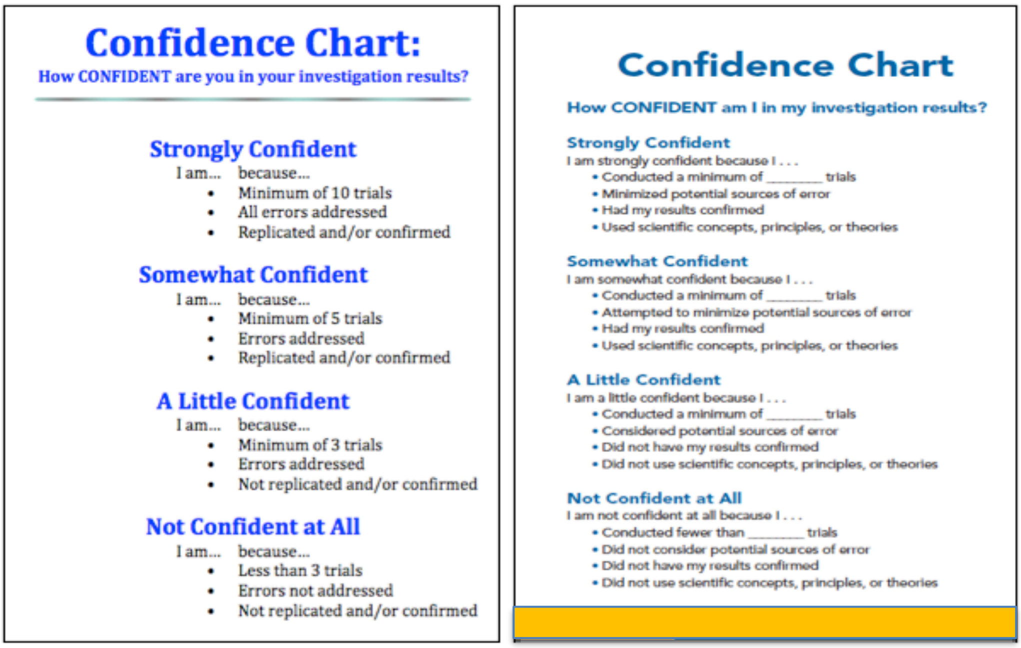


Figure 7.6. Local Adaptation of the Confidence Teaching Poster

The explanation and data analysis posters were also adapted for use within the local context. The first graphic in Figure 7.7 shows the explanation teaching poster as developed by the researcher, while the second graphic shows how the researcher's version was adapted by the local context for their use.

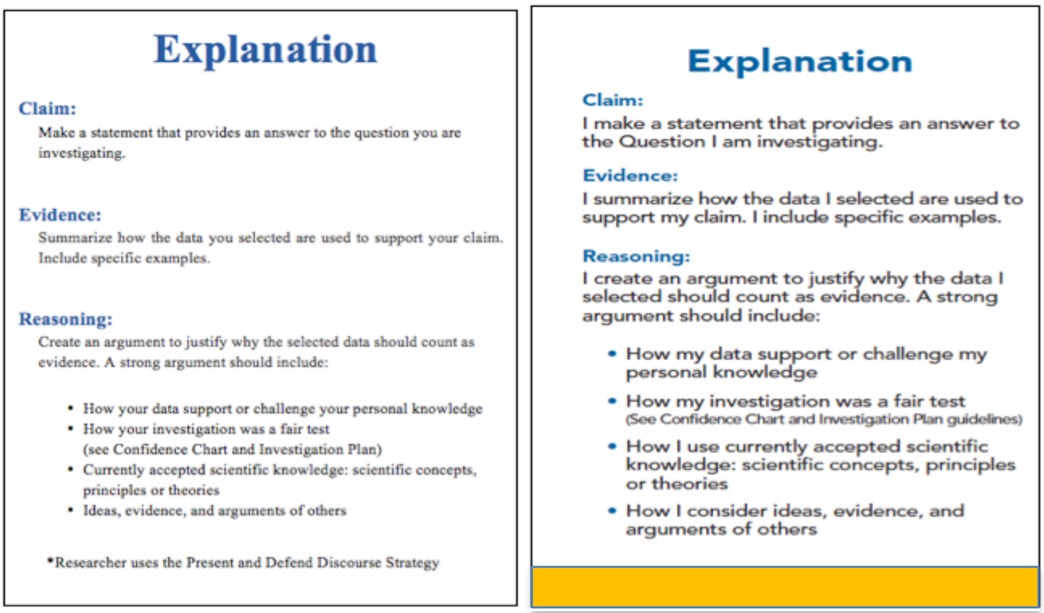


Figure 7.7. Local Adaptation of the Explanation Teaching Poster

The first graphic in Figure 7.8 shows the researcher’s version of the data analysis poster, while the second graphic shows how the local context adapted the researcher’s version for local use.

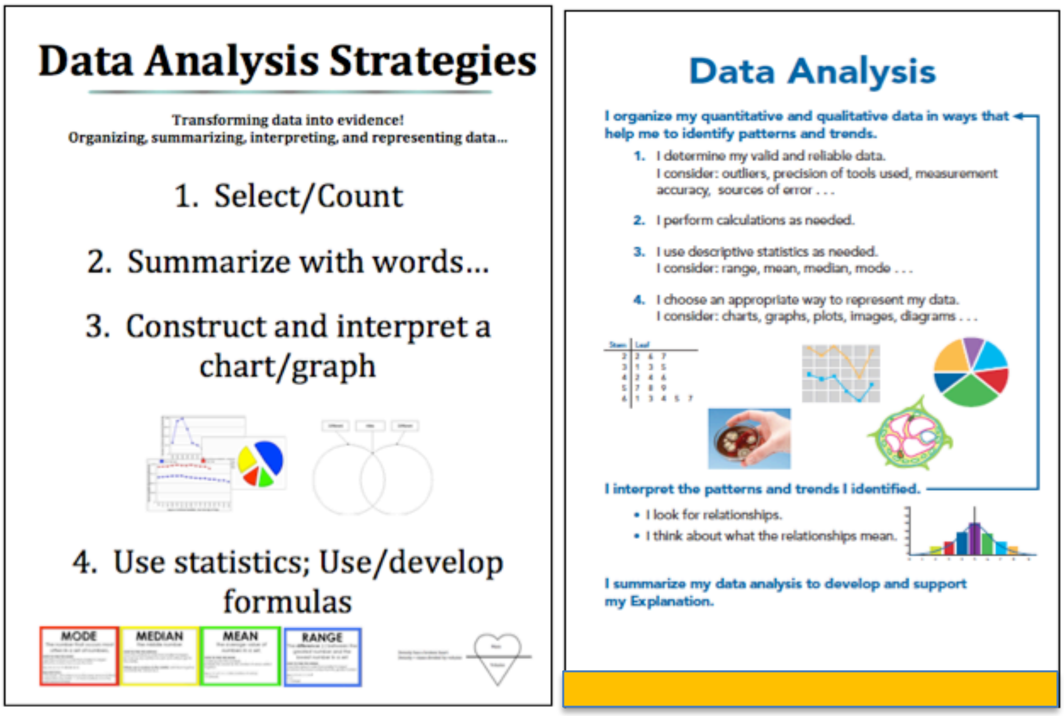


Figure 7.8. Local Adaptation of the Data Analysis Teaching Poster

The intervention included additional posters in support each Q-POE2 process component (see section 5.11). The local context’s team decided to transform the content of many of these posters into the form of a step book that students could use independently. Figure 7.9 shows an image of the finished step book that was developed. In the step book every component has its own page, with all the pages bound at the top. The first image in Figure 7.9 is the step book in its entirety before any pages have been flipped. As an example, the second image in Figure 7.9 shows the step book flipped to the Investigation Plan component of the Q-POE2 process. Each page of the step book corresponds to one of the teaching posters developed to support the intervention. A journal page was added at the end of the step book to support students in the writing of their journals, which was the only component added beyond what was represented by the teaching posters.

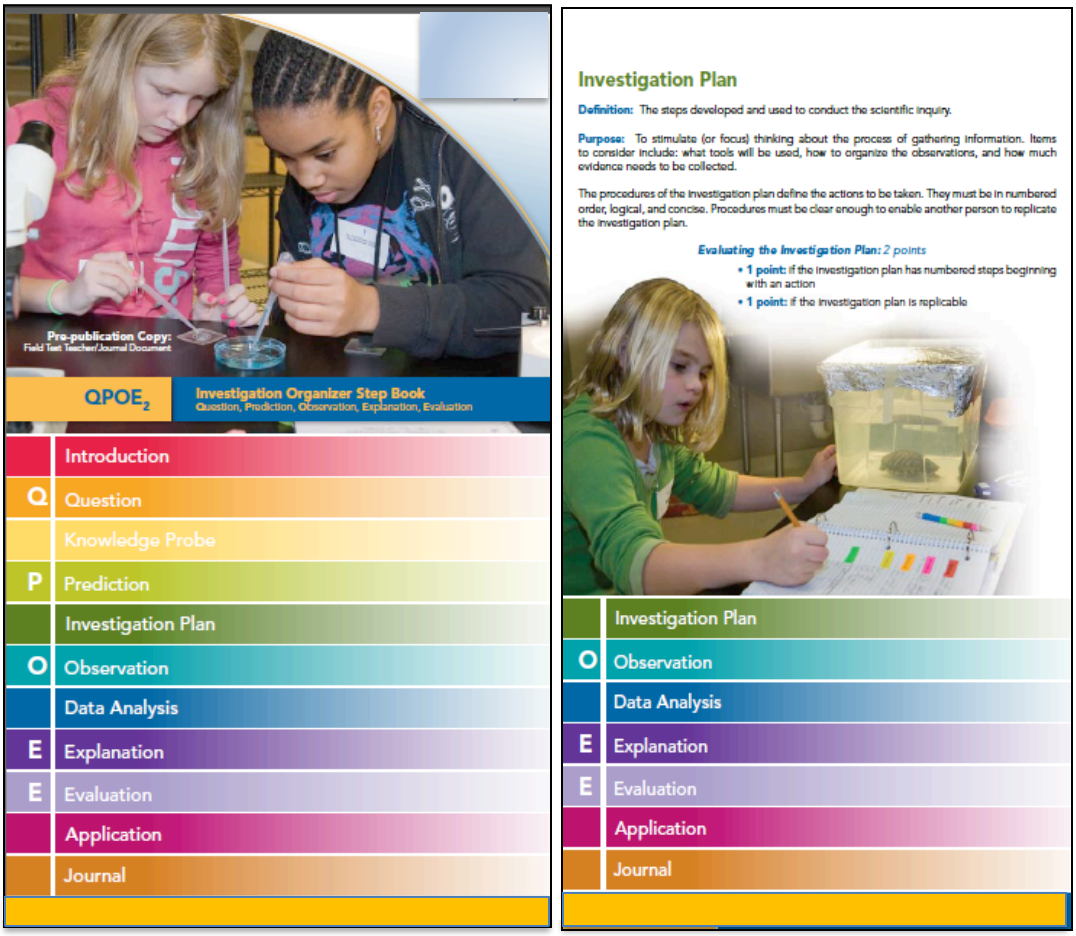


Figure 7.9. Local Adaptation of Teaching Posters into a Step Book for Students

7.2.2 Adoption/Adaption of the Intervention within a Broader Context

At the time of thesis completion, twenty-two school districts and a charitable trust had contracted the local context to provide a training program in using the adapted intervention. How one school district and the charitable trust are implementing the intervention will be highlighted in section 8.9. Plans are also currently underway at the local context to develop an iPad application, which will be an electronic version of the Q-POE2 Step Book and stickers. Future research will be needed to explore the consequences of adapting the intervention for use in the variety of broader contexts the intervention will be used. Plans for exploring how the intervention might be disseminated within a broader context are ongoing.

7.3 Answers to Phase 4 Research Questions

The original research questions for Phase 4 were:

How has the intervention impacted student learning in other contexts? (SLRQ4)

How can the intervention that was implemented in other contexts be described? (LERQ4a)

How did the intervention support how the teacher designed the learning environment in other contexts? (LERQ4b)

It was determined that these research questions, even though an important part of the research design, ended up being beyond the practical scope of the thesis. Consequently, Phase 4 research questions are not answered as part of the thesis. These are great questions for future research, however. Instead, Phase 4 of the research took a narrower look at how the education institute where the research occurred adopted/adapted the intervention for their use within their student and professional development programs after intervention implementation concluded (see Section 8.9 and 9.0 for more detail).

7.4 Chapter 7 Summary

Chapter 7 presented the results of the initiation of Phase 4 of Study #2, Broad Impact Planning and Implementation.

Study #1		Study #2	
Phase 1 Research Problem & Question Exploration	**Phase 2** Intervention Design & Refinement	**Phase 3** Intervention Implementation & Local Impact Evaluation Pre-measures Implementation Post-Measures	**Phase 4** Broad Impact: Planning and Implementation

Phase 4 contained research (Steps 15-16. Initial steps were taken to support the adaptation of the intervention for use within the local context. How the Q-POE2 Process and the Community of Scientific Practice Models were adapted and are being used within both student and teacher professional development programs being offered by the institute were presented. Also described within chapter 7 was how the teaching posters were adapted for use.

Chapter 8 Thesis Summary and Implications for Practice and Research

8.0 Introduction

The initial goal of the thesis was applying a multidimensional conceptual change perspective to the design and evaluation of an intervention aimed at promoting learning within an after-school genetics program. This perspective balanced individual and social dimensions of learning and is shown in Figure 8.1

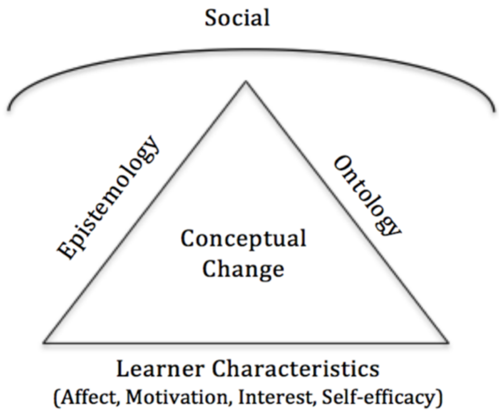


Figure 8.1. Multidimensional Conceptual Change Perspective

As the research progressed this original goal quickly broadened to include improving the teaching and learning of science within a broader context. This broadening occurred as the researcher was drawn into the problem of the failure of science education reform in bringing meaningful and long-lasting change to the teaching and learning of science. Section 8.1 conceptualizes this failure in terms of a meaningful problem of practice, which was also the research problem for the thesis. The research sought to solve the broader problem within a local context of an after-school program, but kept one eye focused on possible generalization to a broader context.

Section 8.2 summarizes the 4-phase, 16-step, educational design research that was carried out over two studies to address the research problem. The methodology and inherent limitations of educational design research will also be discussed in this section along with a description of the sample. Section 8.3 presents a summary of important research, practice, and theory perspectives underpinning the research. Educational design research relies heavily on theory and practice-based perspectives to development design principles, which are in turn used to create local instructional theories. A description of the local instructional theory developed as part of this thesis is summarized in section 8.4, which is part of the results presentation of Study #1. Three concepts (e.g. theory and practice perspectives; design principles; and local instructional theory) drove the iterative design and refinement of the intervention aimed at solving the problem of practice, which was accomplished during Study #1, Phase 2. The results from this activity are summarized in section 8.5. A summary of answers to the research questions for this phase is also presented in section 8.5.

After the detailed intervention was completed in Study #1, Study #2, Phase 3 was undertaken to implement the intervention within the context of a classroom and evaluate its local impact. A summary of the results of this evaluation will be presented in section 8.6. A summary of answers to the research questions for Study #2 also is presented in this section. After the conclusion of Phase 3 research activity turned to planning and implementing for broad impact. As part of this research phase the researcher had to consider whether or not the intervention needed to be brought back to earlier research stages for additional refinement cycles. The summary of this activity is presented in section 8.7. Section 8.8 is an in-depth discussion of how the multidimensional perspective of conceptual change and the enriched visions for science learning are embodied within the intervention. The final research activity for the thesis was to explore possible implications for practice and research, which are presented in sections 8.9 and 9.0 respectively. The chapter concludes was a discussion of research limitations in section 9.1.

8.1 The Research Problem

A problem of practice is an area of education identified as problematic within the context of actual classrooms, and if successfully addressed, brings about meaningful improvement to teaching and/or learning. The problem of practice explored in this thesis functioned as the research problem- There is *a lack of pedagogical tools and effective models of classroom instruction teachers need to implement an enriched vision of science learning promoted by researchers.* An enriched vision of science education includes instructional goals that go beyond cognitive, to include epistemic, affective, and social. Furthermore, the idea of an enriched vision of science education mirrors the idea of promoting a balanced perspective of conceptual change. By balancing multiple dimensions/perspectives instructionally (Vosniadou, 2007), it was conjectured a conceptual shift may be promoted, from viewing learning as the delivery of content to students learning science by doing science. To promote this shift the researcher developed and evaluated an effective model of classroom instruction (e.g. the intervention) needed to support the enriched vision and foster conceptual change.

8.2 Educational Design Research

This thesis used an embedded mixed-method educational research design (Creswell & Plano Clark, 2007), guided by a multidimensional conceptual change perspective, to design and evaluate an intervention to address the research problem. The thesis unfolded through the two related studies over the course of four phases. Study #1 spanned the first two research phases and involved the exploration the problem (Phase 1) and the eventual design and refinement of an intervention aimed at providing a solution to the problem (Phase 2). Study #2 was designed to evaluate the intervention within the context of an actual classroom (Phase 3) and to explore how the intervention might be used within broader contexts (Phase 4). Research questions for each research phase will be presented in the results section for that phase. In addition to details about the research design (section 8.2.1), this section also includes information about the sample (section 8.2.2).

8.2.1 Research Design

A four phase, 16-step educational design research approach was formalized by the researcher to guide the thesis over the course of the two studies. This design is shown in table 8.1.

Table 8.1

Four Research Phases and Corresponding Steps within Study #1 & Study # 2

Study	Research Phases	Research Steps
Study #1	Phase 1: Research Problem & Question Exploration	1. Needs Exploration/Analysis 2. Research Question Exploration 3. Survey the Literature & Field 4. Theory Development 5. Audience Characterization
	Phase 2: Intervention Design & Refinement	6. Research Design 7. Design Principles, Goals, & Strategies 8. Prototype Intervention 9. Iterative Design Mini-cycles 10.Detailed Design
Study #2	Phase 3: Intervention Implementation & Local Impact Evaluation	11. Theory Refinement 12. Implementation/ Data Collection 13. Evaluation of Results 14. Reflection & Discussion
	Phase 4: Broad Impact Planning & Implementation	15. Publish Results 16. Broad Impact Planning &Implementation a. Diffusion, adoption, adaptation b. Consequences

The research used an embedded mixed-methods design, which involved collecting both qualitative and quantitative data in the same study (Teddlie &Tashakkori, 2010). The mixing of both kinds of data provided a greater level of understanding than either set analyzed alone, which offset any weaknesses that would have developed if one type of data was favored over the other (Creswell, Plano Clark, 2003). Qualitative data were used to inform the design of the intervention, document how the intervention was implemented by the teacher and students, and finally help explain the results obtained by the intervention. Quantitative data were used to determine the impact that the intervention had on student learning outcomes. Figure 8.2 was presented to show an overview of the research design and how the data were mixed.

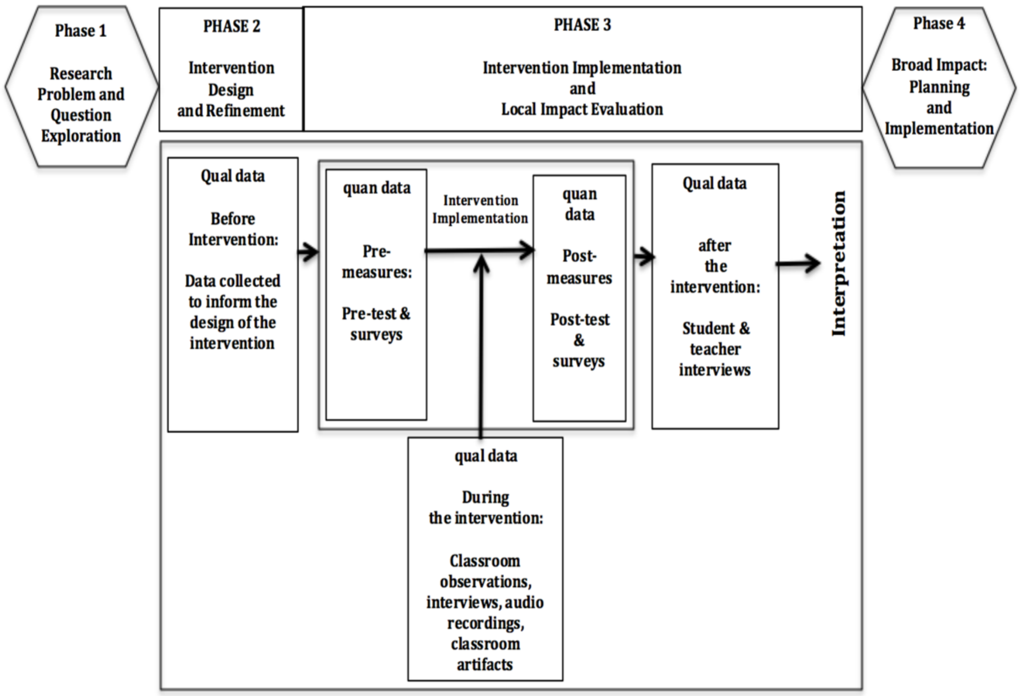


Figure 8.2. Embedded Mixed Methods Design Showing How Data Were Mixed During the Thesis

8.2.2 Sample

The intervention was developed and tested within an after-school program called the *Genetic Diversity and Human Health Cohort Program* for middle school students (grades 6-7). Biodiversity and human health connections at the level of genes/DNA were investigated. There were 18 students (11 female; 7 male) and one teacher in the study. Data were collected at three separate points: 1) Pre-measures (pre-test; surveys) were administered before implementation, 2) Classroom observation data were collected during implementation, and 3) Post-measures (post-test; surveys) were again administered at the end of implementation. Final data were collected one month after the program ended using a semi-structured interview protocol with six students and their parents.

8.3 Summary of Important Research, Practice and Theory Perspectives

Throughout the thesis meaningful improvement to the teaching and learning of science was explored through the lens of one classroom (e.g. a local context), while also keeping one eye clearly focused on how the innovation developed might generalize and impact a broader context. Research suggested that a possible reason that meaningful improvement has not occurred in science education over the past 50 years more broadly, is that teachers have lacked a clear vision of what exemplary science education is, and how such exemplary science education might manifest itself in classrooms. It was found that traditional teaching, which overly focuses on the transmission of knowledge, is still a dominant mode of presenting science education in classrooms. This thesis presented an argument that teachers need both an enriched vision of science education together with effective pedagogical tools to implement this vision, to promote meaningful improvement of science education.

An enriched vision of science education calls for teachers to move beyond a focus of having students memorize content, to include learning goals in epistemic (e.g. what science knowledge is and where it comes from), social/contextual, (e.g. how learning is mediated by the environment) and learner characteristics (i.e. student interest and motivation) dimensions (Duschl & Grandy, 2008). Classrooms organized with an enriched vision in mind focus on creating a student-centered learning environment where outcomes across these multiple dimensions work together to promote powerful learning. The kind of learning promoted within an enriched vision of science aligns with a social constructivist epistemology where learning of individual students is supported through social interaction and discourse with others (e.g. social negotiation).

Educational design research was chosen as the research method for the thesis because it seeks to solve real problems teachers face through the design and testing of practical educational innovations in the context of actual classrooms (McKenney & Reeves, 2012). Educational design research also seeks to add to the knowledge base through the development of design principles and/or instructional design theories that function to guide the development of the innovation, as well as provide broader application in other contexts.

Conceptual change theory (Duit & Treagust, 2012) was chosen to guide the thesis theoretically because it also aligns with, and supports, the enriched vision of science education. Conceptual change theory seeks to understand factors involved with the reorganization of knowledge, and how this knowledge can be actively developed. Individual and social factors of conceptual change have been described by some conceptual change researchers as an either/or proposition. However, a balanced perspective that promotes both individual and social perspectives of conceptual change as important to the learning process was also embraced in this thesis (Vosniadou, 2007). This balanced perspective aligns with, and supports, the enriched view of science education where multiple dimensions of learning are promoted (e.g. cognitive, epistemic, social/contextual, and learner characteristics).

The ideas of balancing individual and social factors of conceptual change (e.g. research side terminology), and ideas of enriching the vision of science education through the inclusion of multiple dimensions of learning (e.g. practice side terminology), align. The goal of this research, then, was to develop an intervention that would help teachers implement an enriched vision of science education by focusing on the design of a learning environment and teaching supports that balanced individual and social factors of learning to promote conceptual change.

A multidimensional conceptual change (Duit, Treagust, & Widodo, 2008) perspective brings coherence to these ideas, and suggests three lenses to analyze learning and interpret a change event - an ontological lens, a social/affective lens, and an epistemological lens (e.g. describe factors of a learning event). This thesis used a multidimensional conceptual change theory in additional ways. Theory was also used to predict and prescribe learning. This allowed the researcher to think of conceptual change theory in ways to support the design of an intervention aimed at promoting conceptual change (e.g. prescribe factors of a future learning event predicted to promote conceptual change).

8.4 Results of Study #1, Phase 1: Problem Exploration

There were two research questions for Study #1, Phase 1- one student learning focused question and one learning environment focused question as shown in Table 8.2.

Table 8.2

Research Questions for Study #1, Phase 1

Research Phase	Student Learning (SL) Focus Research Questions (RQ)	Learning Environment (LE) Focus Research Questions (RQ)
Phase 1: Research Problem and Question Exploration	SLRQ1: What did inquiry-based student learning look like in the study teacher's classroom before intervention implementation?	LERQ1: How did the teacher design the classroom learning environment before intervention implementation?

During Study #1, Phase 1, the researcher completed a needs exploration, explored and developed research questions, surveyed relevant literature and practice perspectives, developed guiding theory, and determined who the intervention was intended for through an audience characterization process. In addition to completing these research steps, the researcher also administered the *Teacher Beliefs Inventory* (Luft & Roehrg, 2007) to the teacher and it was determined that epistemological beliefs held were not in conflict with thesis goals. The researcher also recorded observations of the teacher teaching in order to ascertain critical ideas for inquiry present in the teacher's classroom before intervention implementation, as well as the classroom discourse and participation patterns present. Lastly, the data was used to determine the levels of inquiry present in the lessons observed. These results were used to both answer the research questions for Phase 1, and functioned as the pre-component of a pre/post evaluation that occurred after implementation to determine intervention impact.

The answers to the research questions for Phase 1 are presented next.

What did inquiry-based student learning look like in the study teacher's classroom before intervention implementation? (SLRQ1)

Each of the eight inquiry lessons observed started with snacks and the teacher telling a content story or students having an interactive media experience (i.e. How jellyfish are adapted for survival in their environment). These stories were designed to develop student interest in, and motivation for, the study of particular content. Active engagement of the students was interpreted as high by the researcher. However, students were also observed working individually, in small groups, and in whole group arrangements. The dominant discourse pattern found was class discussion (36%) followed by teacher-dominated talk (31%). This indicates that the students were arranged with the teacher up front of the classroom, with the students attending in a whole group manner, in 67% of the observed class time. Consequently, student sense-making occurred whole group led by the teacher. During investigations students were observed placing stickers and various tape-ins (i.e. teacher provided copies of investigation plans) into their journals as lessons proceeded. This occurred under the direct guidance of the teacher. Students were observed using laptops, various probes (i.e. temperature, humidity, light), document cameras, and an interactive whiteboard at various times during class time.

How did the teacher design the classroom-learning environment to promote inquiry-based learning before intervention implementation? (LERQ1)

The teacher organized the physical space for all activities in two rooms (e.g. laboratory and classroom), which had a variety of tables for the students to sit. The teacher also had the students sit on the floor occasionally. This arrangement allowed for separate investigation and discussion spaces within the learning environment. The teacher could physically move the students out of the investigation spaces for focused discussions. This was important because the investigation spaces, interesting in their own right, also contained a large number of living organisms in cages and tanks, which excited the students greatly.

The rubric scores for the eleven critical ideas for inquiry were analyzed to determine how the teacher designed the learning environment to support their engagement by students. The results indicate that the teacher effectively designed the learning environment to support student use of technology. The teacher was also skilled at supporting student ability to self-manage inquiry activity within the learning environment and designed the learning environment to support application experiences. The teacher also supported students in the designing of investigations, making quality observations, and evaluating the outcomes of inquiry activities. However, the teacher did not design the learning environment to support students asking their own questions, activating and using their prior knowledge during instruction, making predictions of future outcomes, or proposing explanations to answer investigation questions. The teacher did not intentionally design the learning environment support student use of productive habits of mind, such as creative or critical thinking.

8.5 Results of Study #1, Phase 2: Intervention Design and Refinement

There were two research questions, each with two parts, asked during Study #1, Phase 2- one student learning focused, and one learning environment focused question as shown in Table 8.3. An answer to these questions will be provided at the end of the section.

Table 8.3

Research Questions for Study #1, Phase 2

Research Phase	Student Learning (SL) Focus Research Questions (RQ)	Learning Environment (LE) Focus Research Questions (RQ)
Phase 2:		
Intervention Design And Refinement	What is an optimal design for an intervention that supports student learning, especially in light of:	What is an optimal design for an inquiry learning environment, especially in light of:
	a. What is known about factors that promote conceptual change? (SLRQ2a)	a. What kind of learning environment is needed to support the student learning focus? (LERQ2a)
	b. The enriched vision of science learning? (SLRQ2b)	b. How can the intervention be designed to support the envisioned learning environment? (LERQ2b)

During Study #1, Phase 2, practice and theory perspectives developed during Phase 1 were used to design and refine an intervention aimed at solving the research problem. A prototype intervention (see Figure 5.5) was developed first that had three interrelated dimensions: A) Habits of mind, B) A specific process of scientific inquiry called Q-POE2, and C) A socially and language rich learning environment. The habits of mind and socially and language rich learning environment dimensions were viewed as having an important role in supporting (e.g. enhancing) the scientific inquiry process and promoting conceptual change.

Educational design research explicitly produces research-based outcomes in the form of design principles and local instructional theories, which are used to refine prototype interventions. To produce a local instructional theory design goals were first developed using the prototype intervention as a guide. Figure 5.7 showed the overarching design goals produced using the prototype intervention. Local instructional theories are a refinement of design goals, and function as a conjecture of how learning can be promoted. Using the design goals shown in Figure 8.4 a local instructional theory was produced and refined, and is considered a research outcome of the thesis. A summary of the local instructional theory developed and refined through this thesis is presented in Table 8.4, and a detailed version is presented in Table 8.5.

Table 8.4

Refined Local Instructional Theory (Summary)

Conceptual change and Learning will be promoted when all three components of the local instructional theory are embraced: *A. Productive scientific habits of mind are purposefully valued and taught within the learning environment; AND,* *B. Students actively construct knowledge through a process of scientific inquiry. This process promotes science learning as epistemic practice, and as a process of conceptual change; AND,* *C. The learning environment is socially and language rich.*

Table 8.5

Refined Local Instructional Theory (Detailed)

Conceptual change and learning will be promoted when all three of the following components are engaged instructionally:

A. Scientific habits of mind (e.g. shared values, attitudes, and skills) are both valued and taught within the learning environment;

- Curiosity, creative & critical thinking, persistence, self-direction, and imagination are great examples of scientific habits of mind that should be promoted within the classroom.
- Habits of mind should be valued as they bubble up naturally in the learning environment, but also explicitly taught through strategy use.
- Engaging Habits of Mind instructionally will enhance learning through scientific inquiry.

B. Students actively construct knowledge through the practices of scientific inquiry (e.g. learn science by doing science).

- *This process promotes science learning as epistemic practice, and as a process of conceptual change;*
- The practices should be meaningfully linked through the process of scientific inquiry using the Q-POE2 Process

C. The learning environment is socially and language rich.

- A culture where personal knowledge is constructed through a process of social negotiation.
- Students actively participate within varied collaboration structures, cooperative interactions, and purposeful discourse.
- Control is shared between the students and teacher, with the teacher acting as a guide. The teacher actively plans for the purposeful shifting of control to the students.
- Designing the learning Environment to be Socially and Language Rich will enhance learning through scientific inquiry.

The local instructional theory was used as a guide to support the refinement of the prototype intervention into the completed detailed intervention. These design principles, originally presented as Tables 5.4-5.6, were refined and placed in one table (Table 8.6), are considered important research outcomes of Study #1.

Table 8.6

Refined Pedagogical Design Principles

A. Scientific Habits of Mind: Design the intervention to support intentional student use of scientific habits of mind. Great examples:

• Curiosity • Persistence • Self-direction • Imagination
• Openness to new ideas/skepticism • Creative and critical thinking

B. Process of Scientific Inquiry (Q-POE2): Design the intervention to support student learning through the integration of scientific practices:

B1 *Questioning*. Developing, using, and evaluating investigation questions.

B2 *Knowledge Probing*. Supporting the…
- a) Activating, representing, and using prior knowledge and experience
- b) Integrating scientific knowledge, models & theories into inquiries
- c) Evaluating knowledge sources

B3 *Predicting*. Constructing, using, and evaluating predictions and hypotheses.

B4 *Investigation Planning*. Developing & evaluating fair test investigation plans.

B5 *Observing.* Gathering, organizing, and evaluating observations.

B6 *Analyzing Data*. Analyzing and evaluating data (e.g. generating evidence).

B7 *Constructing Explanations*. Proposing and evaluating explanations, including the writing of a claim and providing evidence and reasoning in support.

B8 *Applying.* Using new knowledge and experience meaningfully.

B8 *Evaluating.* Completing a final assessment of the investigation.

C. Socially and Language Rich Environment: Design the intervention to support teacher planning of a socially & language rich environment:

C1 Diverse Social Interactions. Plan for diverse classroom interaction patterns (individual, small group, whole group) to facilitate cooperation, the sharing of control, discourse, and the social negotiation of meaning.

C2 Cooperative Learning. Use strategies to promote cooperative learning.

C3 Shared Control. Scaffold activity (e.g. experience) to actively promoting student self-direction and Independence (e.g. expertise)

C4 Discourse: Oral and Written. Design specific discourse scaffolds that promote social negotiation of meaning.

C5 Social Negotiation of Meaning. Value and promote a culture of social negotiation of meaning within the classroom.

Using these design principles as a guide the prototype intervention was refined into a completed detailed intervention, the components of which are considered important practical outcomes of the research. The detailed intervention had the following components: Q-POE2 Process, Community of Scientific Practice Model, and a suite of implementation supports for both models. The completed Q-POE2 Process with implementation supports is the answer to SLRQ2:

What is an optimal design for an intervention that supports student learning, especially in light of:

a) What is known about factors that promote conceptual change? (SLRQ2a)

b) The enriched vision of science learning? (SLRQ2b)

The Q-POE2 Process (see Figure 5.8), together with the sticker packets students used to implement the model within their journals (see Figure 5.9) proved successful in helping students learn through the process of scientific inquiry envisioned by the design principles. Another tool developed, the Journal Evaluation Protocol (see Figure 5.10), supported student evaluation and self-reflection of how they used the Q-POE2 process in their inquiries. Another component of the detailed intervention was the *Community of Scientific Practice Model* (see Figure 5.13), which was an important practical outcome of the thesis. The *Community of Scientific Practice Model*, with implementation supports, resulted as an answer to LERQ2:

What is an optimal design for an inquiry learning environment that supports student learning, especially in light of:

a) What kind of learning environment is needed to support the student learning focus? (LERQ2a)

b) How is the intervention designed to support the envisioned learning environment? (LERQ2b)

The *Community of Practice Model,* together with implementation supports, proved successful in helping the teacher design the learning environment called for by the design principles. This model and support tools are important practical outcomes of the thesis. See chapter 5 (especially Figure 5.5) for a review of these tools.

Throughout the design and refinement of these components of the detailed intervention, theory and practice perspectives were used to prescribe desired outcomes. To promote confidence during prototype development the researcher evaluated the intervention for soundness, preferability and appeal, rather than functionality, and made sure all of the design principles were embodied within it. When the prototype intervention was refined the researcher conducted additional evaluations. First, the intervention was evaluated in terms of its viability, which means the researcher determined it functioned practically, had relevance within the classroom environment, and prompted sustainable use. Next, the researcher evaluated the intervention to make sure it had legitimacy, the results of which confirmed it was research-based, and embodied conceptual coherence across the design. Finally, the researcher evaluated the efficacy of the intervention within the classroom, and determined that it worked as intended to support both the teaching of, and learning through, scientific inquiry. These results functioned to inform the design of the intervention. To determine if the intervention actually promoted learning and conceptual change as intended through its use, the researcher complete a more formal evaluation, which was completed as thesis Study #2.

8.6 Results of Study #2, Phase 3: Intervention Implementation and Local Impact Evaluation

There were two research questions answered during Study #2, Phase 3 – one two-parted student learning focused question and one learning environment focused question (Table 8.7).

Table 8.7

Research Questions for Study #2, Phase 3

Research Phase	Student Learning (SL) Focus Research Questions (RQ)	Learning Environment (LE) Focus Research Questions (RQ)
Phase 3: Intervention Implementation and Local Impact Evaluation	What does inquiry-learning look like in the teacher's classroom because of intervention implementation? (SLRQ3a) How did the intervention impact inquiry learning in the teacher's classroom? (SLRQ3b)	How did the intervention support how the teacher designed the learning environment and taught the students? (LERQ3)

Using the data collected during this phase the researcher was able to analyze the inquiry-learning occurring in the teacher's classroom pre/post implementation, which resulted in the answer to research question SLRQ3a:

What does inquiry-learning look like in the teacher's classroom because of intervention implementation? (SLRQ3a)

Activity, discourse, and participation patterns were explored using this data and dramatic changes to the teacher's teaching practice were found as a result of intervention implementation. Section 6.2.2 provides an in-depth evaluation of these changes. In summary, teacher talk dramatically reduced (-58% change), while student-to-student talk dramatically increased (+60% change). These changes corresponded to similar changes in how the students were grouped for interaction. For, example the amount of time the teacher spent in front of the class addressing the whole group reduced dramatically (-58% change), which provided more class time for discussions (+14% change), and for students to spend more time working together in small investigation teams (+38% change). Section 6.2.2 discusses the role of two intervention discourse strategies and teaching posters in supporting these changes. The Q-POE2 Process, as implemented with stickers and student journals, also supported the increased time student spent working on investigations (e.g. change in activity).

Learning outcomes were developed for students to determine intervention impact. Using the data collected the researcher was able to answer part b of research question SLRQ:

How did the intervention impact learning in the teacher's classroom? (SLRQ3b)

Student attainment of learning outcomes that resulted from the intervention were determined to answer this question. In summary, students maintained positive attitudes and feelings about science and significantly increased their ability to design, carry out, and communicate the results of a science investigation. Student ability to provide and evaluate evidence for knowledge claims increased significantly, but not as much as the researcher had wanted. This result may have occurred because students needed more support through the process of generating evidence they were confident in before being asked to use this evidence as proof of a knowledge claim. The intervention supported students in the construction of scientific content knowledge, with significant increases found pre/post for all four content questions (see section 6.2.3.1; Figure 6.5)

The last research question answered during Phase 3 was LERQ3:

How did the intervention support how the teacher designed the learning environment and taught the students?

The researcher developed three teacher learning outcomes to help explore this question (see Table 6.5). The first learning outcome specified that the teacher should be able to use the intervention to teach students how to design, carry out, and communicate the results of science investigations. How the teacher taught the students significantly improved likely as a result of the intervention (see section 6.2.2; Table 6.4). Students were able to independently design, carry out, and communicate the results of science investigations based on how the teacher designed the learning environment and taught students. Intervention components best supporting these results: QPOE2 Model & Stickers; Discourse and Evaluation Teaching Posters.

The second teacher learning outcome stated that the teacher should be able to use the intervention to guide the design of a socially and language rich learning environment. The results indicate that the teacher was able to use the intervention to guide the design of a socially and language rich learning environment. Students worked and talked together more often in small teams. Overall, the teacher talked less and the students talked more pre/post based on the intervention (see section 6.22; table 6.2). Intervention components best supporting these results: Community of Scientific Practice Model; Discourse Teaching Posters. The last teacher attainment outcome specified that the teacher should be able to use the intervention to guide the design of a learning environment that nurtures the habits of mind of their students. The intervention successfully supported the teacher in being aware of the role habits of mind have in enhancing inquiry-based instruction. However, the teacher did not intentionally nurture the habits of mind of the students using the intervention. The intervention will need to be refined in ways that better support the intentional teaching of habits of mind with specific strategy use.

8.7 Results of Study #2, Phase 4: Broad Impact Planning and Implementation

There were two research questions developed for Study #2, Phase 4 – one student learning, and a two-parted learning environment focused question (Table 8.8). These research questions were not answered fully during the thesis research, but are an important part of the 16-step research approach developed, and will be addressed further as future research. The researcher explored how the intervention was adapted / adopted by the local context as part of Phase 4 broad impact planning, which will be summarized in this section.

Table 8.8

Research Questions for Study #2, Phase 4

Research Phase	Student Learning (SL) Focus Research Questions (RQ)	Learning Environment (LE) Focus Research Questions (RQ)
Phase 4: Broad Impact Planning and Implementation	How has the intervention impacted student learning in other contexts? (SLRQ4)	How can the intervention that was implemented in other contexts be described? (LERQ4a) How did the intervention support how the teacher designed the learning environment in other contexts? (LERQ4b)

Even though educational design research occurs within the context of a classroom/program, interventions are developed with an eye towards a possible broader impact. Immediately after implementation ended the researcher started developing a plan to promote broad impact of the intervention. The plan developed had two parts. The first part planned for the adoption /adaptation of the intervention within the local context of the education institute student programs where the research took place. The second part of the plan involved promoting the adoption/adaptation of the intervention for use within teacher professional development and in teachers' classrooms more broadly. Within several months of the completion of the implementation, the researcher reviewed the main components of the intervention (e.g. Q-POE2 Process; Community of Scientific Practice Model; Instructional Supports/Teaching Posters, Journals, Sticker Books, Critical Ideas of an Inquiry-based Pedagogy) with the two-part plan in mind. The researcher decided that the two models within the intervention were strong and worked as intended to support an enriched vision of science learning. The researcher also decided that the two discourse strategies (e.g. Research In Progress; Present and Defend) were powerful tools within the developed pedagogy and would not be a focus of refinement, at least right away. However, the researcher determined that four of the teaching posters would benefit from a refinement cycle: 1) Evaluation Poster, 2) Confidence Chart Poster, 3) Explanation Poster, and 4) Data Analysis Poster. The researcher developed refined versions of these posters, which were presented in section 7.2.1.

8.8 Using the Multidimensional Conceptual Change Perspective and the Enriched View of Science Learning to Discuss Phases 2 & 3 Research Questions

8.8.0 Section Overview

This section explores Phase 2 research questions in more depth. During Phase 2 the research explored designs for the intervention in terms of promoting both student learning and the supporting learning environment. To this end, Phase 2 had two-research questions, one student learning focused (SLRQ2 a & b) and one learning environment focused (LERQ2 a & b). Part "a" of each of these questions focused on factors that promote conceptual change, and part "b" focused on the enriched vision for science education. Conceptual change was viewed as being promoted in the classroom by multiple factors. Viewing conceptual change through multiple factors has been described as a multidimensional conceptual change perspective by Duit, Treagust, and Widodo (2008), who utilized the perspective to evaluate learning. Within educational design research theory is also used to predict and prescribe learning. To this end, the thesis used the factors described in the multidimensional conceptual change perspective to prescribe components of the intervention. These factors are: epistemology, ontology, learner characteristics (e.g. affect, motivation, interest) and the social/contextual environment. An enriched view of science education, promoted by Duschl and Grandy (2008), suggest the implementation of a similar set of factors needed to transform science education. The enriched vision for science education served to interpret the multidimensional conceptual change perspective in terms of goals and outcomes of science education practice. Statements were developed based on these perspectives to guide an in-depth exploration of research questions SLRQ2 a/b and LERQ2 a/b. These statements are:

1. How the intervention supported epistemological understanding and development. (Section 8.8.1)
2. How the intervention supported knowledge construction. (Section 8.8.2)
3. How learner characteristics (i.e. interest and motivation) informed the design of the intervention. (Section 8.8.3)
4. How the intervention helped the teacher design an environment that supported multiple dimensions of learning. (Section 8.8.4)

8.8.1 How the intervention Supported Epistemological Understanding and Development

This statement focuses attention on the teaching of science, as dictated by the enriched vision of science learning that was promoted by education researchers as a process of knowledge construction (e.g. as epistemic practice). To foster student epistemological understanding the intervention supported the active construction of knowledge through a process of scientific inquiry. The epistemological dimension of conceptual change was also concurrently promoted in very specific ways within the intervention. The learning process was designed to support a social constructivist epistemology. Knowledge was represented to students as personally constructed, socially negotiated, and open to revision throughout the learning process. For example, a key idea in the learning process promoted by the Q-POE2 was the considering, valuing, and integrating of student prior knowledge and experience during learning. Secondary knowledge (e.g. concepts, laws, theories etc.) integration was planned as knowledge probes that occurred throughout learning in supporting roles (e.g. rather than being presented at the beginning of an instructional sequence before students have started their first-hand inquiries). The support of student reasoning was also integral to the Q-POE2 process. Teaching students criteria in which they evaluated different Q-POE2 components within an investigation was designed to promote student confidence in the eventual evidence they would generate. For example, the *Confidence* and *Fair Test* teaching posters were designed to support student reasoning around the quality of the investigation plan, data analysis process used, and the construction of knowledge claims. This process was intended to support Posner et al. (1982) conditions necessary for conceptual change. This was done to help students confront possible misconceptions with evidence they had generated themselves, and had a great deal of confidence in. The Q-POE2 support stickers were designed to provide structure to the learning process while also supporting student opportunity to pursue quirky learning pathways while self-directing their learning.

The intervention suggested three important and related dimensions needed to be engaged if students were going to experience science as epistemic practice. Learning would be enhanced when a set of linked, and critically important inquiry process components (Q-POE2) were supported with productive habits of mind and the learning environment was both socially and language rich. According to the intervention, a set of critical ideas of an enriched inquiry process (see sections 4.62 and 5.2) worked together to promote learning. The intervention suggested these ideas should not be viewed or taught as a linear, or lock step, progression through an inquiry. For example, questions for investigation often emerged from observations that have were made. Students used their prior knowledge throughout investigations. However, the research indicates that the different critical ideas of inquiry do have natural relationships with each other that often determine how they should be used. An investigation plan of some sort was needed before observations were made. Data analysis occurred after observations were organized. Explanation formalized after data was transformed into evidence through analysis, which then was offered in support of claims. The reasoning, or justification, as to why the evidence offered in support of an explanation counted as evidence was developed through student interaction with other Q-POE2 components. For example, student prior knowledge, which was activated and represented during an investigation, may have been congruent with or alternatively, in conflict with the evidence generated during an investigation. Conceptual change theory says that students will hold on to the validity of their pre-conceptions even when faced with evidence that disputes it. The intervention helped focus instruction on developing student confidence in how the evidence was generated throughout an investigation. Confidence was explored when generating the original investigation question (e.g. can data be collected/accessed that is rich enough to be able to uncover patterns and trends?), during development of an investigation plan that was a fair test, and during the process of data analysis and interpretation. The idea was to help students confront their misconceptions with evidence that they generated themselves and had confidence in (e.g. explore the status of their conceptions). Students were asked to think and write about these ideas explored during reasoning activities. Additional support scaffolds to help with making effective use of these inquiry processes routine should be considered.

8.8.2 How the Intervention Supported Knowledge Construction

The research behind the intervention indicated that students construct many different kinds of knowledge through the engagement with scientific inquiry. Procedural, or scientific process knowledge (e.g. epistemic process knowledge), was constructed through purposeful and ritualized engagement with the critical ideas of inquiry. Students were taught that any claims of knowledge made, needed to be justified (see also section 8.8.1). In order for knowledge justification to become routine students were provided instructional support. Students accomplished knowledge justification by evaluating the epistemic status of their conceptions using the Confidence Poster as a guide. The intervention was intended to be used as a knowledge construction, evaluation, refinement, application, and communication support tool (e.g. science as epistemic practice; science as a process of conceptual change). The students constructed scientific knowledge using the intervention as a support. The implementation of the intervention made thinking visible throughout instruction, thus helping the teacher explore needed ontological belief revision, mental model transformation, and categorical shifting (Chi, 2008). The critical role of the activation, representation (through talk, writing, drawing, etc.), and use of student prior knowledge and experience was a central focus of enacting the intervention (Lemke, 2001).

The curriculum developed to support the intervention presented an ontologically coherent framework intended to support conceptual change. The curriculum was research-based (Catley, et al., 2005), offered depth over breadth (Duschl, et al., 2008) and carefully considered the order of the instructional concepts (Vosniadou, et al., 2007). The curriculum (see section 5.15) focused on evolution as a central theory of importance in biology. Evolution was presented as a process that promotes biological diversity within species, habits, and genes (Cateley, et al., 2005), and is shown conceptually in Figure 8.3.

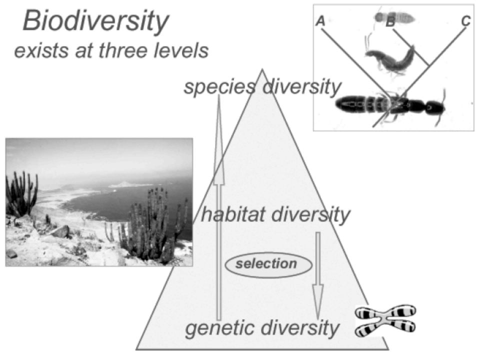


Figure 8.3. Conceptual framework for curriculum: biodiversity exists within species, habitats and genes (Catley, et al., 2005)

8.8.3 How Learner Characteristics Informed the Design of the Intervention

Supporting the learner characteristic dimension of conceptual change (Linnenbrink & Pintrich, 2002) was an important design consideration when developing the intervention. Positive learner attitudes and feelings towards learning tasks have been shown to improve learning through increased interest and motivation (Pintrich, 2003). Giving students choice within a curriculum, designing activities that are highly social, and providing opportunities for student autonomy within the learning environment have been shown to engender positive attitudes and feeling (Pintrich, 2003). Pintrich (2003) also suggests that when students believe they can be successful within a learning environment they develop a strong self-efficacy. The development of strong self-efficacy promotes strong feelings of confidence, which improves student learning. The development and implementation of activity promoted by the intervention scaffolded and took note of student success and confidence. Students were prompted to develop achievement goals which has been shown to promote more effective learning (Sinatra & Mason, 2013).

8.8.4 How the intervention helped the teacher design an environment that supported multiple dimensions of learning

The intervention supported the social/contextual dimension of conceptual change with a specific focus on promoting student-centered discourse, activity, and interaction patterns (NRC, 2007). The intervention served as an instructional model that described a learning process where students constructed personal knowledge through a process of social negotiation. The design of the intervention was intended to value both the process of individual knowledge construction and the nature of the social negotiation that promotes it. A view of knowledge as socially negotiated considers knowledge to be dynamic and in a constant state of refinement (Treagust, Duit, & Fraser, 1996). The intervention promoted social negotiation as an act of sense making, which was facilitated through the use of various collaborative structures (individual, small group, whole group), as well as through the cooperative participation that occurred within them (Myake, 2008). Collaborative structures were used as grouping patterns to promote student use and development of language through the promotion of discourse. In a traditional classroom, the dominant collaborative structure is often the teacher talking to the whole group (Lemke, 1990). The dominant collaborative structure promoted through the intervention facilitated student-to-student collaboration and discourse. This occurred through structuring of students in small groups, but also engaged students in whole class sense-making and clarification sessions. How students interacted within these collaborative structures needs to be further addressed within the design. In addition, the intervention supported the idea of shared control in order to create instructional space for the scaffolding of student self-regulation within the learning environment (Sinatra & Taasoobshirazi, 2018).

The research behind the intervention also indicated that powerful learning environments support a classroom culture where productive habits of mind are purposefully selected, valued, and intentionally taught. Productive habits of mind included in the intervention emerged out of the research within the nature of science (AAAS, 1989; NGSS Lead States, 2013). Promoting and nurturing habits of mind within classrooms through purposeful classroom design produces culture. Habits of mind, then, become shared attitudes, values, and skills (AAAS, 1989). Both the science education reform and conceptual change literature promoted the idea that productive habits of mind should be nurtured within the classroom environment to promote learning. Arguments for the inclusion of additional habits of mind selections could be made, but the idea was to keep it as simple as possible and promote selections as examples.

8.9 Implications for Practice

This research sought to solve a practical problem of practice that is occurring broadly within the context of a small study within one informal classroom with 19 students. The intervention developed is the main practical contribution produced through the thesis. The intervention was designed for actual use within the local context, where it has been adopted, adapted, implemented in other programs, and sustainably used over the course of the several years that have transpired since the thesis research concluded. These outcomes indicate that the intervention had a positive impact on the local context. A powerful reason why this occurred was because the intervention proved practical in promoting the enriched vision of science education and resulted in the attainment of established student outcomes.

The intervention has also been used by the local context as the framework for professional development of 1,000's of teachers locally, and across several states, where it has been adopted and enacted in classrooms. For example, the Tukwila School district in Washington has adopted the intervention for use with their secondary science students. Another example of adoption is the Murdock Charitable Trust, located in Vancouver, Washington. The Murdock Trust operates a Research Experience for Teachers (RET) program across five states in the pacific northwest. Twenty-five teachers are selected each year from across these states to participate in multi-year research project with a scientist mentor. Trained teacher leaders provide training in how to implement the intervention as part of the program. However, it is too early to tell if the intervention will generalize to these other contexts in a way that produces sustainable change more broadly.

This points toward a need for additional research. Research Phase 4 was developed in order to explore how the intervention could generalize to these other contexts. As discussed earlier in this chapter, the design principles and local instructional theory developed through this research had a powerful impact on the design of an intervention that was successful within the local context. However, the intervention will need to be validated through replication across various contexts in order to determine if and how generalization is occurring. This could best be accomplished within a research program. In the end it will be the consumer of the intervention who actually will promote this transfer across contexts (Plomp, 2013).

8.10 Implications for Research

The thesis research was intentionally broad, aiming to fully explore the teaching and learning of science within the complexity of a real classroom learning environment. Duit and Treagust (2012) acknowledge this complexity as they discuss the theoretical frameworks presented by other researchers (Vosniadou, 2008; Vosniadou et al. 2008; Chi, 2008; Sinatra & Pintrich, 2003; Duit & Treagust, 2003) in terms of those aspects of conceptual change that are similar in each. The similarities listed present a multidimensional, or inclusive framework consisting of epistemology, ontology and affective/social/learner characteristics (Duit & Treagust, 2012). Each of these areas is rich in research possibilities in their own right. However, an important point within all of these perspectives is that the various factors work together to promote conceptual change. What this research attempted to do was interpret these multiple interacting factors of conceptual change through the lens of practice-based science language (e.g. the enriched vision) in hopes of making them more accessible and understandable for teachers. Additional research exploring how to apply perspectives of multidimensional conceptual change to the development of practical instructional outcomes based on the enriched vision of science education would be helpful in supporting sustainable improvement. Within this broader framework several additional areas of needed research emerge out of this thesis. These will be explored next.

Section 4.6.1 explored the relationship of the epistemological beliefs that a teacher holds and the ability of that teacher to transform practice when presented with reform-minded curricular and instructional tools, like the intervention produced in this thesis. It is clear that beliefs directly affect how the teacher designs the learning environment and teaches students. Luft and Roehrig (2007) developed a semi-structured interview protocol called the TBI to evaluate teachers against a continuum from traditional to reform-minded (e.g. traditional, instructive, transitional, responsive and reform-based). These authors state that a teacher must hold beliefs at least consistent with the transitional category in order to successfully transition their practice to align with responsive or reform-based perspectives. This suggests that additional research exploring how to support teachers as they transition to reform-minded perspectives is needed.

In the completed intervention the idea of evaluation occupied the center portion of the Q-POE2 Process. In Section 5.3 we report that early versions of the intervention contained the words metacognition, self-regulation, and reflection in the place of evaluation. However, these ideas were removed from later versions of the intervention with suggestions noted by the researcher to reconsider if they should be included in some other way. In the end, the researcher decided to address self-direction as a habit of mind, and reflection was included as one of the stickers in the sticker packets provided to students. The actual word, metacognition, was removed from the model because when tested with students it was deemed confusing. The researcher theorizes that the intervention promotes self-regulated and metacognitve thinking, but in the end was not satisfied with the level of attention addressed to these ideas by the intervention, especially when addressing the idea of epistemic cognition and conceptual change. Gunstone and Mitchell (2005) discuss how metacognition and conceptual change are importantly intertwined:

> The processes recognizing existing conceptions, evaluating these, deciding whether to reconstruct, and reviewing are all metacognitive processes; they require metacognitive knowledge, awareness, and control. (p. 137)

Sinatra (2016) connects these ideas through the exploration of the metacognitive and conceptual change aspects of epistemic cognition. Sinatra (2016) connects epistemic practices in general to a wide variety of epistemic phenomena (i.e. conducting investigations, theorizing, etc.) and inquiry practices (i.e. justification and reasoning as a part of constructing explanations) represented by the intervention. For example, one of the design goals of the intervention was to have students experience science as epistemic practice. Future research on how interventions designed to promote conceptual change through inquiry-based science impact the metacognitve and conceptual change aspects of epistemic cognition as described by Sinatra (2013) is intriguing. How these ideas specifically relate to student learning and conceptual change within science education grounded in having students learn science by applying science practices should be pursued further.

8.11 Limitations

This thesis has limitations that are inherent in mixed method educational design research. One limitation is that the intervention designer is also the person who evaluated the design, which is often the case with this type of research (van den Akker, Gravemeijer, McKenney, & Nieveen, 2010). This situation created the potential for conflicts of interest that needed to be addressed in the research design. To address this conflict the researcher used multiple raters when evaluating student assessments. Another inherent limitation is the complexity of students' learning processes, coupled with the additional complexity of the sociocultural environment where the learning is taking place, which makes it very difficult to account for everything that occurs during the course of a study (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003). To begin to address this limitation an inclusive research approach was adopted that focused attention on the relationship of multiple dimensions of learning (i.e. cognitive, affective, social) as part of the research design. Cobb et al. (2003) suggest, however, that care must be taken when making any cause-effect relationship claims within such inclusive research designs because unknown contextual factors may be having an impact. Martínez, et al. (2018) discuss how these factors, which they describe as contextual mitigating factors (CMFs), need to be recognized in support of better research designs. To begin to address this limitation the researcher developed separate outcomes for students and how the teacher designed the learning environment. A third potential limitation within educational design research is the use of both qualitative and quantitative data in the same study (Teddlie &Tashakkori, 2010). The basic idea of mixed methods research is that by mixing both kinds of data sets the researcher is provided with a greater level of understanding than either set analyzed alone. However, for this not to be a limitation the researcher specified exactly how and why the data was being mixed as part of the research design (Creswell & Plano Clark, 2007).

Another limitation to the design was a lack of a control group for comparison purposes. The researcher considered using two groups of students attending the program within the local context. With two groups participating one group could have received the treatment (e.g. the intervention) and one group not (e.g. the control group). This proved problematic for several reasons, the most important of which was that the local context did not want participants of its programs to have different experiences. Additionally, as the intervention rapidly assimilated into the other local context programs, it would have been difficult to make claims control group participants had not experienced the intervention in any form. This limitation served to limit conclusions to the success of the intervention in promoting outcomes, not if the intervention was more successful in doing so than any other treatment. Limitations also arose because students self-selected into the program based on an already high interest in science, and also attended science classes as part of their regular schooling while also attending the after-school program. To minimize these limitations the surveys and content assessments provided language that sought to contextualize them within the after- school program.

There was one additional limitation to the research. As part of the original research design the researcher created a data collection tool (see Appendix K) adapted after Venville, Gribble, & Donovan (2005) to uncover possible student misconceptions related to genes The tool was a semi-structured interview protocol designed to determine whether students could differentiate between genetically inherited and socially and culturally acquired traits. The tool also was designed to determine student understanding of how and why offspring resemble their parents, and to see if they can determine the difference between characteristics (phenotype) associated with inheritance and the causal mechanisms such as DNA, chromosomes, or genes. If students were able to demonstrate that they understood these first two concepts, the protocol sought to determine if the student understood the concept of genetic inheritance and whether they had incorporated an understanding of genetics/inheritance into a theory of biology. After completing the interview protocol with each participating student, the researcher was disappointed to discover that no misconceptions were uncovered through its use. Instead, the researcher found the students were in need of enrichment, the evaluation of which was covered by the already in place content assessment tool.

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Appendix A

Teacher Beliefs Inventory (TBI)
Interview Protocol

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1. How do you maximize student learning in your classroom? (learning)

2. How do you describe your role as a teacher? (knowledge)

3. How do you know when your students understand? (learning)

4. In the school setting, how do you decide what to teach and what not to teach? (knowledge)

5. How do you decide when to move on to a new topic in your classroom? (knowledge)

6. How do your students learn science best? (learning)

7. How do you know when learning is occurring in your classroom? (learning)

Appendix B

Critical Ideas Rubric

Category	0	1	2	3
Generating Questions (GQ) A.	No questions were used to organize the lesson.	Teacher generated a question(s) that was used to organize the investigation, but it was not tested through observation.	Teacher generated a question(s) which was student tested through investigation.	Students generated their own questions, which were tested through investigation.
Knowledge Probe (KP) B.	NA	The only source of knowledge for the lesson was the teacher, and/or text.	In addition to the teacher and/or text, student personal knowledge & other secondary sources of info were used.	Personal and scientific knowledge integration was evident in student oral & written discourse.
Prediction/ Hypothesis (P/H) C.	Students were not asked to make predictions/ hypotheses	Students were asked to make predictions/ hypotheses that were connected to a question.	Predictions were stated as a relationship between variables and were tested through investigation.	Predictions were stated as hypotheses and tested through investigation. (If/then statements)
Investigation Design (ID) D.	No investigation procedures were evident in the lesson.	Teacher provided the procedures for students to use in an investigation, but they were not clear.	Teacher provided clear, step-by-step procedures, which were successfully followed students. Design followed "Fair Test" guidelines for the lesson.	Students designed clear, step-by-step procedures for the investigation. Design followed "Fair Test" guidelines for the lesson.
Observation (O) E.	No data was collected during the lesson.	Data was collected but not organized during an investigation.	Appropriate data was collected and organized during an investigation.	Appropriate data was collected and organized during an investigation using a technological tool.
Data Analysis (DA) F.	No data analysis occurred.	Minimal data analysis occurred.	Data analysis occurred, but was not organized in a meaningful way.	Meaningful data analysis occurred. Data was appropriately organized, summarized, interpreted, and represented.
Proposing Explanations (PE) G.	No explanations were proposed.	Explanations were solicited by the teacher, but not supported in their development.	Appropriate explanations were proposed by the students and included a claim and supported with evidence.	Appropriate explanations were proposed by the students and included a claim which was supported with evidence and reasoning.
Evaluation (E) H.	Evaluative thinking by the students is not evident or supported by the teacher.	Evaluative thinking by the teacher is evident in the lesson.	Students were asked to do evaluative thinking often during the lesson. Established criteria not evident.	Students were asked to do evaluative thinking often during the lesson. Established criteria evident.

Application Experience (AE) I.	No application experience was evident.	Students were asked to apply new knowledge and/or skills at a minimal level.	An application experience was evident, but not highly developed.	Students were asked to apply new knowledge at a high level by: (examples) •Generating, testing, or revising a theory or model; •Defending theories/ideas through argument; •Other
Use of Technology (UT) J.	No instructional technology was used teacher or students.	The teacher used instructional technology.	The teacher and students used instructional technology.	Instructional technology was used by students to collect, organize, represent, and communicate.
Habits of Mind				
Supporting Habits of Mind	Habits of mind thinking and support not evident in the classroom.	Habits of mind thinking is evident in the classroom but teacher support was not noted.	Habits of mind thinking is evident in the classroom and teacher support was noted.	Habits of mind thinking is integrated into the classroom practice and culture.
Student Self-direction	Teacher controlled all aspects of the lesson.	Teacher and students shared control during the investigation.	Students primarily self-controlled an investigation with teacher supplied supports.	Students self-directed an independent investigation.

Appendix C

Content Questions Assessment

Name ______________________________

Date ______________________________

1. How does our health depend on genetic diversity? Answer with an explanation that has at least two examples.

2. Why are certain organisms [zebra fish, xenopus frog, bacteria] used as models to learn about and improve human health? Answer with at least three reasons.

3. How are plant and animal **cells** alike and how are they different? Answer with at least two ways the cells are alike and two ways the cells are different.

4. How does DNA cause biodiversity?

Appendix D

Note this means "2+ correct responses w/no explanations" = Level 1

Science Content Knowledge Rubric

	Beginning Level 1	Developing Level 2	Meeting Level 3	Exceeding Level 4
1. How does our health depend on genetic diversity? EX: food; ecosystem cleaning – land, water; medicines; models; organism diversity	Response includes at least one correct example, but no explanation	Response includes one correct example and an explanation	Response includes 2 correct examples with explanations	Response includes at least 2 correct examples with strong, clear explanations
2. Why are certain organisms (zebra fish, xenopus frog, bacteria) used as models to learn about and improve human health? EX: similarity to humans; ability to infer from organisms and apply to humans; ease of collecting observations; life span of organism	Response includes one correct reason	Response includes two correct reasons	Response includes three correct reasons	Response includes at least three correct reasons, plus the ethics of using organisms
3. How does DNA cause biodiversity?	Response indicates we get our genes/DNA from our parents; proportions not given or incorrect	Response indicates we get ½ our genes/DNA from one source (mother) and ½ from another source (father)	Response indicates we get ½ our genes/DNA from one source (mother) and ½ from another source (father) through heredity/reproduction	Response includes all of level 3 plus the role of dominant and recessive genes
4. How are plant and animal cells alike and how are they different?	Response indicates one way the cells are alike OR one way the cells are different	Response indicates one way the cells are alike AND one way the cells are different	Response indicates two ways the cells are alike AND two ways the cells are different	Response indicates more than two ways the cells are alike AND more than two ways the cells are different

Appendix E

Performance Assessment

Name______________________ Date ____________________________

You have an **organism** to observe. Write or draw as much as you can to answer each of the following about your **organism**:

I How do the **traits** of a/n ______________________ help it survive in its environment?
(name of your **organism**)

1. List at least 5 things you already know about this **organism**.

2. Use at least 3 of your senses to list as many observations [QUALITATIVE; QUANTITATIVE] as you can about the **organism** you have been given. Use any of the tools given to you.

3. USE YOUR OBSERVATIONS FROM #2, ABOVE, to answer the question: How do the **traits** of your **organism** help it survive in its environment?

4. What is a question you would like to investigate further about your **organism**?

5. Make a plan to carry out the investigation for the question you wrote in #4.

Appendix F

Performance Assessment Rubric

	Beginning	Developing	Meeting	Exceeding
1. What do you know about this organism?	Lists 1 – 2 things known about the organism	Lists 3 – 4 things known about the organism	Lists 5 things known about the organism	Lists more than 5 things known about the organism and makes connections to the human organism
2. What are your observations about this organism?	Uses 1 of their senses; words or diagrams; qualitative and/or quantitative observations	Uses more than one of their senses; words or diagrams, may have inaccurate measurements; qualitative and quantitative observations	Uses at least 3 senses, words, diagrams, and accurate measurements; qualitative and quantitative observations	Uses all the appropriate senses, words, scientific diagrams, and accurate measurements; qualitative and quantitative observations
3. Explain how the different parts of your organism help it to survive in its environment.	Explanation does not use observations from question #2. Explanation is not supported by evidence (question#2 observations).	Some of the explanation is supported by evidence (question #2 observations).	Explanation is supported by evidence (question #2 observations) and is logical.	Explanation is supported by evidence (question #2 observations), is logical, and complete.
4. What question would you like to investigate further about your organism?	Testing the question is not possible	Testable question but time and/or resources prevent answering scientifically through firsthand data collection.	Testable question that may be answered scientifically through firsthand data collection.	Clear and concise testable question that is specific, based on scientific concepts, and may be answered scientifically through firsthand data collection.
5. Make a plan to carry out the investigation of the question you wrote.	Design of investigation contains major flaws in sequence and logic; extensive teacher intervention is necessary	Design of investigation contains minor flaws; teacher intervention is necessary	Plans a replicable investigation that has logical steps; experimental design requires minimal teacher intervention	Identifies what variable is controlled and what variables are manipulated; design of investigation is sequential and logical

Appendix G

Questionnaire: How You Feel About Science and Learning Science

How you feel about science and learning science

Name____________________________

Date____________________

As you read each sentence, you will know whether you believe each sentence is true or false. You will be asked to decide about how true or false each sentence is **for you.**

Do not spend much time with any sentence, *but be sure to answer every one.* Work fast, but carefully.

There are no "right" or "wrong" answers. The only correct responses are those that are correct ***for you***. Whenever possible, let the things that have happened to you in the past help you make a choice.

Directions: Please use the following scale to give your opinion for each of the sentences below. Circle the letter that best describes how true or false each sentence is for you. You won't use an answer sheet for these questions – circle your answers on this paper.

F	F	F	T	T	T
Definitely False	**Mostly False**	**A little bit False**	**A little bit True**	**Mostly True**	**Definitely True**

1	I am sure that I can learn science.	F F F T T T
2	When a science problem is hard for me to understand, I ask for help.	F F F T T T
3	Knowing science will help me get a job when I'm older.	F F F T T T
4	It's a waste of time to learn more science than what is taught in school.	F F F T T T
5	I work as long as necessary to understand a science problem.	F F F T T T
6	I will need science in the work I will do when I am adult.	F F F T T T

Appendix G Continued

7	I am sure of myself when I do science.	F F F T T T
8	I don't expect to use much science after I'm done going to school.	F F F T T T
9	When a science problem is hard for me, I usually give up on it.	F F F T T T
10	I will use science in many ways as an adult.	F F F T T T
11	Science is one of my worst subjects.	F F F T T T
12	I think I could handle more difficult science than what I learn in school.	F F F T T T
13	When I can't figure out a science problem, I try again.	F F F T T T
14	Science will **NOT** be important to me in my future work.	F F F T T T
15	When a science problem is difficult to solve, I try harder.	F F F T T T
16	I can handle most subjects OK.	F F F T T T
17	I get good grades in science.	F F F T T T
18	I will work as long as necessary to solve a hard science problem.	F F F T T T
19	I am sure I could do difficult work in science.	F F F T T T
20	Science is **NOT** important for my life.	F F F T T T
21	When a science problem doesn't work like I think it should, I quit working on it.	F F F T T T

Appendix H

Your opinions about science and learning science

Name_______________________________

Date_____________________

As you read each sentence, you will know whether you believe each sentence is true or false. You will be asked to decide about how true or false each sentence is **for you.**

Do not spend much time with any sentence, *but be sure to answer every one.* Work fast, but carefully.

There are no "right" or "wrong" answers. The only correct responses are those that are correct ***for you***. Whenever possible, let the things that have happened to you in the past help you make a choice.

Directions: Please use the following scale to give your opinion for each of the sentences below. Circle the letter that best describes how true or false each sentence is for you. You won't use an answer sheet for these questions – circle your answers on this paper.

F	F	F	T	T	T
Definitely False	**Mostly False**	**A little bit False**	**A little bit True**	**Mostly True**	**Definitely True**

In your opinion how true is each of the following sentences?		
1	My family is interested in the science programs I take.	F F F T T T
2	My family encourages me to study science.	F F F T T T

Appendix H Continued

3	People in my family are interested in science.	F F F T T T
4	My family talks about my choosing a science career.	F F F T T T
5	Having a science career would be interesting.	F F F T T T
6	I would like to have a career in science.	F F F T T T
7	My friends like science.	F F F T T T
In your opinion how true is each of the following?		
8	...made science seem more interesting.	F F F T T T
9	...increased my excitement for science.	F F F T T T
10	...increased my interest in a science career.	F F F T T T
11	...made science seem more fun.	F F F T T T
12	...made me feel better about learning science.	F F F T T T
13	...increased my confidence about doing science.	F F F T T T
14	...improved my knowledge of science.	F F F T T T
15	...taught me ways of doing science I did not know before.	F F F T T T
16	...gave me a better understanding of what science is all about.	F F F T T T
17	...helped me learn skills needed in science.	F F F T T T
18	...gave me the chance to make friends with people who are a lot like me.	F F F T T T

Appendix I

Student Interview Protocol

Student's Name: ____________________ Cohort: ______________

Session Completed: ____________________ Date: ______________

1. What was your reaction to the end of the session?

2. One of our goals was to prepare and motivate you to take more science classes. Did that happen?

3. How is the Science Academy like/not like your school experience?

4. What was most interesting to you?

5. What would you like to see changed?

6. Have you/are you participating in any science related activities since attending Science Academy?

7. What science classes are you taking in school?

8. Are you different at home/school as a result of the Academy experience?

9. What is the biggest change in you as a result of the Academy experience?

10. Is there anything else you'd like to share?

Appendix J

Parent Interview Protocol

Student's Name: ______________________ Cohort: ______________

Session Completed: ______________________

Parent Interviewed: ______________________ Date: ______________

1. What was your child's reaction to the end of this session?
2. What is your child's current level of interest? Was his/her interest in science sustained during the program?
3. What did you expect from the Academy?
4. Did it meet your expectations?
5. One of our goals was to prepare and motivate students to take higher level science classes and ultimately pursue a career in the sciences/science related field. Is that more likely as result of the Science Academy out-of-school-time experience
6. What other science related experiences has your child participated in since he/she entered the ' Academy out-of-school-time program?
7. Is your child doing anything different at home/school as a result of the experience?
8. What, if anything, would you like to see changed?
9. How was the Science Academy experience different than your child's school experience?
10. Should we impact science in the schools? Why? How?
11. Is there anything else you'd like to share?
12. Are there any further questions/comments?

Appendix K

Interview Protocol: Theory of Biology/ Theory of Genetics

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1. Select students to be interviewed.
2. Prepare interview summary sheets.
3. Gather audiotape equipment.

There are four parts to the interview protocol.

Part 1:

Goal… To determine whether interviewee can differentiate between genetically inherited traits and socially and culturally acquired traits.

Tell the following story to the interviewee:

Due to the illness of her parents a six-month old baby girl born in Fiji is adopted by a mother and a father from the United States.

(Show picture of baby girl, her Fijian biological mother, and her adopted mother from the United States).

Ask the following questions:

1. Will the girl look like Fijian or American parents?
2. Will the girl prefer Fijian or American food?

Part 2:

Goal… The goal of the second part of the interview is to determine the interviewee's understanding of how and why offspring resemble their parents. That is, to probe for an understanding of how and why offspring resemble their parents and whether the interviewee can differentiate between visible characteristics (phenotype) associated with inheritance and the microscopic (abstract) causal mechanisms such as genes, DNA, or chromosomes (genotype) associated with genetics.

Show the interviewee photos of puppies and dogs.

Ask the following questions:

1. Do you think any of the dogs were the puppies parents?
2. Why do puppies look similar to their parents?
3. What causes the similarities between parents and offspring?

Appendix K Continued

Part 3:

Goal… The goal of the third part of the interview is to determine the interviewee's conception of the means of genetic inheritance.

Only proceed with part three if the student has mentioned genes, DNA, or chromosomes in part one or two.

Ask the following questions:

1. Where do you think genes/DNA are in the body?
2. What do you think genes/DNA look like?
3. How do you think genes/DNA work?

Part 4:

The goal of the fourth part of the interview is to determine whether the interviewee is able to incorporate their understanding of genetics/inheritance into a theory of biology.

Show students a variety of pictures of living and non-living things (bird, cat, fly, dinosaur, tree, plant, car, fire, sun, and a picture of Shrek.

Ask the following question:

1. Which one of these things has/had DNA/genes in it?