INQUIRING INTO INQUIRY LEARNING IN SECONDARY SCIENCE EDUCATION

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By
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Heather Rene Ann Haynes, candidate for the degree of Master of Education in Curriculum & Instruction, has presented a thesis titled, *Inquiring into Inquiry Learning in Secondary Science Education*, in an oral examination held on April 23, 2012. The following committee members have found the thesis acceptable in form and content, and that the candidate demonstrated satisfactory knowledge of the subject material.

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ABSTRACT

This research study investigates the creation, use, and effectiveness of inquiry lab activities in a secondary science classroom. The study begins by reflecting on what leads the teacher-researcher to convert traditional, step-by-step lab activities into student-centered inquiries by turning them inside-out and gains momentum as positive student-participant feedback is obtained.

Using the reflective practice and narrative inquiry influenced approaches as the central research tools teacher-researcher and student-participants can provide one another with feedback into their experiences with both traditional and inquiry approaches to lab activities. The two-way communication between teacher-researcher and student-participants is illustrated within the thesis text itself as “My Story” and “Student’s Stories” and provides an opportunity for students to directly influence their teacher’s approach to lesson planning.

Through engagement in the Osmosis/Diffusion Inquiry student-participants and teacher-researcher explore and examine their experiences within different aspects of science inquiry (background research, experimentation, documentation, presentation of work and application); student-participants reflect on how participation in the inquiry activity impacts their understanding of how science is done and how scientific knowledge is obtained; and participants describe their learning experiences during the inquiry activity in comparison with traditional lab activities. Student-participant feedback shows a preference for an inquiry approach over a traditional approach to lab activities in all areas explored consistent with
participant observations of increased student engagement and rich opportunities for students to construct their own knowledge.

Findings suggest that science teachers examine the limitations of traditional lab activities and attempt teaching practices that incorporate student-centered inquiry. Because this is not done easily process of professional development through collaborative teaching communities as explained in this study are recommended. In this way educators who wish to explore innovation of change in pedagogy can receive the inspiration, support, and motivation to help them move in various directions including inquiry-teaching practice.
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DEDICATION

I would like to dedicate this thesis to each of my students—what a joy is it to learn with you and to learn from you. I would also like to dedicate this thesis to my Mom and my Dad who, through both their actions and their words, taught me about the importance of life-long-learning. I would like to thank Averie for the Gerber daisies—the memory of them still brightens my day.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>i</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>iii</td>
</tr>
<tr>
<td>Dedication</td>
<td>iv</td>
</tr>
<tr>
<td>Table of Contents</td>
<td>v</td>
</tr>
<tr>
<td><strong>CHAPTER 1: THE JOURNEY BEGINS</strong></td>
<td>1</td>
</tr>
<tr>
<td>Stepping onto the Path</td>
<td>1</td>
</tr>
<tr>
<td>Keeping the Pace</td>
<td>2</td>
</tr>
<tr>
<td>Finding my Stride</td>
<td>3</td>
</tr>
<tr>
<td>Taking a Moment to Reflect and Find my Bearings</td>
<td>5</td>
</tr>
<tr>
<td>Allowing my Questions to Chart a New Course</td>
<td>8</td>
</tr>
<tr>
<td>Checking my Coordinates - Turning Labs Inside-out</td>
<td>9</td>
</tr>
<tr>
<td><strong>CHAPTER 2: REVIEW OF LITERATURE</strong></td>
<td>14</td>
</tr>
<tr>
<td>Rationale for Inquiry Learning in the Science Classroom</td>
<td>14</td>
</tr>
<tr>
<td>What is Inquiry?</td>
<td>19</td>
</tr>
<tr>
<td>Why Teachers Should Provide Opportunities for Inquiry in Science?</td>
<td>21</td>
</tr>
<tr>
<td>Why Students Should Participate in Inquiry Learning in Science?</td>
<td>24</td>
</tr>
<tr>
<td>Inquiry Learning Requires Students to Formulate Questions</td>
<td>25</td>
</tr>
<tr>
<td>Inquiry Learning Allows Students to Acquire Laboratory Skills</td>
<td>25</td>
</tr>
<tr>
<td>Inquiry Learning Motivates Students and Promotes Positive Attitudes</td>
<td></td>
</tr>
<tr>
<td>Toward Learning</td>
<td>26</td>
</tr>
<tr>
<td>Inquiry Learning Provides Students with a Better Appreciation for the</td>
<td></td>
</tr>
<tr>
<td>Nature of Science</td>
<td>29</td>
</tr>
</tbody>
</table>
Inquiry Learning Provides Opportunities for Students to Construct Knowledge ................................................................. 30

CHAPTER 3: METHODOLOGY & METHODS ............................................................. 32
Overview of Research Questions ............................................................................. 32
Methodology ............................................................................................................ 33
Research Participants ................................................................................................. 34
Data Collection and Analysis .................................................................................... 35
Autobiography ........................................................................................................... 36
The CRYSTAL Project - Creating a Community for Change ................................. 39
Creating Inquiry-Learning Opportunities - Turning Labs Inside-out .................... 42
Introduction and Overview of the Osmosis/Diffusion Inquiry .............................. 46
Assessment for the Osmosis/Diffusion Inquiry ....................................................... 51

CHAPTER 4: OUR STORIES AND MY ANALYSIS OF THEM ................................. 52
New Knowledge is built upon Existing Knowledge .................................................. 54
My Story .................................................................................................................. 54
Students’ Stories ....................................................................................................... 56
Natalie ...................................................................................................................... 56
Allison ...................................................................................................................... 58
Courtney .................................................................................................................. 59
The Purpose of Playful Exploration ........................................................................... 59
My Story .................................................................................................................. 59
Students’ Stories ....................................................................................................... 61
Allie ......................................................................................................................... 61
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inquiry Activities Versus Traditional Experiments</td>
<td>67</td>
</tr>
<tr>
<td>My Story</td>
<td>67</td>
</tr>
<tr>
<td>Student’ Stories</td>
<td>67</td>
</tr>
<tr>
<td>Mindful learning</td>
<td>71</td>
</tr>
<tr>
<td>The Nature of Science</td>
<td>79</td>
</tr>
<tr>
<td>Alternative Approaches to Laboratory Assessment and Evaluation ......</td>
<td>83</td>
</tr>
<tr>
<td>Comic Life</td>
<td>84</td>
</tr>
<tr>
<td>My Story</td>
<td>84</td>
</tr>
<tr>
<td>Students’ Stories</td>
<td>84</td>
</tr>
<tr>
<td>The Genesis of the Broader Application</td>
<td>94</td>
</tr>
<tr>
<td>My Story</td>
<td>94</td>
</tr>
<tr>
<td>Students’ Stories</td>
<td>95</td>
</tr>
<tr>
<td>The Independent Wrap-up Assignment</td>
<td>102</td>
</tr>
<tr>
<td>Students’ Stories</td>
<td>102</td>
</tr>
<tr>
<td>Natalie</td>
<td>102</td>
</tr>
<tr>
<td>Adam</td>
<td>103</td>
</tr>
<tr>
<td>CHAPTER 5: IMPLICATIONS AND CONCLUSIONS</td>
<td>105</td>
</tr>
<tr>
<td>Different degrees of inquiry</td>
<td>105</td>
</tr>
<tr>
<td>Transitioning from Traditional Labs toward Inquiry Learning............</td>
<td>109</td>
</tr>
</tbody>
</table>
Figure 3 - Example of Student Lab Report Showing Details of Lab work with Pictures and Text ........................................ 93

Figure 4 - Example of a Student Summary of Laboratory Experience ... 96

Figure 5 - Student Slide from a Power Point Presentation ............... 99

Figure 6 - A Final Expression from the Student Data ..................... 104

Figure 7 - The Student Participants have the Final Words ............. 117
CHAPTER 1: THE JOURNEY BEGINS

Stepping onto the Path

Although I was not aware of it at the time, my journey towards inquiry based learning began many years ago when, as a new teacher, I became concerned with the struggle that many of my students were having with Science 10. It was not uncommon, within the school that I was teaching at the time, to have five to seven students fail the course each semester. As a junior science teacher I found this high failure rate to be unnerving as most students who struggled in Science 10 had successfully completed the Science 9 course the year before.

Now after fifteen years of teaching Science 9, Science 10, Biology 20 and Biology 30 to hundreds of students in three urban high schools, I am taking the time to reflect upon and write about the significant personal discoveries that I have made and compel me to change my teaching practice.

In casual conversation I would say that I have always loved science, especially biology and that I always knew that I would have a science related career. However, it was probably in the seventh grade that I really came to know that there was such a thing as science. Grade 7 is the first time that I can recall science as an official subject with its own designated block on our classroom’s weekly Bristol board timetable and Grade 7 is also when I realized that I really enjoyed science. Even so, my memories of science from Grade 7 are limited. I can remember only two science lessons—dissecting an earthworm and growing mold as a science fair project.
In Grade 11 I was introduced to biology as a distinct area in science. My most vivid and proud memory of high school biology was when I created a self-sustaining aquatic ecosystem that survived in the biology lab for over a year. As I reflect on my own experiences of science in school what stands out is the link between me learning science by doing science and how this approach resulted in me really enjoying science.

As I reflected on the types of experiences that had me hooked on science at a young age during the early years of my teaching career I continually drawn to discrepancy between successes of my Science 9 students and struggles of my Science 10 students. It seemed to me that these two outcomes had more to do with my lessons than with my students’ capabilities. Upon reflection I could see that my lesson planning for my Science 10 course was quite different from my lesson planning for my Science 9 course. Consequently, my teaching and the students’ engagement were different in the two courses. I wondered, what accounted for the different approaches I took when planning these two courses and in turn, what impact did these approaches have on lesson planning and subsequently on the level of student engagement and learning outcomes?

Keeping the Pace

A factor that played a role in how I presented the Science 10 course was that most of the Grade 11 and 12 science teachers also taught Science 10. Perhaps, in an effort to ensure that students entering Grade 11 physics, biology, or chemistry would be prepared for the subject matter and
accustomed to the types of lessons that would be presented, I was shown not only what was taught within the Science 10 course, but also how it was taught. Consequently, I inherited lessons that had been created and taught over the years.

On the surface this continuity of lessons seemed like a good idea for with everyone teaching and presenting the material in more-or-less the same fashion, there appeared to be a similarity between Science 10 classes. In addition, the fact that everyone was using the same lessons gave the impression that they were ideal. Subsequently, I did not question the validity of the lessons for the first few semesters. However, I soon discovered that the problem with conforming to this uniform structure of instruction was that it left little room to explore and experiment with different ways of teaching to accommodate different learning styles. Even though I did give students opportunities to express themselves in creative ways through activities such as Element Advertisements and Cell Organelle Cartoons, these creative opportunities were limited and did not necessarily reflect the personal interests of my students nor connect to their everyday experiences. Furthermore, the traditional lab activities with their rigid, recipe book-style instructions provided students with little opportunity to experience the genuinely creative nature of scientific investigations.

Finding my Stride

In contrast to Science 10, as a beginning teacher I experienced far more autonomy when planning lessons for my Science 9 students. Given that the
teaching of this course seemed to be left to the best efforts of new teachers, including those without a science background, I experienced more freedom (in fact the necessity) to create my own activities and projects. Consequently, I approached lesson planning for my Science 9 class with far more flexibility than I had for my Science 10 program. Science 9 activities were often modified or created anew to accommodate students’ interests and suggestions. In fact, we often worked together to design and conduct laboratory investigations, research projects, and demonstrations.

The flexibility and spontaneity that my Science 9 students and I enjoyed is illustrated by a memory I have regarding a lesson about the factors that increase rates of corrosion. As one of the last topics in the unit, I was looking forward to a fairly simple lesson involving a short reading from a textbook and a brief discussion on the issue of whether it would be better to place one’s car into a heated garage or to leave it outside in the cold after driving on wet, salted roads. Not long into the lesson, as a result of a student’s suggestion that we should test what we were reading about, the simple discussion that I had planned evolved into a science experiment complete with controls and a number of variables. By the end of the class three sets of four test tubes per set labeled as: dry; distilled water; salt water; and Coke (as proposed by students who had heard that Coke was very corrosive) sat on the counter awaiting the nails that I would purchase that evening. The next day a common nail and a galvanized nail was placed into the test tubes. One set was placed on the counter in the classroom, another set was put into a warm incubator to
represent a heated garage, and the last set, representing the car that was parked outside, was placed into the freezer. For several days students checked the nails for signs of rusting and eventually determined which of the conditions caused the nails to corrode the fastest. My students’ willingness to help design the lab, set up the materials, and track the progress of the nails’ corrosion were all indicators that my students were engaged in this classmate-initiated experiment.

Taking a Moment to Reflect and Find my Bearings

In addition to teaching Science 9 and Science 10, I also teach Biology 30. While high failure rates were not a concern with the Biology 30 students, my Science 10 and Biology 30 programs did share a common characteristic that contrasted with my Science 9 program. Even though my Science 10 and Biology 30 programs contained lab activities and projects, the perceived pressure to get through the curriculum’s foundational and learning objectives resulted in the need to limit the number of time-consuming, student-centered activities in Science 10 and even more so in Biology 30. In addition to reduced numbers of activities, the activities were traditional step-by-step, recipe-style lab activities that neither arose from student interests and queries nor lent themselves to student modification. Putting the rigidity of the traditional lab activities aside, the fundamental issue was that participation in the traditional lab activities did not appear to significantly increase students’ understanding of the concepts.
What I was experiencing as a classroom science teacher was far from unique. Leonard, Speziale, and Penick (2001) write:

In response to what was widely perceived as inadequate teaching of precollege science in the United States, the National Science Foundation supported the development of the Benchmarks for Science Literacy (AAAS 1993) [American Association for the Advancement of Science] and the National Science Education Standards (NRC 1996) [National Research Council]. One of the specific problems addressed by these national standards efforts was that secondary science historically has been taught primarily through lecture with emphasis on long lists of trivial facts and vocabulary words, which often are to be memorized. (p. 310)

As a result of these findings:

Both AAAS and the NRC attempted to aid science curriculum developers in content selection by identifying a small subset of the most important science concepts rather than a long set of facts that attempt to cover an entire subject, as is the case for many traditional science curricula. Also, unlike the dominant traditional curricula, AAAS and NRC strongly recommend that science curricula devote significantly more time to developing scientific thinking skills and understanding the nature of science. Both organizations promote student learning through engaged investigation as opposed to passive listening and speak also to the desirable role of the teacher as being distinctly student-centered and inquiry-oriented. (Leonard, Speziale, & Penick, 2001, p. 310)

It is important to clarify, that while the current Science 10 curriculum (Saskatchewan Learning, 2005) is more in line with the AAAS and NRC recommendations, these particular reflections are based on lessons taught and outcomes seen while I was teaching from the more traditional-style Science 10 curriculum written in 1991 (Sask Education, 1991) and the current Biology 30 curriculum (Saskatchewan Education, 1992) written in 1992.

This said, in an attempt to improve student learning, I experimented with the order in which lessons would unfold and concepts would be presented. In so doing I found that whether my students completed a lab activity before
the concept had been presented through lecture and notes or after, had little impact on student understanding and learning outcomes. In fact, it was not unusual to have students carry out a lab activity’s step-by-step procedure flawlessly and collect proper data, but end up having an unclear understanding of the lab activity’s purpose; little, if any, insight into why the procedural steps unfolded as they had; no appreciation for how the materials related to each other; only a vague sense of the need for controls and variables; and an inability to interpret the results. This inability to interpret their findings was in turn demonstrated by their failure to participate in meaningful post-lab activity dialogue, to successfully complete lab activity discussion questions, and to apply their findings to real life phenomena. As a result, most students were able to answer questions that relied on their ability to remember, retrieve, recognize or recall relevant information from the lab activity, but many of them were unable to demonstrate an understanding of the materials and procedures employed or the concepts explored.

The Revised Bloom’s Taxonomy (RBT) states that to show an understanding of a concept a student must be able to complete activities which require him/her to construct meaning, make inferences, compare, and differentiate or explain (Forehand, 2005). Being mindful of this statement and my students’ learning outcomes I was led to conclude that a number of the traditional lab activities my students were carrying out did not result in their thinking beyond the lowest level of the taxonomy—remembering. Witnessing students demonstrating higher order thinking behaviors such as understanding,
applying, analyzing, evaluating, and creating, as a result of participating in one of the traditional lab activities, was the exception, not the rule.

In 1971 Bruner wrote that:

It seems imperative ... to develop an approach to learning that is more effective in nature—an approach to learning that allows the child not only to learn the material that is presented in a school setting, but to learn it in such a way that he can use the information in problem solving. To me this is the critical thing: How do you teach something to a child? (p. 70)

Even though I had not read Bruner’s work until some time later, I had begun to have the same thoughts. What was the point of a two or three hour lab activity if at its conclusion the students had only a vague sense of the lab activity’s purpose, no rationale for performing certain procedural steps, and an inability to transfer understanding? By raising this question I am not suggesting that I was considering eliminating lab activities; rather, I had begun to question whether the recipe style, step-by-step, traditional lab activities that I had known as a student and continued to use as a teacher provided students with sound opportunities for learning.

Allowing my Questions to Chart a New Course

In retrospect it was with this question that my personal journey into the realm of inquiry teaching and learning had begun. The intent of this research is two-fold. The first is to chart my pedagogical journey as I strive to transform my teaching practice from a teacher-centered, guided-instruction approach to a student-centered, inquiry-based practice. An approach in which lessons and activities are modified, created anew or even abandoned in an attempt to engage my students on a deeper level. In so doing I share what motivates me to
transform traditional style lab activities into inquiry learning opportunities for my students.

The second intent of this research is to receive the feedback of my students. The creative time, energy, and effort put into developing new inquiry-based investigations is all for naught if my students do not perceive the process as having any value. Consequently, I am interested in exploring the following questions in my research:

1) What are my students’ experiences with aspects of the inquiry activity such as background research, experimentation, documentation, presentation of work and the application of knowledge?

2) How did participation in the inquiry activity impact my students’ understanding of how science is done and how scientific knowledge is constructed?

3) How do my students describe their learning experiences during the inquiry activity and how does it compare to their learning experiences during traditional lab activities?

**Checking my Coordinates - Turning Labs Inside Out**

Post-lab evaluation of student learning outcomes brought me to the realization that just because students were actively doing something did not mean that they were mindful of the task at hand and actively learning something. This awareness caused me to reexamine the types of lab activities I had been using and in doing so it became clear that simply using hands-on activities did not always result in student understanding.
Raloff (1996) describes minds-on science as “deeply involving, experiential investigation[s] ... [which go] beyond mere hands-on activities—performing specific experiments under the guidance of a teacher or book” (p. 72). As opposed to hands-on science, minds-on science “engages the student in formulating original questions, brainstorming to find answers, and critically evaluating subsequent test results” (Raloff, 1996, p. 72).

Furthermore, “data on teaching have come to ‘suggest that people don’t learn science by absorbing stuff that has been poured into them ... but rather by constructing meaning out of experiences that the teacher provides’” (Raloff, 1996, p. 73). Such an approach epitomizes the fundamental epistemological framework that informs my praxis—the individual constructs knowledge as he/she explores and experiences concepts and the relationships between concepts (Novak, Mintzes, & Wandersee, 2005). After reflecting on the generally poor, post-lab learning outcomes that my students had been demonstrating for years, I came to appreciate that following the steps outlined in a traditional lab activity no more required my science students to explore the concepts presented than a recipe would require a baker to investigate the use of baking soda. Traditional lab activities exposed my students to scientific procedures and concepts and conclusions were produced, but the activities were ineffectual at providing them with opportunities to create the procedures and explore the concepts on their own. Subsequently, participation in the activities resulted in the construction of neither procedural nor conceptual
knowledge. The traditional osmosis/diffusion lab activity provides many examples of this; the following is one of them.

Students are instructed to set up two test tubes. Into one of the test tubes is placed some starch solution and into the other some glucose solution. A few drops of Benedict’s solution are added to both test tubes and the test tubes are placed into a hot water bath. Upon heating, the test tube containing the glucose and Benedict’s solution turns orange while the one containing the starch and Benedict’s solution remains unchanged.

With this completed students are then directed to place both starch and glucose solution into a length of dialysis tubing which they then tie off to create a solution sausage. This sausage is placed into a beaker of distilled water and left for twenty-four hours. The next day students are instructed to transfer a small amount of water from the beaker to a test tube into which they add a few drops of blue Benedict’s solution. The test tube is then placed into a hot water bath where within a few minutes the mixture in the test tube turns orange. Students then record this resultant color change in their data collection tables.

Later, during the analysis portion of the lab activity, students are asked to explain why the beaker water turned orange. Many of my students were unable to state that it was because glucose molecules had diffused out of the tubing and into the beaker water, and fewer were able to explain the experimental evidence they had for such a claim. It was clear that the students were not making the connection between the concept of diffusion, that was
presented prior to the lab activity, with what they were observing within the lab nor were they connecting the procedural steps that revealed Benedict’s solution as an indicator for the presence of glucose to its application within the experimentation portion of the lab.

As a result of this experience and others like it, I realized that the lab activities would need to be turned inside-out in order for them to be effective methods for providing students with opportunities to construct conceptual and procedural knowledge within a lab setting.

Over the course of a few years I began to move further away from the traditional Science 9 and Science 10 lab activities and more towards the investigations I was creating. Barrow (2006) has characterized traditional lab activities as one hour experiments through which students, who follow the steps, are able to get answers and come to conclusions they then share privately with their teacher. He contrasted traditional lab activities with another type of lab activity that he explained often extends over the course of a few days and requires students to manage ideas and information instead of equipment and materials. These activities call for students to use evidence and strategies to develop or revise explanations that they then share in a public format through class presentations. My inside-out investigations have been designed with this aim in mind. I later came to understand that by changing the emphasis of my lessons I was moving my teaching practice in a direction which promoted not only hands-on, but also minds-on learning and that my inside-out lab activities were called inquiries.
Reworking certain traditional lab activities enables me to transform them into improved inquiry-learning opportunities for my students. Unlike traditional labs, where students must follow the prescribed directions in pursuit of achieving the same conclusions, my intention for the inquiries is to provide students with a task to achieve or a concept to explore while leaving the how to achieve the goal or to explore the concept in my students’ hands. The creation of one such inquiry lab activity and the exploration of my students’ participation within the lab activity is the focus of this research project.
CHAPTER 2: REVIEW OF LITERATURE

This chapter is composed of three sections. The first section contains a brief rationale for the introduction of science education into elementary and secondary schools in the 19th century and continues with an overview of curriculum reforms that have occurred since. The second section focuses on providing a description of inquiry within the context of science education. And the third section offers arguments for why science teachers should provide students with inquiry learning opportunities—citing positive student learning outcomes that result from participation in inquiry activities.

Rationale for Inquiry Learning in the Science Classroom

Prior to the middle of the nineteenth century classical studies such as mathematics and grammar with their rules and logical inferences, dominated school curriculums (Deboer, 2006). In the 1800s it was the sharp contrast of scientific work’s inherently inquisitive nature against the “rules and clear logical inferences” (p.22) of mathematics and grammar which first provided a compelling incentive for the inclusion of science in school curricula. Deboer writes that:

It was not until scientists in Europe and the United States began promoting the value of science for its contribution to intellectual development that it became a regular part of the school curriculum. ... What was special about science was its basis in observation and inductive reasoning. ... The study of science was justified largely on the basis of its ability to develop the intellect in ways that were fundamentally different from what was usually done in schools. (p. 21-22)

However by the mid-1800s and into the early 1900s academics such as Huxley and Dewey were already calling for reforms in science classrooms. They
encouraged teachers to engage their students in lessons that would allow for
the discovery of scientific knowledge and implored educators to place less
emphasis on facts and terms to be memorized.

In 1899 Thomas Henry Huxley, a well-known British biologist and
President of the Royal Society, wrote the following in support of science classes
in the schools:

The great peculiarity of scientific training, that in virtue of which cannot
be replaced by any other discipline whatsoever, is the bringing together
of the mind directly into contact with fact, and practicing the intellect
in the completed form of induction; that is to say, in drawing
conclusions from particular facts made known by immediate
observations of Nature. ... In teaching him botany, he must handle the
plants and dissect the flowers for himself; in teaching him physics and
chemistry, you must not be solicitous to fill him with information, but
you must be careful that what he learns he knows of his own knowledge.
(as cited in Deboer, 2006, p. 22)

This belief in how science should be taught became the foundation for
the development of science laboratory instruction (Deboer, 2006). Teaching
science through the use of laboratory investigations received much support
from the British philosopher and scientist Herbert Spencer (1820-1903) who
stated that, “Children should be led to make their own investigations, and to
draw their own inferences. They should be told as little as possible, and
induced to discover as much as possible” (as cited in Deboer, 2006, p. 23). He
believed that “the generalizations that were discovered by students through
their own inquiries would be remembered longer and the process of inquiry
would make the learner independent of the authority of the teacher” (Deboer,
2006, p.23). In 1910 John Dewey observed that there was “too much emphasis
on science facts without enough emphasis on science for thinking and an
attitude of mind” (Barrow, 2006, p. 266). These observations resulted in his recommendation that inquiry be included in the K-12 science curriculum (Barrow, 2006).

It is important to note that the recommendations made, over one hundred years ago by Spencer and Dewey regarding science education, were not widely implemented by the educators of their time. In fact, it would be another fifty or sixty years before science education in North America would garner much attention.

In 1957 the Soviet Union’s launch of Sputnik left the American people with the unsettling feeling that they were falling behind in the areas of science and technology. Consequently, “dissatisfaction grew about the poor output of the education system in terms of meeting the increasing demand of the labour market for personnel with the appropriate training in science and technology” (van den Akker, 1998, p. 424). In the early 1960s, motivated initially by fear, the U.S. government initiated a wave of science education reform. The government called upon the National Science Foundation (NSF) to provide funding for projects that involved developing new science curricula and providing professional development for implementing the curricula (Barrow, 2006). “The initial emphasis in these projects (especially those for secondary education) was the modernization of the curriculum content and objectives” (van den Akker, p. 424) as well as “the importance of science processes, especially scientific inquiry” (p. 424). The new curriculum emphasized “thinking like a scientist” and focused on the teaching of “science processes as
individual skills (i.e., observing, classifying, inferring, controlling variables, etc.)” (Barrow, 2006, p. 266), but “attention to practical and technological applications of science were usually limited” (van den Akker, p. 425).

These new curricula, which included Physical Science Study Committee (PSSC), Biological Sciences Curriculum Study (BSCS) and Chemical Education Materials Study (CHEMS), were nick-named the *alphabet-soup* curricula and were characterized by development teams comprised of prominent science scholars and educational theorists; frequent writing conferences; and the involvement of publishers in the production of textbooks, worksheets, teacher guides and audiovisuals (van den Akker, 1998). Only once all of the teaching materials had been generated were classroom teachers brought into the equation—as participants in inservice training workshops (van den Akker).

These programs, often described as *teacher-proof* curriculum packages, operated “from the theoretically erroneous assumption that *all* students can learn from the same materials, classroom instructional techniques and modes of evaluation” (Giroux, 2009, p. 37) and were designed with the belief that *if* teachers taught exactly what was in the curriculum, exactly how it was outlined the result would be an increase in the number of high school graduates pursuing careers in science and science related fields. Needless to say, the principles underlying the teacher-proof curricula were “at odds with the premise that teachers should be actively involved in producing curricular materials suited to the culture and social contexts in which they teach”
(Giroux, 2009, p. 37) and before long it became apparent that teachers were not delivering the curricula exactly as intended.

Van den Akker (1998) writes that studies conducted in the late 1970s and early 1980s concluded that “‘that the gap between the expectations and the teaching practices was ... formidable’” (p.426) as:

- Preparation for the next academic level seemed to be the almost exclusive goals of most teachers;
- science instruction appeared to be overly dependent on textbook use; [and]
- direct experience, inquiry approaches and other forms of intellectual stimulation were uncommon. (p. 425)

Other studies emerging from the 1970s through the 1990s documented a “shallow level of understanding engendered in what is argued to be the decontextualized approach to teaching science,” (Reiser, Smith, Tabak, Steinmuller, Sandoval, & Leone, 2001, p. 264). These studies provided explanations for “poor student learning outcomes in science” (van den Akker, 1998, p. 428) and “the low achievements of American students in international comparisons” (p. 429)—observations that inevitably led to the second wave of science education reform in North America.

In 1989 the American Association for the Advancement of Science (AAAS) published Science for All Americans: A Project 2061 report (AAAS, 1989) in which inquiry was:

... considered as a science content topic using the following recommendations: start with questions about nature, engage students actively, concentrate on the collection and use of evidence, provide historical perspective, insist on clear expression, use a team approach, do not separate knowledge from finding out, and deemphasize the memorization of technical vocabulary. (Barrow, 2006, p. 267)
In 1996 the National Research Council (NRC) (NRC, 1996) published the *National Science Education Standards* in which inquiry was considered “as the overarching goal of scientific literacy” (Barrow, 2006, p. 268). This document described “inquiry experiences as those that allow students to ‘describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others’” (Campbell & Bohn, 2008, p. 37). As is apparent by this overview, the call for the unique inquiry learning opportunities that science can offer—while perhaps voiced for slightly different reasons over the years—is not new.

**What is Inquiry?**

To understand what is meant by the term *inquiry* within the teaching context is somewhat complicated, as “inquiry seems to be used in a variety of ways without careful distinction as to the differences” (Anderson, 2002, p. 3). In addition, educators will sometimes use the terms *inquiry learning* interchangeably with the term *discovery learning* (Mills, 2005)—a learning theory, often credited to Jerome Bruner, which emerged in the 1960s. While both find common ground in Bruner’s belief that “a necessary component in human learning ... [is] namely, the opportunity to go about exploring a situation” (Bruner, 1971, p. 70), the two are not synonymous. “One distinction made between the two approaches is that with discovery learning students are provided with data or information and are expected to determine the particular principle hidden in the lesson objective. With inquiry learning the
goal is for students to develop their own strategies to manipulate and process information” (Mills, 2005, ¶ 6).

To confuse matters further, inquiry is also “seen both as a characteristic of a desired form of teaching and as a certain kind of activity” (Anderson, 2002, p. 3). Anderson cites the NSES stating that, “Inquiry into authentic questions generated from student experiences is the central strategy for teaching science” and that inquiry learning “refers to the activities of students in which they develop knowledge and understanding of scientific ideas as well as an understanding of how scientists study the natural world” (p. 2-3).

The NRC’s and the AAAS’ descriptions of inquiry, provide a clearer understanding of the concept.

The NRC states:

Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known in light of experimental evidence: using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternate explanations. (NRC, 1996, p.23)

And the AAAS explains that scientific inquiry is:

... more complex than popular conceptions would have it. It is, for instance, a more subtle and demanding process than the naïve idea of making a great many careful observations and then organizing them. It is far more flexible than the rigid sequence of steps commonly depicted in textbooks as the scientific method. It is much more than doing experiments, and it is not confined to laboratories. If students themselves participated in scientific investigations that progressively approximate good science, then the picture they will come away with will likely be reasonably accurate. (AAAS, 2009, ¶ 22)
The AAAS makes it clear that a typical high school science experiment is not at all like the real thing as decisions involving what to investigate, the materials to use, how to proceed and what data to collect are all decided upon by outside entities such as the teacher or the lab manual (Llewellyn, 2005, p.6). The AAAS describes a typical high school experiment as one in which repetition of the experiment, revision of the procedural steps, and presentation of findings to peers is not the norm.

These descriptions suggest that inquiry learning requires students to become actively involved in the creation of scientific investigations and to demonstrate behaviors, attitudes and skills more like those of working scientists. While the NRC provides a comprehensive list of characteristics of inquiry learning, the AAAS’ approach is to juxtapose inquiry learning against the more common traditional laboratory investigations. The results of this comparison reveal a contrast that makes clear why traditional laboratory activities are not forms of inquiry learning.

**Why Teachers Should Provide Opportunities for Inquiry in Science**

Convincing teachers to stop what they have been doing for years and to try something new is at best of times a hard sell. It becomes even more challenging when one cannot provide teachers with evidence from studies that show clear-cut rates of success (Anderson, 2002). Anderson states that, “While much research [into inquiry teaching] has been done, the results are not as definitive as some would hope” (p. 4). Nevertheless, studies carried out by Shymansky, Kyle and Alport (1983) and more recently by Haury (1993), show
that inquiry teaching leads to positive results in “cognitive achievement … scientific literacy, science processes, vocabulary knowledge, conceptual understanding, critical thinking and attitudes towards science” (Anderson, 2002, p. 4-5).

Nevertheless, studies such as those cited above, are becoming more difficult to find because research in the area of inquiry has matured and “has tended to move away from the question of whether or not inquiry teaching is effective, and has become focused more on understanding the dynamics of such teaching” (Anderson, 2002, p. 6). Perhaps, the more pressing question that needs to be answered by individual educators and discussed amongst colleagues is: What are your objectives for science education for your students, within your school, within your school division and what grounds your objectives?

The NRC’s inquiry standards state that students should be able to

- identify questions and concepts that guide scientific investigations,
- design and conduct scientific investigations,
- use technology and mathematics to improve investigations and communications,
- formulate and revise scientific explanations and models using logic and evidence,
- recognize and analyze alternative explanations and models, and communicate and defend a scientific argument. (as cited in Llewellyn, 2005, p.5)
If teachers accept these descriptors then it seems quite reasonable that they would be interested in incorporating inquiry learning opportunities into their science units.

In addition, Saskatchewan science curricula specifically call for teachers to provide students with opportunities to develop scientific literacy. The *Science 10 Curriculum Guide*, (Saskatchewan Learning, 2005) describes scientific literacy as “an evolving combination of the science-related **attitudes**, **skills** and **knowledge** students need to develop inquiry, problem-solving, and decision-making abilities, to become lifelong learners, and to maintain a sense of wonder about the world around them” (p. 1).

To achieve the vision of scientific literacy, students must increasingly become engaged in the planning, development, and evaluation of their own learning activities. In the process, students should have the opportunity to work collaboratively with others, to initiate investigations, to communicate findings, and to complete projects that demonstrate learning. (Saskatchewan Learning, 2005, p. 1)

Saskatchewan Learning (2005) states that, “although the particular context of these learning experiences will vary among classrooms, the overall scope and focus of Science 10” must include an emphasis on “**science inquiry ...**, in which students address questions about the nature of things, involving broad exploration as well as focused [sic] investigations” (p. 1).

The document, *A Curriculum Guide for the Secondary Level Biology 20/30* (Saskatchewan Education, 1992) refers to science “as both a body of knowledge and a process of inquiry [which] extends beyond understanding of abstract laws and principles of nature into the realm of technology and applied sciences” (p. 1). To this end, Saskatchewan Education asserts that:
In both Biology 20 and Biology 30, [an] emphasis should be placed on concrete experiences for the students. Manipulations of equipment, personal investigations into a variety of systems, visiting sites which illustrate the principles which are discussed in class or which encourage students to launch investigations of their own, are examples of ways in which the students may become directly involved in the study of biology. ... A general guideline is that approximately 30% of the time allotted to the study of biology should be spent in investigative activities. Some of these activities should be relatively long-term investigation of phenomena. The time spent on these activities should be reflected in the evaluation scheme. (p. 81)

It is evident from the requirements of the Saskatchewan science curricula, that employing a variety of teaching strategies and learning opportunities will help students achieve a number of the learning objectives outlined. However, certain dimensions of scientific literacy such as working cooperatively, questioning, predicting, inferring, controlling variables, formulating models, and designing experiments can only be met by engaging students in inquiry learning activities.

**Why Students Should Participate in Inquiry Learning in Science**

When teaching a child to tie her laces we place the laces into her own hands. When teaching a child to bicycle we let her steer and peddle for herself. When teaching a child to print her letters we give her a pencil and a piece of paper. Why then, when we teach our students science would we do anything other than provide them with the proper tools and give them opportunities to use them? If one believes that the basis of learning is the act of doing, then wouldn’t it be wise to provide students with as many opportunities to *do* science as possible? Inquiry learning provides students with authentic and unique hands-on, minds-on opportunities to do science in a
manner that allows them to not only learn about the concepts of science, but the behaviors and practices of scientists as well.

**Inquiry Learning Requires Students to Formulate Questions**

At the heart of both *good* inquiry learning and *good* scientific inquiry is the same fundamental need for a *good* question. The act of “questioning is an integral part of meaningful learning and scientific inquiry... and at the heart of what doing science is all about” (Chin & Osborne, 2008, p. 1). For that reason alone I believe that it is beneficial to include inquiry-learning experiences in science. The authors call attention to the important role that students’ questions play in learning science stating that, “questions from students indicate that they have been thinking about the ideas presented and have been trying to link them with other things they know” (p. 2). Chin and Osborne go on to point out that a “source of students’ questions is a gap or discrepancy in the students’ knowledge” and that, “for students, posing their own questions is a first step towards filling their knowledge gaps and resolving puzzlement” (p. 2). In other words, this act of questioning, which is then followed by the other aspects of inquiry (hypothesizing, experimenting, etc.), becomes the students’ first step towards acquiring and constructing missing pieces of knowledge or resolving conflicts in their understanding (Chin & Osborne, 2008).

**Inquiry Learning Allows Students To Acquire Laboratory Skills**

Oates (2002) states that most practicing scientists agree that the goal of science education “must be to instill a sense of inquiry ... foster a research strategy” (p. 184) and provide students with opportunities to “acquire skills
and knowledge” (p. 184) which will allow them to “think and act scientifically” (p. 184).

In the past, I have had students practice laboratory skills, such as measuring volume or finding length, without any real need to do so other than as practice for the future. My rationale was that if I taught all students how to use the individual measuring tools at the beginning of the semester, then for the rest of the semester they would have these skills on hand to use whenever the need arose. I soon discovered, however, that students rarely appreciated the fact that the measuring tools were to be used in the practiced fashion each time they used the tools not only during activities specifically designed to practice accurate measuring.

Inquiry learning not only presents students with opportunities to pursue their own lines of thought and to collaborate in the development of experimental design, but also provides students with genuine opportunities to develop and practice laboratory skills. Because student inquiry teams are often pursuing different questions and using different experimental designs, which require different laboratory skills, these skills often have to be developed and practiced as required by the tasks at hand.

Inquiry Learning Motivates Students and Promotes Positive Attitudes Toward Learning

Chin and Osborne (2008) state that the act of posing inquiry questions could also pique student curiosity as well as arouse student motivation and interest in the topic of study. They cite the work of Chin and Kayalvizhi (2005)
who “found that about three-quarters of the Grade 6 students in their study preferred investigating questions that they themselves had posed compared with simply answering the investigative questions given in their practical activity books. These students reported feeling happy, excited, or proud about generating their own questions for the investigations, and describe the experience of investigating their own questions as thrilling, fun, and interesting” (Chin and Osborne, 2008, p. 5). Martin, Sexton and Franklin (2009) write that, “Mental action is the planned or guided metacognitive activity of cognitive constructivism, a mental state influenced by physical and social interaction with the learner’s world. Hence, learning is not limited to cognitive activity; emotion also influences learning” (p. 47). Educators must recognize that the way a student feels during science class plays a significant role in his/her ability to learn the subject matter. A ‘grin and bear it’, ‘you need to know this because it’s in the curriculum’ approach towards science education will not produce enthusiastic, scientifically literate learners.

In addition to presenting students with opportunities to investigate their own queries, the hands-on nature of inquiry learning increases their engagement that can lead to evoking “the ‘minds-on’ experiences recommended in the National Science Education Standards” (Taraban, Box, Myers, Pollard & Bowen, 2007, p. 976). Taraban et al (2007) cite the work of Ajewole (1991) who found that, unlike passive listening that may lead to boredom and negative attitudes towards science and learning, interacting with materials as required by inquiry learning leads to positive attitudes about
learning. A review of science laboratory literature carried out by Campbell and Bohn (2008) supports the above finding citing that research has shown an increase in “students’ interest and attitudes towards science” (p. 38) when inquiry-based activities are employed.

Lastly, Mehalik, Doppelt and Schuun (2008) conducted a study which focused on a systems design approach—an approach to learning which shares many of the same educational doctrines as inquiry learning—and found that the “Why do I need to know this?” (p. 81) obstacle to learning was removed when students were allowed “to ask their own questions for investigation ... design their own experiments ... [and] investigate their own ideas” (p. 81). In addition to this finding, they noted that because of the self-directed nature of their investigations students were responsible for their own learning (Mehalik et al, 2008). In the end, Mehalik et al stated that “the findings showed that it was possible to achieve higher science concept learning when the scientific inquiry process was integrated into a design setting, motivated by meeting needs that students articulated for themselves” (p. 81).

Finally the evidence from students themselves speaks volumes: “Do you like using inquiry? I asked the rambunctious fourth period class. Several Yeah’s. [Pause.] What would happen if Ms. Hill went back to teaching traditionally? I’d go back to sleep. -Terrence, African-American 10th grader” (Deneroff, Sandoval & Franke, 2002, p. 1).
Inquiry Learning Provides Students with a Better Appreciation for the Nature of Science

Most traditional high school laboratory investigations do not reflect authentic scientific work. These are the same investigations that have been performed year after year, with clearly outlined procedural steps that read like instructions in a cookbook and with results that are well-known, predictable and meaningless to the student beyond the mark s/he will receive (Oates, 2002). In addition, these types of activities generally have no relevance to the individual students’ lives; likely do not engage their minds or interests beyond the superficial level; and certainly do not provide students with any appreciation for real scientific work.

Inquiry learning, however, can be more authentic as it is born out of a genuine interest or query, and is intentionally designed to find answers that satisfy the curiosity of the inquirers. Inquiry learning requires students to “actively engage in experiments, interpret and explain data, and negotiate understandings of the findings with co-experimenters and peers” (Taraban, et al, 2007, p. 961). Inquiry learning activities, unlike traditional laboratory investigations, are not clear sequential processes, rather they are often messy, non-linear endeavors “where students are free to argue, make mistakes, and challenge each other” (Taraban et al, 2007, p. 976).

Taraban et al (2007) state that, “In this model, the teacher puts less emphasis on memorizing information and more emphasis on inquiry and hands-on activities through which students develop a deeper knowledge and
appreciation of the nature of science” (p. 961). When students are given opportunities to actively participate in scientific inquiries they come to understand that scientific knowledge and theories are not absolute. Rather, they are subject to change as new data are collected, analyzed, and negotiated amongst those within scientific communities (Taraban et al, 2007). Taraban et al add that when learning occurs in active ways students not only gain factual knowledge but also a deeper understanding of the experimental methods and practices of scientific communities. This aspect of science education should not be taken lightly. While most of our students will not end up studying sciences in university, they still “need to comprehend the process and nature of science, its benefits, and its limitations” (Taraban et al, 2007, p. 976). Lastly, Chin and Osborne (2008) add more support to the benefits of inquiry learning as a result of its reliance on student posed questions. They point out that regardless of whether or not students go on to pursue scientific studies “the ability to ask good thinking questions is ... an important component of scientific literacy, where the goal of making individuals critical consumers of scientific knowledge requires such a facility” (Chin & Osborne, 2008, p. 2).

Inquiry Learning Provides Opportunities for Students to Construct Knowledge

which can “be transferred to students ready-made” (p.10). Based on his constructivist view of how learning occurs von Glasersfeld asserts “that concepts can be formed only in the experiential world of an individual” and advises teachers to have a repertoire of teaching strategies in which the concepts that are to be addressed are presented in such a manner that will “trigger the students’ own thinking” (p. 10). In addition, he advises, “these situations should be such that they evoke the students’ spontaneous interest” (p. 10).

St. Omar (2002) writes of the value of interactive presentations as an aspect of inquiry learning suggesting that, “questions from students will often allow them [the students] to examine concepts presented and redefine new constructs” (p. 320). Chin and Osborne (2008) agree, stressing the important role that students’ questions play in learning science, “questions from students indicate that they have been thinking about the ideas presented and have been trying to link them with other things they know” (p. 2). Furthermore, Chin and Osborne also recognize that “the questions embedded in the conversation of peer groups help learners to co-construct knowledge” (p. 3) and when this occurs learning “involves not only the individual but also the social construction of knowledge” (p. 3).
CHAPTER 3: METHODOLOGY AND METHODS

Chapter 3 is composed of three sections. The first section provides an overview of the research questions and methodology used. It also provides insight into who the research participants were as well as to how the data was collected and analyzed. The second aspect of this chapter is my autobiography and an overview of my experiences as a member of the CRYSTAL Project. This section establishes the backstory and allows the reasons for why I chose to embark on the journey from traditional laboratory activities towards inquiry learning to become clear. The final section of the chapter provides a description of my process for converting traditional lab activities into inquiries and a description of the Osmosis/Diffusion Inquiry that played a central role in this study.

Overview of Research Questions

Dissatisfied with poor student learning outcomes following participation in traditional Biology 30 laboratory activities and looking to improve these outcomes I became interested in exploring the use of inquiry learning activities within the course. The purpose of this research is to try to deepen understanding of student’s learning experience when engaged in senior science laboratory activities, as evidence for rethinking science curriculum applications in pedagogy.

This research was conducted to explore whether or not participation in an inquiry learning activity could provide senior science students with a more authentic and meaningful experience of laboratory work and in doing so, could
students achieve a deeper understanding of how science is done and how scientific knowledge is constructed. This research also provided students with the opportunity to compare the depth of learning they achieved using an inquiry approach to laboratory work as opposed to a traditional lab activity.

**Methodology**

Choosing a methodology for the research was influenced by a desire to reflect on the frustration I experienced while employing traditional laboratory activities and my subsequent move towards inquiry learning strategies, as well as my wish to obtain my students’ accounts of their learning experiences within the laboratory setting. To this end, data collection and analysis for this study was influenced by the narrative inquiry method of research which is defined as:

...a way of understanding experience. It is collaboration between researcher and participants, over time, in a place or series of places, and in social interaction with milieus. An inquirer enters this matrix in the midst and progresses in the same spirit, concluding the inquiry still in the midst of living and telling, reliving and retelling, the stories of the experiences that made up people’s lives, both individual and social. (Clandinin & Connelly, 2000, p. 20)

As a teacher researcher who was using my own students as participants and whose interests lay determining the effectiveness of using an inquiry approach to improve student learning outcomes, it was important to acknowledge and try to level the power *playing field* between myself and my students. Employing a narrative inquiry approach allowed for the construction of research relationship in which both my students and myself had a shared opportunity to have our voices heard. To this end, not only did I collect students’ stories of their experience with inquiry learning, but I also employed
autobiographical writing as a way of collecting data about my personal experiences of inquiry teaching and learning. This approach is in keeping with Connelly and Clandinin’s (1990) directive on narrative inquiry which “emphasizes the importance of the mutual construction of the research relationship, a relationship in which both practitioners and researchers feel cared for and have a voice with which to tell their stories” (p. 4).

Clandinin and Rosiek (2006) state “that narrative inquirers study an individual’s experience in the world and, through the study, seek ways of enriching and transforming that experience for themselves and others” (p. 42). Interested in transforming high school laboratory activities into more enriching experiences for my students I understood that analysis of their stories, in conjunction with my own, would provide me with valuable insight into their learning. I could then use this insight to inform my teaching practice.

**Research Participants**

To achieve my research goals I requested the involvement of my Biology 30 students who were about to embark on an inquiry learning activity. As I was using data collected from my own students it was important to assure them, their parents, the Regina Catholic School Division and the University of Regina’s Research Ethics Board (REB) that students agreeing to participate in my research would not be required to do any *additional* work and that participants would be unknown to me until student grades were submitted at the end of the school year. With this understanding, both my School Board and the REB (see Appendix F) granted their approval for my school based research.
In the presence of a colleague who acted as my third party, I introduced my Biology 30 students to my research and informed them of the role that they could play in it. I assured them that I would not be privy to who had volunteered to participate in the research until marks were submitted at the end of the school year. Students were then given permission forms (see Appendix G) and instructed to return the forms to the third party. Of the seventy students who enrolled in my Biology 30 classes, twenty-nine students agreed to participate in my research. Twenty of the participants were female, nine were male and they ranged in age from sixteen to nineteen years old.

**Data Collection and Analysis**

Since I solicited feedback from my own students I had to stress the importance of providing me with sincere responses, not what they thought I might want to hear. I told them that I wanted to improve student-learning outcomes and that honest feedback would increase the chances of that occurring. Student data is drawn from documents including the Comic Life lab reports, the Broader Application presentations, and student narratives obtained through the Individual Wrap-up Assignments. Within the research paper these narratives are labeled as “Students’ Stories”.

Given that I am a teacher and that my research focused on inquiry learning, a non-traditional teaching approach, I thought it imperative that my story also be told. Almost immediately upon conception and implementation of the Osmosis/Diffusion Inquiry I knew that this particular activity would likely be the focus of my Master’s thesis research. The first time I engaged students
in the Osmosis/Diffusion Inquiry I did not have REB approval to use student products in my research. I began, however, to keep a journal documenting my personal thoughts and observations regarding the inquiry. This journal served as a place for me to record descriptions of the behaviors I witnessed and the conversations I either overheard or had with my students as they worked through their inquiries as well as a place for me to reflect on my teaching practice in general. The “My Stories” portions of this research paper are my personal narratives and they draw on the totality of my experiences with the Osmosis/Diffusion Inquiry activity, inquiry learning in general, and my teaching practice as a whole.

Lewis (2007) states, “The human mind is a storied mind possessed of a narrative capacity and ability to use story to create meaning” (p. 2). He goes on to raise the question, “does it not make sense then to use narrative … in our schools in order to understand human experience, but more importantly human learning and meaning?” (p. 39).

With these words in mind, I analyzed the data gathered from student narratives and my own and in conjunction with secondary resources (published articles and literature), I sought to gain a better understanding of what it means to learn, how learning can be facilitated and how teachers can create opportunities to engage learners on a deeper, more meaningful level.

**Autobiography**

Writing the following autobiography gave me the opportunity to reflect upon the events that lead to me engaging my students in educational research
that focuses on inquiry learning. Bruner (1996) states that “a narrative involves a sequence of events [and that] the sequence carries the meaning” (p. 121). The following autobiography explores experiences I’d had as a novice teacher, a more seasoned science educator and as a participant in the CRYSTAL Project and by doing so I begin to make meaning out of the learning outcomes I was witnessing with my students.

In 1995 I completed my Bachelor of Education degree at the University of Regina with a major in biology and a minor in general sciences. Shortly after graduation I was hired by the Regina Catholic School Division and after a couple of days as a substitute teacher I was offered and accepted a short-term, halftime position as the grade five through eight science teacher at an inner city elementary school. At the conclusion of that contract I returned to the role of a substitute teacher and took some time to travel. In the spring of 1998 I was offered another short-term, halftime contract. This contract required me to teach grade nine English and was accompanied by the understanding that it would be followed by a full-time, high school science position in the fall of 1997. Since that time I have held science education teaching positions at three of the four Catholic high schools in Regina.

The majority of my fifteen-year teaching career has been almost evenly split between two of the high schools in the city of Regina. The first of the two high schools is situated in a more affluent part of the city, has a more socio-economic homogenous population, and considered itself in the late 1990s early 2000s to be an academic school. The high school where I am currently
teaching, which will be referred to by the pseudonym Lakeview High School, is more centrally located within the city and offers a wide variety of courses. These courses range from those offered in the practical and applied arts, such as mechanics and commercial cooking, to more academic courses such as law and biology. Lakeview High School also meets the needs of a wide range of learners, employing teachers who are specially educated to teach students enrolled in the Alternative programs through to the AP (Advance Placement) programs. As a result of both location and courses available Lakeview attracts students from all over the city and from a wide range of socio-economic backgrounds.

Even though there is less than a ten-minute drive between the two schools, my experience within each was quite different. As I mentioned in Chapter 1, at the high school I taught at prior to my transfer to Lakeview I was one of the new, less experienced teachers for quite some time. However, because of the retirement of a biology teacher and the move of another teacher to Student Services, I began to teach the Biology 20 and 30 level courses regularly in my last two years at that school. With my transfer to Lakeview High School, however, I went from being one of the teachers with the least experience teaching Biology 20 and 30 to being the one with the most experience teaching Biology 20 and the only one teaching Biology 30.

With this new role I soon felt the freedom, in fact the responsibility to critically question what I was teaching, how I was teaching it and more importantly how my students were learning and how they were demonstrating
what they had learned. With these questions in mind I felt compelled to return to the University of Regina to pursue a Master’s degree in Education in the fall of 2006.

The CRYSTAL Project - Creating a Community for Change

I feel that it is important to include a short discussion of the CRYSTAL Project in this section, as the support of the CRYSTAL participants proved invaluable as I explored the use of inquiry learning within my classroom. Not only did many of the participants use, with their own junior science students, the inquiry activities that I had created, but their enthusiasm for the activities and their reported successes gave me the confidence to create and implement the inquiry-learning activity that became central to this research project. The following is a short account of my experiences as a CRYSTAL Project participant.

My decision to return to university seemed serendipitous as Warren Wessel had just received funding from NSERC (Natural Sciences and Engineering Research Council of Canada) for a CRYSTAL (Centre for Research in Youth, Science Teaching and Learning) project. Warren gathered a small group of high school science teachers and science education PhD candidates together and we began to meet regularly to discuss our experiences as high school science educators. Though Warren provided our CRYSTAL group with leadership and focus, he had no agenda for the direction that our meetings would take us.

During our initial meeting it became apparent that the concerns and frustrations I was feeling as a Science 10 teacher were not unique. In the early
days of working together we came to agree that providing students with activities that allowed them to experience scientific phenomena, laws, and concepts made for richer, more meaningful learning experiences than lectures, worksheets, and traditional lab activities. Agreeing on this point was easy. Creating the student centered activities and curbing our natural inclination to teach the students proved more challenging.

It is often said that science teachers teach in the way that they were taught and why wouldn’t we? The fact that I became a science teacher suggests that not only did I enjoy the science classes I took, but also that the methods my former teachers used to engage me worked well for me. I suspect that many of my colleagues would report that their teaching practices have been similarly influenced by their experiences as science students.

As participants in the CRYSTAL Project first we agreed that activities, which may take many hours to complete, must be designed in such a manner that they cover a number of learning and behavioral objectives required in the provincial curricula. St. Omar (2002) pays heed to that fact that the “emphasis in science classes is primarily on completing laboratory activities” (p. 310) and reminds us that “students must not only be taught to do science and develop science skills, but they should also be guided in the process of learning the scientific information discovered during these laboratory experiences” (p. 310).

Secondly, we acknowledged the fact that as classroom teachers we would have to control our desire to jump in and help our students do the activity the right way, as we recognized that much learning comes from making
mistakes. In addition to assuaging our desire to set the students on the right path, students’ anxiety over taking more ownership of their experiential learning had to be addressed. Since most of our students were accustomed to “‘traditional experiments’ [which] are well-known, predictable and have been performed a hundred times before them” (Oates, 2002, p. 185) they had to be assured that making mistakes, refining their processes, and trying multiple approaches during the investigation were important aspects of engaging in the processes of science and were not weaknesses in their work which would be penalized.

Finally, we had to have faith in the process. We had to trust that we were moving in the right direction; that within what would appear as not much more than disorganized, noisy confusion was actually a progression of deep, rich learning opportunities that our students were creating for themselves. Bruner (1996) states, “getting to know something is an adventure in how to account for a great many things that you encounter in as simple and elegant a way as possible” (p.115). He continues by saying, “there are lots of different ways of getting to that point, and you don’t really even get there unless you do it, as a learner, on your own terms” (p. 115). I believe that student-centered, “hands-on activities [which] ‘promote peer interaction where students are free to argue, make mistakes, and challenge each other’” (Taraban, Box, Myers, Pollard, and Bowen p. 976) provide students with opportunities to venture, in unique ways, towards a place of knowing. Furthermore, “hands-on experiences
are a medium for evoking the ‘minds-on’ experiences recommended in the
*National Science Education Standards*” (p.976).

**Creating Inquiry-Learning Opportunities - Turning Labs Inside-out**

“Research into teaching and learning, as well as leading national science education organizations, support a shift in science instruction that moves away from laboratory experiences that illustrate, demonstrate, and verify known concepts (traditional laboratory activities), and moves towards inquiry experiences” (Campbell & Bohn, 2008, p. 37). Campbell and Bohn describe inquiry experiences as those which give students opportunities “to describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others” (p. 37) and in this way are capable of presenting science “content and process seamlessly” (p. 46). They go on to acknowledge that research has shown that engaging students in inquiry-based activities has great potential to increase the learner’s interest and attitudes towards science (Cavallo & Laubach, 2001; Chang & Mao, 1999; Paris, Yambor, & Packard, 1998), to increase their understanding of the nature of science (Schwartz, Lederman, & Crawford, 2004), and to increase students’ understanding of science in general (Chang & Mao, 1999; Ertepinar & Geban, 1996; Hakkarainen, 2003).

Fortunately for myself another Science 10 teacher at Lakeview High School, was likewise witnessing the disinterest of her students for the subject matter and was similarly dissatisfied with the learning outcomes of her students. Even though she felt—as a first year teacher teaching out of her
area—that she neither had the time nor the skills to create new activities, she was eager to try with her students the activities that I would create. Consequently, I sat down with the Science 10 Physical Science: Motion in Our World curriculum (Saskatchewan Learning, 2005) and began to recreate the unit by developing student-centered, hands-on, minds-on activities that I believed would better engage our students in their learning process.

Bruner (1996) writes that, “the scientific method is certainly not the only route to understanding the world” (p. 131) and not being a strong advocate of the scientific method, I agree. Even though it can set the stage for talking about process in science, I believe that attempting to adhere to it for every classroom experiment may lead students to think that scientists make all discoveries by following a set group of instructions. Martin, et al (2009) write that, “Eventually, most science classrooms abandoned … the scientific method as something to be memorized, perhaps because the mechanistic certainty of the steps did not reveal the true nature of science, its history, and its implications for society (p. 10”). Armed with the desire to have our students engage in thought provoking science and my aversion to the scientific method (especially as a learning mechanism or description), my motivation to create new activities was strong.

I later shared these activities (which I would soon come to understand were inquiry activities) with the CRYSTAL Project members. I explained that the activities I had created, shifted focus away from teacher-centered lectures, notes and worksheets that acknowledged only one or two objectives
at a time, towards student-centered lab activities that covered a large number of curriculum objectives at once.

When asked to share my method for creating the activities I explained that, while I created some from scratch using the curriculum objectives and materials found in my science storage room, others were created by simply taking the traditional-style lab activities and *turning them inside-out*. It should be understood that turning labs inside-out was a pedagogical change which focused on *how* students interacted with the curriculum content, not the content itself.

To turn a traditional lab inside-out I first determined the original purpose or focus of the activity. Once this was established I then explored the activity’s potential for meeting other learning outcomes as well. For example, in addition to learning about the different scientific concepts outlined in the Science 10 Physical Science: Motion in Our World curriculum (Saskatchewan Learning, 2005), I also wanted our students to start to appreciate the nature of science and how scientists carry out their work and record and display their data. Once the new objectives of the activity were established, I removed the step-by-step instructions that students would normally follow and provided them instead with tasks to accomplish and concepts to explore while leaving the *how* to achieve the goal or to explore the concept in the students’ hands. Even though the activities I was creating used the same materials and equipment as the traditional recipe-style labs, my colleague and I observed that this unconventional approach to science teaching and learning was having
a noticeable impact on our student’s levels of engagement and their learning outcomes.

Converting traditional lab activities into inquiry-learning opportunities resulted in our students taking on a more team-like approach to their work. To reach the goals of the lab activities students worked together to make decisions, identify and isolate variables, create data tables, interpret data and draw conclusions from findings that were attained using approaches that were unique to their individual lab groups. The focus of our students work went from following the lab activity’s procedure to creating it; from verifying scientific phenomena to exploring them; from filling in data tables to constructing them; and from answering questions about procedures and findings to applying their newly constructed knowledge in ways that helped them to explain and make sense of real life experiences.

The support that I received from both my colleague at school and my peers in the CRYSTAL Project group along with the literature that I was reading on the topics of science education reform, the benefits of inquiry-learning, and knowledge construction all provided me with the encouragement to continue to create inquiry-style activities. My greatest motivation to continue moving my teaching practice towards the inquiry approach to learning, however, came from the increased levels of engagement that my students were demonstrating and the success that they were having with their course work.

By reworking certain traditional lab activities I was aiming to transform them into inquiry-based learning opportunities for my students. Students were
no longer simply being exposed to content and procedures, but were now being challenged to think and act creatively; to manage frustrations and develop a sense of fortitude; to critically evaluate outcomes; to apply what they had learned in relevant and meaningful ways; and to organize, present and defend their work to their peers. I think that it is important to reiterate that the *Science 10 Curriculum Guide* calls for these types of learning opportunities for Science 10 students. The document not only states that there should be an emphasis on “science inquiry”, but in my view the learning objectives outlined in the Physical Science: Motion in Our World unit are congruent with inquiry learning activities (Saskatchewan Learning, 2005).

**Introduction and Overview of the Osmosis/Diffusion Inquiry**

Encouraged and motivated by the improved learning outcomes that my junior science students were demonstrating with inquiry learning activities and discouraged and frustrated by the unsatisfactory learning outcomes achieved by the traditional osmosis/diffusion lab I had been using in Biology 30, I decided to make a change.

I initiated the change by sharing with my students the frustration I felt when past classes, who had completed the traditional osmosis/diffusion lab, could not demonstrate much new knowledge as a result of doing the lab. Then I shared with them the success that my grade nine and ten science students were experiencing with the inquiry approach to learning and how their success had inspired me to make a change to the traditional Biology 30 osmosis/diffusion lab. I proposed to my Biology 30 students that we turn that
traditional lab inside-out and what resulted was *An Inquiry into Osmosis and Diffusion*—the most ambitious inquiry lab activity that I have created and engaged students in to date.

The fundamental purpose of this newly designed osmosis/diffusion inquiry was to have student research teams design, conduct and document experiments with the goal of demonstrating the processes of osmosis and diffusion of molecules across a semi-permeable membrane. In creating my inquiry approach I carried out a complete redesign of the original traditional lab activity (see Table 1). Gone was the traditional step-by-step, recipe style procedure; teacher created data tables; pointed discussion questions; and the traditional lab write-up.

I asked my students to create research teams of three or four people and told them that within their teams they would be carrying out an inquiry style lab activity. I explained to them that they would not be provided with a step-by-step procedure or instructions from me, but rather each team would have the freedom to choose the methods and approaches they would take to complete the task.

I then told them their task was to design and conduct experiments that would allow their team to investigate and demonstrate the processes of osmosis and diffusion of molecules across a semi-permeable membrane. I showed them the different materials that I had available for them to use, which included glucose, starch, Benedict’s Solution, iodine, dialysis tubing, string, distilled water, safety glasses, glassware and associated clamps, holders
<table>
<thead>
<tr>
<th><strong>TRADITIONAL APPROACH</strong></th>
<th><strong>INQUIRY APPROACH</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>The purpose of the lab is clearly stated.</td>
<td>Students formulate their own purpose statements.</td>
</tr>
<tr>
<td>A list of materials is provided, but little to no information about the materials or how they interact with each other is given.</td>
<td>Students are provided with the materials required to carry out their inquiry. They are required to conduct research and mini-experiments to discover how the materials can be used.</td>
</tr>
<tr>
<td>Step-by-step instructions tell students how to proceed throughout the experiment. All are expected to follow the same procedure.</td>
<td>Students must think about and decide upon how they will proceed with the experimental portion of their inquiry.</td>
</tr>
<tr>
<td>Revision of procedural steps is neither suggested nor recommended.</td>
<td>The need to revise procedural steps is likely and is seen as the norm.</td>
</tr>
<tr>
<td>Adequate time and materials needed to allow lab groups the opportunity to carry out the experiment more than once is the exception.</td>
<td>Adequate time and materials are provided and lab groups are encouraged to try a number of experimental designs.</td>
</tr>
<tr>
<td>Documentation of the lab consists of rewriting much of what is seen in the lab manual beforehand and filling in an observation table during the lab. Documentation of procedural “mistakes” is not required.</td>
<td>Ongoing documentation is done through digital photography and written word. All aspects of lab work are to be documented including those aspects which do not necessarily result in answering the questions posed, but do help to guide the work of the research team.</td>
</tr>
<tr>
<td>Presentation of experimental procedure and findings is done through a traditional lab write-up that includes the following: title, lab partners, purpose, hypothesis, procedure, observations, conclusion, and discussion questions.</td>
<td>Presentation of experimental procedure and findings is done through the creation of a comic book designed to tell the comprehensive and unique story of the research teams’ inquiry into osmosis and diffusion.</td>
</tr>
<tr>
<td>Individual lab write-ups (one/student) are handed into the teacher and are corrected using criteria that are established by the teacher.</td>
<td>Team lab reports are collected by the teacher and graded based upon a rubric created collaboratively by the students and the teacher.</td>
</tr>
</tbody>
</table>
| Extension and application of concepts studied is done by individuals answering discussion questions that have been posed by the teacher. Discussion questions are handed into the teacher | Extension and application of concepts is done through internet/book research which is guided by the interests of the individual research groups. This broader application is then presented to the
and corrected using an answer key. The class and the presentation is graded using a rubric created collaboratively by the students and the teacher.

| Time for students to reflect upon their individual experiences with regards to lab skills, confidence within the lab setting, group skills, the nature of science, etc. is not a focus and is not formally encouraged by the teacher. | Time for students to reflect upon their individual experiences with regards to lab skills, confidence within the lab setting, group skills, the nature of science, etc. is a focus and is purposefully facilitated by the teacher. |

and racks, hotplates, paper towels, and electronic scales. I did not give them any information about how these materials would interact with each other, but rather left that goal as one of the tasks they would discover as a team.

Having recently been introduced to the computer program Comic Life\(^1\) I suggested to the teams that creating a comic book style lab report, using Comic Life, rather than a traditional lab write-up, might be a more interesting and engaging way to document and share their work. I told them that to use Comic Life they would need to create a record of their work by taking digital photographs. Students liked this idea and were eager to give it a try.

Teams were informed that even though their lab report would be in the style of a comic book it would still need to provide an overview of the typical aspects of lab work (lab partners, purpose, hypothesis, materials, procedural steps, findings and conclusions) while at the same time telling the story of the highs and the lows, the trials, the *failed* experiments, the revelations, the breakthroughs, and the discoveries that their team made along the way. I also encouraged them to think about why it would be just as important to document

\(^1\)Comic Life is computer program created by plasq that allows the user to create comic books using their own digital photographs.  [http://comiclife.com/](http://comiclife.com/)
and pay heed to what went wrong in their inquiry as it would be to document and pay heed to what went right.

Having informed my students of the inside-out experimental procedures and lab report, I had only one more inside-out aspect of the lab to share. Compared to the independence, flexibility, and creativity being encouraged by the rest of the inquiry the discussion questions that accompanied the traditional lab now seemed not only rigid, but also simplistic. Acknowledging these shortcomings led me to consider other ways that students might demonstrate their understanding of the concepts in question. This reflection led to what I refer to as the “Broader Application Presentation”.

I told the teams that to meet the requirements of the Broader Application Presentation they would be required to share with their classmates an osmosis- or diffusion-dependent process (broader application) that occurs within a living organism. To do so research team members would have to work together: to decide upon the topic of their broader application; to carry out the necessary research; to create a PowerPoint presentation which explained how their broader application relied on either the process of osmosis or diffusion; and finally to present an overview of their experimental design and findings along with their broader application to both their classmates and myself.

While the length of the inquiry activity met the recommendation put forth by Saskatchewan Learning (1992) that some of the activities in Biology 30 “should be relatively long-term investigation of phenomena” (p. 81) I did feel
the need to help my students to manage their time wisely. Consequently, I provided students with a timeline, to use as a guide, so that they could complete all aspects of the Inquiry into Osmosis and Diffusion within the time allotted (see Appendix A).

**Assessment for the Osmosis/Diffusion Inquiry**

In the past, once my students had completed the traditional osmosis/diffusion lab activity, correcting answers to the lab discussion questions had served as my main means of assessing what they had learned. However, once the traditional osmosis/diffusion lab had been turned inside-out it became evident that I would need some new assessment tools as my students were now demonstrating behaviors, creating products and displaying a depth of understanding I had not seen before in my Biology 30 lab setting. My students and I collaborated to create rubrics that they could use to critique their Comic Life lab reports (see an example in Appendix B) and Broader Application presentations (see Appendix C) and I would use to evaluate them. In addition, students also had the opportunity to evaluate fellow research team members using a class created rating scale which focused on individuals’ participation and sharing of the workload within the team (see Appendix D). Finally, students were evaluated independently by means of an assessment tool that I created and graded, entitled “Osmosis/Diffusion Individual Wrap-up Assignment” (see Appendix E). Within a short time, assessment of the inquiry became as multifaceted as the inquiry activity itself.
CHAPTER 4: OUR STORIES AND MY ANALYSIS OF THEM

The following chapter recounts the experiences had and insights made by my students and myself as we ventured together into The Osmosis/Diffusion Inquiry. The content of the chapter has been organized into four different sections.

The first section, *New knowledge is often built upon already existing knowledge*, describes how I used knowledge gained from past teaching experiences as the basis for creating a new inquiry activity. As well, in this first section students describe how their own background research played a role in shaping their inquiry investigations. In the second section, *The purpose of playful exploration*, students speak of their playful approach to learning about how laboratory materials could be used to demonstrate osmosis and diffusion and I explore the impact that a playful approach can have on student behaviors, attitudes, and learning outcomes. The third section *Inquiry activities versus traditional experiments*, cites student feedback as they compare the self-directed approach of the inquiry to the scripted approach of a traditional lab. In this section students’ reflect on both approaches and share their opinions regarding which approach they feel offers them the best opportunity for learning, for retaining new knowledge, and for understanding and experiencing the nature of science. The final section, *Alternative approaches to laboratory assessment and evaluation*, explores the value of having students present the knowledge they have attained through laboratory
activities in ways different from the traditional discussion questions and formal lab write-up.

In addition to the chapter having these four distinct sections, each section is, in turn, made up of three interwoven parts. The portions titled “My Story” are my personal narratives consisting of observations and reflections made before, during and after the implementation of the Osmosis/Diffusion Inquiry. Another aspect of each section is the student narrative. These narrative reflections are excerpts from the “Independent Wrap-up Assignment” (see Appendix E) that each student completed at the close of the inquiry. In some cases these narratives are grouped, as my “Students’ Stories”, and in other cases they are integrated into the final aspect of each section; the analysis. In the analysis portion of each section I attempt to make sense of what I observed, in conjunction with my students’ reflections on their learning experiences and research literature that I used to inform my own discussion.

It is also important to note that the student research participants in this study were members of a Biology 30 course that I taught at Lakeview High School, an average size high school in the city of Regina. The participants are representative of a wide socio-economic demographic; they demonstrated diverse interests in both academics and extracurricular activities; and they displayed a wide range of interest levels and aptitudes for the course. In other words, the participants are similar to the diverse range of students that I teach each year. Student responses were elicited using the Independent Wrap-up Assignment. This assignment was designed to give students the opportunity to
reflect on their own learning experience with The Osmosis/Diffusion Inquiry and to share these reflections with me. I told my students that there were no wrong answers to the questions that asked for their thoughts and opinions regarding their learning and the inquiry process. I impressed upon them that I would be using their feedback to inform my teaching practice which would in turn influence how I taught future students. As a result, it was important that they tell me what they really thought to be true not what they thought I wanted to hear.

New Knowledge is built upon Existing Knowledge

My Story

When I have something that I need to mull over and figure out, but I don’t have the time it dedicate to it during the day, I often resort to sleeping on it and if all goes well I wake with what I think may be the solution. Well, this is exactly what happened during the fall semester of 2008.

My Biology 30 class was fast approaching the point in the course where the concepts of osmosis and diffusion would be taught and this meant that I would need to make a decision about whether or not I was going to have my students do my usual traditional Osmosis/Diffusion Lab. The lab was designed to allow students to investigate the movement of molecules through a semi-permeable membrane and in past years I had had my students complete the traditional lab activity. Over time, however, I had become disillusioned by what I saw as the activity’s inability to help my students gain a deeper understanding of the concepts of osmosis and diffusion, let alone their understanding of certain procedural steps and techniques. The flaw of the traditional lab lay in the fact that students could easily follow the lab’s procedure and achieve the desired results while at the same time demonstrating very little understanding of the lab’s purpose, procedures and findings. This lack of understanding was demonstrated by the fact that students were often unable to discuss the rationale behind certain procedural steps, appreciate the significance of their findings, or relate the concepts of osmosis and diffusion to processes found within living organisms. Simply stated, my students could carry out the traditional Osmosis/Diffusion Lab Activity whilst never fully engaging in the learning process.

Frustrated by what seemed to be a poor use of class time one semester I chose not to do the lab activity at all. The next semester, thinking that a more guided approach would allow me to draw my students’ attention to key aspects of the lab, I decided to bring it back as a demonstration and discussion lesson. I soon found,
however, that student attentiveness waned quickly and learning outcomes did not improve. In addition, removing one of the already limited Biology 30 lab activities did not sit well with me.

Finding neither of these methods for teaching osmosis and diffusion particularly favorable, I decided to sleep on it. And so it was, in the wee hours of the night, that the inquiry into osmosis and diffusion was conceived. Having successfully turned a number of traditional science nine and ten labs inside-out to create inquiry activities I began to reason that I should be able to do the same with the Osmosis/Diffusion Lab. What if I simply supplied my students with the same materials that were used in the traditional lab and challenged them to demonstrate the processes of osmosis and diffusion without assistance from either a lab procedure or myself? This would leave my students with no alternative but to engage in the activity and think their way through it if they were to be successful.

That morning I decided to share this idea with my students and ask them if they would like to give it a try. I told them that I had a very good feeling that this approach would achieve what the others had not. Since they would have to design their own experiments, analyze and make meaning of their own findings and draw their own conclusions, they would have to know what they were doing! Because I was presenting them with an inquiry that was far more demanding than the ones I had them do in Science 9 or 10, I readied myself to answer a lot of questions and concerns. To my surprise, other than a question about how long they would have to do the inquiry, my students were willing to give it a try.

My belief that the traditional osmosis/diffusion lab could successfully be converted into an inquiry did not come out of the blue but rather was rooted in the knowledge that I had successfully converted a number of traditional Science 9 and Science 10 labs into inquiry activities by turning them inside-out. Therefore, encouraged by the success that my junior science students were experiencing by learning science through inquiry, I decided to extend the use of inquiry learning into my Biology 30 program. That semester I engaged my Biology 30 students in a full-inquiry laboratory experience into the concepts of osmosis and diffusion.
Students’ Stories

Prior to beginning the experimental portion the inquiry I gave students one class period to conduct some background research on the terms osmosis and diffusion as well as on the different materials that I was providing for their experiments. I asked the students to reflect on the quality of their background research and its impact on the experimental portion of their inquiry.

Natalie

More often than not, labs or assignments are given when there is no preexisting knowledge, and if there is we are solely basing our work from knowledge that has been given to us. I personally believe that this knowledge that was asked of us to learn helped immensely when we began to start our lab. I felt that because we ourselves had to learn and research, the understanding of the lab was 100% better and stronger.

Natalie’s comment regarding the lack or type of preexisting knowledge that proceeds a traditional lab activity gives me insight into what she perceives as a disconnect between what is learned in the lessons preceding the activity and the lab activity itself. The fact that Natalie has alluded to this disconnect does not surprise me as I often noticed this same divide when students did not recognize traditional lab activities as hands-on explorations of the concepts introduced in previous lessons. Students, however, did have preexisting knowledge of the concepts being investigated by the activities, garnered either from within the course itself or from lived experiences. Nevertheless, students often did not make the connection between the two. Even after I recognized my student’s lack of transference and took the time to help them make these connections, engagement in activities still did not improve student
understanding of the concepts being studied and their ability to discuss experimental techniques and procedures used within the lab activities did not improve.

To gain some insight into this phenomenon I am again drawn to Natalie’s words. I wonder if there is some connection between the perceived lack of foundational knowledge that Natalie experienced as she embarked on a traditional lab activity and my experience that students often did not see the connection between the concepts presented in previous lessons and the traditional lab activities which were designed to reinforce the concepts. Rereading what Natalie has written regarding knowledge, I find her choice of vocabulary interesting. Natalie refers to the preexisting knowledge she bases traditional lab work on as “knowledge that has been given to us”, while she describes her research acquired knowledge for the inquiry lab activity as “knowledge that was asked of us to learn”. Natalie makes it known that she is not only aware of two distinctly different views of knowledge—one that views knowledge as something that can be dispensed by the teacher and another, which views knowledge as something to be actively acquired by the student—but she also makes a personal judgment about which type of knowledge she finds more useful stating that the latter type of knowledge “helped immensely”. Natalie makes it clear that by conducting her own background research she was able to construct for herself a purpose for the work ahead of her.
Allison

My group and I completed our background research, but didn’t really apply it to the experiment at hand before we began “creating”. Instead of working with the information we found, we decided to just start trying to put the puzzle pieces together with what information we knew. The previous information also didn’t seem to make much sense when we read it, but once we actually started working with our materials it all started to come together and make sense. I do believe that by reading what each material did before hand, we would have saved a little bit of time during the experiment, but by doing it the way we did, we got a better understanding of how it all worked, as well as how it all came together.

Allison noted that even though her team had completed the background research they were unable to understand its relevance until after they had begun to work with the materials. In hindsight Allison speculates that if she and her team had made more use of their background research from the start they could have saved time during the experimental portion of their inquiry. It may have changed their approach and it may have taken less time. I do not believe that teaching strategies or approaches should be evaluated on the grounds of how long it takes to accomplish the task. If this were so, I certainly would not engage my students in the Osmosis and Diffusion Inquiry as this particular inquiry took longer to complete than its traditional counterpart. Rather, lessons and activities should be assessed on whether or not they provide students with the necessary time, space and opportunity to make sense out of and to construct for themselves a personal understanding of the concepts being studied. As for Allison’s team, regardless of whether or not they could have saved some time during their inquiry, Allison appreciated that the approach
they took really enabled them to understand what they had done, and understanding is of utmost importance.

Courtney
Due to the fact that our background knowledge was thorough we were able to have a better understanding of where to start our lab. The beginning stages of our lab were slow moving but with the information we had already obtained we were able to better grasp where to start with each concept. Without the background research we did, I could easily conclude that we would have no idea where to begin. Our research became a type of road map for directing us where to go.

Reading what Courtney has written we see the background research having yet another impact on a team’s work. Courtney states that the thoroughness of her team’s background research deepened their understanding of the concepts and materials and that this knowledge was then purposefully used to initiate and direct their lab work.

Paying attention to the three different descriptions of how these teams used their background research we are able to catch a glimpse at how the construction of knowledge does not follow a linear path—research, read, learn, know—but rather is a complex journey. We can also come to appreciate that there are many ways for students to reach a point of knowing. Some routes may appear to be quite direct while others may be the product of many intersecting roads and round-a-bouts; no one way is best.

The Purpose of Playful Exploration

My Story
As my students used the computers to conduct their background research I quickly began to notice that some of the teams’ information was quite thin; amounting to not much more than Wikipedia definitions of the terms. Knowing that this type of information would not be enough to help them understand how the
materials could work together to allow them to design experiments that demonstrated osmosis and diffusion I encouraged them to do what I called “deep research” – research that took them beyond simple definitions to a point where they would discover the connections between different materials.

Touching base with the teams throughout the hour I could see that some were starting to find these connections and were planning on testing their ideas in class the next day. However, other teams seemed content to end their background research session with just the definitions.

Anticipating that the teams with the shallow background research would—once they discovered they had very little information to work with—be begging for more computer time I booked out some laptops and took them to my classroom. As expected, the next day while some teams began creating mini experiments to test their ideas, the teams who had conducted rather superficial background research were stumped. Being prepared for this I offered these teams the use of the computers so that they could delve a little deeper but, to my surprise, no team took me up on my offer.

A few minutes later I saw a team, that I considered to be the least prepared, conducting some experiments. I approached them and asked what they were doing and they told me that they were “just trying some stuff”. When I asked them what they were trying they shrugged their shoulders and told me again that they were “just trying stuff”. Knowing that the “stuff” they were “just trying” would yield them some good information I smiled and left them alone to continue trying stuff.

As I walked from team to team asking them what they were doing and how they knew what to do I realized that many of the teams, even those with quite good background information had tossed it aside and were opting instead to “just try stuff”. Shaking my head and laughing to myself—at myself—I thought, “Of course you are! You’re playing!”

With this new understanding I returned to a team that was struggling with where to start and said to them, “Don’t let yourselves become paralyzed by the fear of making a mistake. There is no one way to do this, if you’ve got an idea just run with it”. To which one of the girls responded, “Fine then. If no one else is going to do an experiment then I will!” and with these words they were off.

During a discussion with Patrick Lewis, which occurred after the research data had been collected, it was suggested that the word play was not theoretically the correct term to use to describe my student’s actions, rather the terms exploration or playful exploration would be more appropriate.
Consequently, even though student narratives contain the words “play” and “playing” the behaviors being described are characteristic of those that Johnson, Christie and Wardle (2005) attribute to the play-related behavior, *exploration*. Exploration, they state, is similar to play “in that they are both intrinsically motivated behaviors and are not directed by external goals” (Johnson *et al*, 2005, p. 17). However, they go on to distinguish between the two by stating that:

> ... exploration is a stimulus-dominated behavior that is concerned with acquiring information about objects and situations. It is controlled by the stimulus characteristics of what is being explored. Play, on the other hand, is organism-dominated behavior, governed by the needs and wishes of the player. Play is concerned with generating stimulation rather than with gaining information. (p. 18)

Here we see that while play and exploration have some distinctly different characteristics they are closely related.

**Students’ Stories**

Fascinated by my students’ use of playful exploration as a way of acquiring experience I was interested in gaining some insight into their reasons for choosing it as a way of advancing their knowledge. To this end I asked them to reflect on the role that their play-like approach to the inquiry served for themselves and/or their team. Because of the close relationship between exploration and play, it is not surprising that the behaviors and feelings students write about in their narratives are similar to those observed in and expressed by children at play.

*Allie*

It [playful exploration] gave us a sense of what the materials were and even gave us different ideas that we could work with. It also took
a lot of the stress off of the actual lab itself, it made us know that we don’t have to take things too seriously and can still have fun. Because sometimes when you are just ‘playing’ with something you can come up with something good.

Allie comments that the playful approach her team took to exploring the materials not only allowed her team to generate ideas, but their approach also reduced the stress she may have otherwise felt. Johnson et al.’s (2005) description of play as activity that “liberates us for a time from the ... stress and anxiety that come from ... having to meet the demands of reality or master developmental tasks ” (p. 13) helps us understand why the playful approach Allie’s team took, when exploring the laboratory’s materials, was less stressful.

**Sally**  
While we were fooling around with our materials initially, we were also thinking of how to begin our experiment. This ‘playing’ allowed us to brainstorm and let ideas come to us. Many times this ‘playing’ led to an important discovery.

Sally, like Allie, reflects upon how her team’s playful approach to exploring the materials resulted in the generation of ideas for the experimental portion of the inquiry. She goes on to say that discoveries were made in this fashion as well. Once again Johnson et al’s (2005) description of play, as being important to “imaginativeness and creative problem solving,” (p. 13) parallels the students’ descriptions of their initial stages of the inquiry activity.

**Michelle**  
‘Playing’ with the materials allowed us indirectly to discover what we were supposed to do with the materials, and gave us the freedom to explore what we were supposed to be doing. I found that once we were well acquainted with our materials we were less afraid to try different experiments and were more confident in our intuition. This
'play' enabled my team to feel secure in our thinking, and to have a positive outlook on the rest of the experiment.

Michelle uses the word freedom when discussing her experience of playing with the materials and says that this sense of freedom led to her team feeling secure and positive. Johnson et al’s (2005) assertion that a playful approach results in “feeling a certain freeness of spirit” which allows one to achieve a sense “being in control” and enables one to “perform self-initiated behaviors” (p. 13) echoes Michelle’s experience.

While student research teams may not have been, theoretical, engaged in play, the approach taken during the initial exploratory stages of their inquiries does reflect the intellectual play Bruner (1996) alludes to when writing, “En route to producing testable hypotheses, we play with ideas” (p. 126). In addition, this intellectual play produced emotional responses often associated with more common notions of play as Allie, Sally and Michelle report that the experience was a relaxing, fun, freeing and creative approach to a laboratory work.

Reading student responses it becomes clear that playful exploration served an important role in the students’ inquiry process. However, there is a sense that some students viewed the play process as the less rigorous precursor to the experimental portion of their inquiry; that the insights made through playful exploration were important but only in so far as being able to provide themselves with the information needed to design their experiments. And that with the designing and carrying out of the experiments the more serious work
portion of their inquiries would begin. What is interesting, however, is that the “fooling around”, reported by Sally and the “just playing” portion of the inquiry, that Allie spoke of, often resulted in teams at least partially achieving goals of the inquiry—to demonstrate the processes of osmosis and diffusion. As a result, the seemingly more contemplative and deliberate experimental aspects of the inquiry were sometimes rendered unnecessary.

Why is it then that some students’ stories portray playful exploration as a less valued way of constructing knowledge and deepening their understanding of scientific phenomena when compared to experimenting? What gives rise to the idea that exploration (trial and error) and working (carrying out designed experiments) occupy two different planes on the learning hierarchy? And at which point then did play end and work begin? To get some insight into this phenomenon I have turned to literature regarding the ideas of work and play as seen through the lens of education.

Rieber (1996) sheds some light on why play is often viewed in schools as a lower form or approach to learning and I have used his research to shed light on why my students may be reflecting this view in their stories. He says that:

Perhaps it is because the word play can invoke so many misconceptions. For example, play is traditionally viewed as applying to only young children. Play seems to be something that you have to give up when you grow up... Work is respectable, play is not. Another misconception is that play is easy (and) that the activity of play is irrelevant or inconsequential to either formal or informal learning. (Rieber, 2011, p. 43-45)

Rieber goes on to say that different eras (WW II, the Space Race), with their different political agendas, have had an impact on the philosophical views
of education and on society’s attitude towards play. “In one era, play can be viewed as a productive and natural means of engaging children in problem solving and knowledge construction, but in another era it can be viewed as a wasteful diversion from a child’s studies” (Rieber, 1996, p.45). With such opposing viewpoints it is understandable that students, who are products of an educational system whose stance on the play versus work continuum is vague, would be unsure of how to value the knowledge they constructed during playful pursuits. Johnson et al (2005) unite the concepts of work and play stating “good lessons and good learning are deadly serious but very playful at the same time” (p. 12) and continue by citing the work of Elkind who “points out that play is not the opposite of work. Play and work are complimentary parts” (p. 12).

In their article *Revisiting Play: Analyzing and Articulating Acts of Inquiry*, Youngquist and Pataray-Ching (2004) discuss the fact that the word *play* is often seen by society as a purely recreational pursuit. As a result it becomes difficult to use the term play in an academic setting where learning is to be rigorous, theoretically driven and curricularly meaningful (Youngquist & Pataray-Ching, 2004). With this limitation in mind they saw the need to describe the play they were observing in the classroom in a way that could communicate to others its rich educational focus. The play they witnessed was “an enjoyable, self-amusing activity … that resided within the child, controlled by the child’s acts, driven by the child’s motivations, … based on the child’s sense of reality … [was] personally and socially meaningful to the learner … and
every act of play contributed to the theories the learner [was] constructing” (Youngquist and Pataray-Ching, 2004, p. 172). The authors also make the point of stating, “once these factors are located externally ... these acts are no longer considered play” (p. 172). The following statements give us insight into how students perceived the work that they were doing at the onset of the inquiry.

**Laura**
Besides having fun before actually doing the lab, playing with the materials allowed us to know what to do and how they react with each other. It helped us know how to prepare the experiment and what to expect. It also served as a confirmation to what we found on the background research, that what we researched was actually true.

**Ella**
By allowing us to play with the materials, it gave us a chance to figure out the process on our own. It also allowed us to fully understand the concept that we were trying to achieve, because we had to figure the steps out by ourselves.

The similarities between the learning-rich play that Youngquist and Pataray-Ching witnessed and the playful exploration that my students describe are clear. In fact, I could have used the same words to describe what I was witnessing in my Biology 30 classroom as Youngquist and Pataray-Ching used to describe the play they observed at the preschool level.

To better communicate with public audiences about a type of academically rich play that allows children to construct new knowledge by thinking and acting in a critical and reflective manner Youngquist and Pataray-Ching (2011) chose to use the word *inquiry*. In retrospect, I have used the term inquiry to describe the overall teaching approach or strategy that I had taken
as a teacher; much like one would choose to teach through lecture or through worksheets. But here Youngquist and Pataray-Ching use the word inquiry to describe a type of academic learning where each *instance* is an individual act of inquiry. Armed with this new, less narrow view of the term inquiry I am able to see that my students’ playful exploration did not end and work did not begin, but rather that within the Osmosis/Diffusion Inquiry they were inseparable. This new understanding also confirms what was already well known to me; that the value of the knowledge acquired through the playful, trial-and-error approach was no less well-constructed than the knowledge they were constructing during their more purposefully designed experiments.

**Inquiry Activities Versus Traditional Experiments**

*My Story*

From the early stages of the Osmosis/Diffusion Inquiry it was apparent that the inquiry approach was providing my students with an opportunity to learn about more than just the concepts of osmosis and diffusion. As research teams worked on their inquiries it was obvious that this approach, not only required my students to understand the point of the investigation, but it also required them to think about what they were doing. Without traditional step-by-step instructions complete with their built in experimental designs and adherence to variables, controls, safety precautions, etc. my students were now responsible for seeing that these demands were being met.

Watching my students come into class each day and head straight to work on their inquiries was reaffirming my decision to transform the traditional osmosis/diffusion lab into an inquiry. Teams were often debating experimental designs, collecting data or assessing the results of experiments well before the bell to start class had rung. It was wonderful to see that my students were thoughtfully engaged in the learning process!

*Students’ Stories*

I began to wonder if my students were able to appreciate all the different learning opportunities that the inquiry was providing for them that
traditional lab activities might not. With this in mind I asked them to reflect on how the inquiry was different from traditional “recipe book” style experiment and to comment on 1) which approach they felt was more engaging, provided them with the better opportunity for learning, and would lead to greater retention of what they had learned; and 2) which approach they felt gave them a better understanding of the nature of science.

As I read and re-read student statements regarding these queries similarities began to surface. Some similarities were found in my students’ views of traditional lab activities and the lack of thinking that is required when carrying them out. Andrea states, “The recipe style labs that we’ve always been given are just like writing notes. … You know what you have to write down, but it doesn’t stay in your head long enough to be processed”. And Dave responds that, “The traditional method of being given steps and told what to do is easier but not the greatest learning experience. … I believe that learning from a step by step [traditional experiment] would allow me to memorize”. In both cases the students describe situations that seem more like rote learning experiences than the rich hands-on learning opportunities that teachers, engaging their students in laboratory activities, intend. Langer (2000) would likely characterize the students’ approaches to traditional lab activities as mindless.

Langer (2000) explains that:

... when we are in a state of mindlessness, we act like automatons who have been programmed to act according to the sense our behavior made in the past, rather than the present. ... We are stuck in a single, rigid
perspective, and we are oblivious to alternatives ways of knowing. ... our behavior is rule and routine governed. (p. 220)

Langer (2000) continues by stating that mindlessness can come about by two different means. The first and most common way of fostering mindlessness is through repetition of the same thing over and over again for in doing so “we come to rely on a mind-set for how to accomplish the goal” (Langer, 2000, p. 220). The second way to create mindlessness occurs when one is first exposed to information. “If when first given information we process it without questioning alternative ways the information could be understood, we take it in mindlessly” (Langer, 2000, p. 220). Each of the following student reflections typifies one of these paths towards mindlessness. Reflecting on her approach to traditional labs Natalie states, “To be honest, I tend to slack and or not do things that are repetitive” and Rebecca explains that, “When teachers give me a step by step procedure I don’t think for myself, as it is easier to simply shut off my mind and go through the motions.”

Understanding the circumstances by which mindless activity is born we are able to identify characteristics of traditional lab activities which make them particularly susceptible to mindless interaction by students instead of the mindfully engaging opportunities that educators are seeking to create and provide. With regard to mindlessness borne of repetition, it is not that individual traditional lab activities become mindless due to repetition, rather, I argue, that it is the student’s approach to traditional lab activities in general which becomes repetitive, routine and therefore mindless. If each traditional lab activity requires the same repetitive behavior of the student—to simply
follow the instructions provided—and students follow the instructions without question or revision, the conditions for cultivating mindlessness are exacerbated. Hence, the mindless activity that I often witnessed in my classroom during traditional lab activities and that my students have admitted to participating in carries on.

Reflecting on past students’ participation in the traditional osmosis/diffusion lab activity I can see that the going-through-the-motions approach to traditional lab activities as described by my students and the mindlessness described by Langer are one in the same. In all likelihood the students, with whom I had done the traditional osmosis/diffusion lab, had approached it in much the same way they had approached other traditional labs they had completed throughout their schooling. Consequently, they had fallen into a routine of copying down the outline, collecting their materials, following the procedure, recording the data, and then sitting down at their desks with analysis questions in front of them trying to make sense of what they had just done and why. In other words, the routineness of yet another traditional lab activity may have caused some of my students to become mindless.

One may question the problem with this type of approach if in the end students complete the traditional lab activity successfully in-so-far as they reach the correct conclusions. Langer (2000) states that the downfall of processing information mindlessly is that one commits “to a single way of understanding it even if it later would be to our advantage to view the
information differently” (p. 220 - 21). This statement is important for if it is true, and I believe it is, it sheds light on why students often cannot apply what they have learned during traditional lab activities to everyday experiences and phenomena. If a student can only make sense of the information within the narrow context of the lab activity itself opportunity to use the information in the future is limited.

Mindful Learning

Compared to comments made regarding traditional lab activities, student reflections concerning their level of engagement within the inquiry conveyed a distinctly different tone. Student engagement in his or her schoolwork is a complex and multifaceted phenomenon that Lewis (2007) states, “is generally defined in terms of three interrelated or intertwined dimensions” (p. 48). Lewis goes on to cite the work of Fredricks, Blumenfeld & Paris who in turn define the three dimensions as follows:

*Behavioral engagement* draws on the idea of participation; it includes involvement in academic and social or extracurricular activities and is considered crucial for achieving positive academic outcomes and preventing dropping out. *Emotional [or affective] engagement* encompasses positive and negative reactions to teachers, classmates, academics, and school and is presumed to create ties to an institution and influence willingness to do the work. Finally, *cognitive engagement* draws on the idea of investment; it incorporates thoughtfulness and willingness to exert the effort necessary to comprehend complex ideas and master difficult skills. (p. 48, emphasis in original)

Informed by these descriptions I began to see evidence of the three dimensions of engagement in the students’ statements. Steve writes:

The most rewarding moments were working together as we hypothesized what may happen, and of course the moment when we
realized that our idea actually worked. ... it was fun to challenge myself as I tried to come up with the solution to the problem along with Peter and Eric.

Steve’s statement leaves little doubt that he was not only intellectually challenged during the inquiry, but that he found working with his teammates to accomplish their goals to be enjoyable and rewarding—characteristics which speak to his high level of behavioral engagement.

The following statements made by Rebecca and Tara give us a sense of how emotionally engaged they were in their work. Rebecca’s drive and passion for her work is palpable in the following statement:

When you know what diffusion and osmosis are you have a desire to ... achieve the results showing that you made them occur. We were not going to take a break until it [osmosis and diffusion] occurred and the frustration from a failed attempted only got us more fired up and engaged. ... It made me feel as though I was more intelligent and mature using the inquiry method

Rebecca’s words allow us to understand that hard work, followed by failure and frustration did not result in negative feelings and a desire to give up, but rather resulted in her feeling empowered and becoming even more engrossed in her work.

Tara, in turn, reflects on how the inquiry approach to laboratory work required her to take on more responsibility. She reveals how increased responsibility influenced her work environment and touches on how this made her feel about her own abilities. Tara states:

The opportunity to participate in the inquiry was a good experience for me. ... We were put into a position where we had a lot of
responsibility put on our shoulders to know what we were doing. It made me take more control in the assignment; it seemed more like my own. … There was less written information to constantly be looking at; it made it a more relaxing environment to work in … and I felt a lot smarter during the lab.

Contrary to what one might assume, the absence of a traditional lab procedure did not make Tara feel apprehensive, anxious or lost within the inquiry lab activity; rather the experience made her feel more in control, relaxed and smart. Michelle and Allie both echoed Tara’s positive emotional response to the working environment that emerged during the inquiry activity. Michelle states, “I find that I am able to learn well in a comfortable and relaxed atmosphere, and this lab was not only comfortable and relaxing, but it was also fun” and Allie responded that, “It was also a more fun experiment, because I got to think for myself”—a statement that is supported by Langer’s assertion that “mindful learning engages people in what they are learning, and the experience tends to be positive” (p. 222).

The following reflection by Erin speaks quite directly to the depth of her cognitive engagement as she states:

This is the coolest way to learn I think, because to me, learning is asking questions and finding answers, which is exactly what the inquiry provided me with the opportunity to do. [It] forced me to ask my own questions and provide my own answers rather than being told what to do. … We got the chance to shape our own learning to our own curiosity. … With having no direction as to what steps to take, I had to critically think and manage my time wisely, which teaches students self-discipline to stay on task. … The inquiry made me feel like a teacher believed in me that I could actually do something on my own. Doing the experiment myself promoted a great deal of intellectual growth in me.
Reading Erin’s statement it is clear that she felt the inquiry activity *forced* her to ask questions and provide her own answers and that participation in the inquiry *challenged* her to think critically, manage her time, and stay on task and in light of all of this responsibility she still viewed the inquiry as an *opportunity* that left her feeling that I, her teacher, *believed* in her. Erin’s statement leaves little doubt that she was truly cognitively invested in her work and willing to exert the effort necessary to achieve the goals of the inquiry.

Reading student statements such as the ones above and many others, it became apparent that the inquiry approach to the lab activity elicited from my students a deeper level of engagement in their work. This in turn resulted in providing a substantially richer learning experience than that provided by the traditional version of the activity. Dave compares the potential for learning through traditional means to the learning that can be achieved using inquiry-learning methods in the following statement:

*Given freedom and minimal instructions on this experiment allowed me to use my knowledge and my problem solving skills to figure out the experiment.*

*I believe learning from a step by step [traditional experiment] would allow me to memorize the material but for me to comprehend what is going on and retain and recall the information completing the assignment with minimal instruction is best ... as I have to put more effort into the experiment and have to think more thoroughly into working out the task.*
In addition to citing that the inquiry approach required him to become deeply engaged in his learning, Dave also touches on how he feels that learning concepts using inquiry approaches increases his ability to retain and recall the information at a later date; this sentiment was shared by many of his classmates and is explored in the following paragraphs.

When asked to comment on which approach (traditional or inquiry) they believed would increase the chances that they would learn the concepts and once learned that they would be able to retain them, the students chose the inquiry lab method over the traditional method one-hundred percent of the time. Furthermore, students cited the opportunity to engage in trial and error methods of experimentation as an important aspect of the inquiry, saying that it contributed to an increase in both their understanding of the concepts in question and their ability to retain the knowledge for future use. Michelle states that:

I think that the inquiry that I have just completed has provided me with a better opportunity for learning about the scientific concepts in questions ... in comparison to that of a recipe-book style experiment. ... Personally experimenting allowed me to learn what would and would not work and I feel that this is a method that helps me to remember and learn more in contrast to being told what to do in a systematic experiment.

This process allows room for the students to make mistakes first hand and to learn directly from them ... and in the end [I] came out with the outcome I desired solely based on my perseverance. ... I feel that this discovery is exciting, and due to its excitement, the student is able to retain the information for longer.

Allie shares Michelle’s point of view on the value of trial and error
experimentation saying:

This lab would help me retain knowledge a lot more than a traditional lab would because I can learn things in my way, and not memorize … And I tend to retain knowledge better when I find something more interesting and a lot more fun. … It’s easier to wrap your head around something when you can use your own words, and you have a chance to try and even fail at it more than once. … You need the chance to learn things on your own and be able to work towards them. … I was able to start with basically no knowledge about this and end up with a lot of new things in my brain. … I accomplished it all on my own and I didn’t need to get the steps of what to do from a teacher … and the knowledge seems to stick in my brain better.

Andrea adds another dimension to the discussion as she speaks about the depth of thought and reflection that was required in order for her team to move forward with the experimentation process.

By making us think about what we had to do, it allowed our knowledge to sink in; because that’s all the information we had to work with. We had to apply what we were seeing and hearing each time we wanted to do something different. This made us think long and hard about how we were going to approach the experiments. The process of thinking things through allowed the information to be stored instead of going through one ear and out the other in a quick manner.

Tammie agrees with Andrea’s belief that the inquiry activity required a thoughtful approach to her work and stating:

I think that doing an inquiry lets you work your brain more and you will have to think about what you are doing. … After the project has ended I still think of ideas that we could have done … and I think that is a good thing because if it were a regular lab [activity] I would have forgotten about it already.
It is evident that by using the trial and error approach to explore the concepts of osmosis and diffusion research teams were able to learn that a failed experiment, in other words, one that did not yield the results they had expected was often more instructive than those that yielded the expected results (LaManna & Eason, 2011, p.228). Natalie wrote, “I didn’t find frustration in things not going ‘correct’ because I truly felt like for once, mistakes were okay. ... [We had] an opportunity to make mistakes and still learn from them, which improved our future findings”. It seems apparent that Natalie would agree with Bruner’s (1961) argument that employing a hypothetical mode (as opposed to a more didactic approach) in the classroom allows the student:

To go beyond the information [s]he has been given to generate additional ideas that can either be checked immediately from the experience or can, at least, be used as a basis for formulating reasonable hypotheses. ... the child is able to experience success and failure not as reward and punishment, but as information. ...[s]he can now treat success as indicating that [s]he is on the right track, failure as indicating [s]he is on the wrong one. (p. 408)

By approaching their work in a trial and error fashion my students were employing a constructivist approach to learning. von Glasersfeld (2001) describes the constructivist approach to learning as one in which the learners construct knowledge about their experiences in such a manner that they are able to incorporate new experiences and connect them to prior knowledge, while also being able to keep account of potential ways to use the information. Edmondson and Novak (1993) describe this type of learning as meaningful learning and explain that it “occurs when new information is linked with
existing concepts, and integrated into what the learner already understands” (p. 548). This more meaningful approach laboratory work not only resulted in my students being more behaviorally, emotionally, and cognitively engaged, which in turn, allowed them to achieve a deeper understanding of the concepts being studied, but it also reduced their stress levels within the lab setting; improved their self-esteem; and left them with the perception that their ability to retain their new knowledge and recall it in the future was improved.

In short, students statements made regarding their participation in the Osmosis/Diffusion Inquiry, which contain expressions of self-actualization, mindful participation in the processes of learning, and the construction of knowledge, are quite different from those my students made regarding participation in traditional lab activities.

Langer’s (2000) description of mindfulness provides a context for understanding the level of engagement, the depth of learning and the enjoyment that my students experienced as they worked their way through their inquiries. She describes mindfulness as “a flexible state of the mind in which we are actively engaged in the present, noticing new things and sensitive to context” (p. 220). Furthermore, “when we believe we are encountering something novel, we approach it mindfully” (p. 220). The following statement made by Natalie illustrates this view of mindfulness beautifully:

I was continuously engaged because I wanted to see the end result. I thought that this was extremely interesting and something that could benefit me, it seems to be knowledge that can be later applied.
As students worked their way through the inquiry they engaged in unique cycles of designing, experimenting, observing, and evaluating. All of these activities Langer cites as characteristics of mindfulness.

How is it that the inquiry approach resulted in a learning experience that was perceived by my students as being quite different from that attainable through traditional lab methods? In contrast to the outcomes and limitations of mindless learning, that were described earlier and are often inadvertently nurtured through traditional lab activities, a state of mindfulness was fostered during the inquiry. Bruner (1996) states that,

...instruction in science from the start to the finish should be mindful of the lively processes of science making, rather than being an account only of “finished science” as represented in the text book ... good science teachers in fact do just what I have been proposing: place emphasis on live science making rather than upon the achieved remains of, so to speak, already accomplished science. (p. 127)

The mindfulness that my students experienced relies directly on what Bruner calls for—the utilization of mindful approaches in science education. When this occurs the result is what Langer (2000) describes as an increase in competency, memory, creativity, and a decrease in stress—all of which my students professed to having experienced.

**The Nature of Science**

If one believes, as I do, that a fundamental goal of science education is to help “students understand the history and nature of science, including what science is, how it works and how it differs from other ways of knowing,” then we as educators must look to broaden our personal understanding of the nature of science and the breadth of our instructional methods in order to facilitate
student understanding of the true nature of science (Reeves, et al 2007, p. 31). This said, even though I had the desire to have my students come to a better understanding of the nature of science, prior to my introduction of the Osmosis/Diffusion Inquiry, I was not sure how this could be achieved. This is not to say that I had not emphasized the importance of variables, controls, accuracy in measuring, data collection and reporting of results, but these had always been inherent aspects of the traditional lab activity’s procedural steps and data tables. As a result my students themselves were not required to think much about these aspects of laboratory work and experimental design and were not given the opportunity to experience the ramifications of not employing proper techniques and skills. It was not until I witnessed the research teams’ blossoming appreciation for how science is done that I realized that experiencing and gaining a better understanding of the nature of scientific inquiry was not only an important aspect of science education, but also an attainable one.

With this in mind I asked my students to compare the Osmosis/Diffusion Inquiry with traditional lab activities they had done in the past and reflect on which they believed provided them with a better understanding of the nature of scientific work and why. Erin’s response was:

*Scientific work arises from a question or hypothesis a person has. Someone out there has to have the initial question that prompts him or her to make a discovery. A scientist isn't given a recipe that falls out of the sky! In the inquiry, I was the scientist, I had curiosities, and I was able to satisfy my questions independently.*
In her response Erin speaks about what initiates scientific work and reflects on how the inquiry approach to lab work resulted in a more authentic laboratory experience.

Laura’s reflection focuses on the imaginative nature of scientific work stating that:

The nature of scientific work involves use of creativity. This inquiry ... allowed us a stress-free atmosphere to be creative by leaving us lots of time to figure out how to show both osmosis and diffusion and providing us with all those materials.

In her response Laura acknowledges that the opportunity for her team to be creative and having ample time to nurture their creativity were aspects of the inquiry that resulted in her team accomplishing the challenge presented. Creativity—a concept not often associated with traditional high school science experiments—was in Laura’s opinion an important aspect of her inquiry.

Richmond (1984) writes that in the absence of a formulated approach to finding answers to their questions scientists often rely on creative intuition, otherwise known as imagination, to provide them with “novel ideas about reality as possible solutions to the problems of science. ... According to Karl Popper’s view of scientific discovery, new theories are discovered through creative acts of intuition. ... Creative insight provides theories for testing” (p. 83). This statement corroborates what Laura knows to be true and provides us with some important historical insight into the creative nature of science.

Natalie placed more emphasis on the analytical nature of science saying that, “Having to think critically made me understand the concepts more easily
and it helped me remember them better. It exposed me to how scientists must work through problems.” Not only does Natalie believe that thinking critically helped her to reach a deeper level of understanding, she also experienced an improvement in her ability to remember the concepts. Bruner (1961) attributes the effect of improved retention on evidence that shows that the “attitudes and activities that characterize figuring out or discovering things for oneself also seem to have the effect of making material more accessible in memory” (p.412). He goes on to explain that the new information “is more likely to be placed along routes that are connected to one’s own ways of intellectual travel” (Bruner, 1961, p. 412).

Megan was able to draw on the experiences she had within the inquiry lab to come to a better understanding of how scientists draw conclusions and shares this stating:

[The inquiry approach] makes us think about the materials we are using and what they should be used for. After seeing it react, instead of expecting a certain result like in normal labs, we had to apply our knowledge to determine what our results meant. ... We had to—like real scientists—make conclusions from our results.

It is apparent that participation in the inquiry gave Megan, and others, the opportunity to make discoveries and draw conclusions based on their discoveries. Bruner (1961) states that, “Practice in discovery for oneself teaches one to acquire information in a way that makes the information more readily viable in problem solving” (p. 406).

LaManna and Eason (2011) echo my desire to have students attain a truer sense of the nature of science and agree with my students that inquiry lab
activities are able to provide these opportunities whilst traditional labs are not.

Biology students often miss the excitement of discovery because they are assigned highly structured, “cookbook” laboratories, which tend to appeal to teachers and students because they are simple and usually “work” (i.e., the expected result is indeed the outcome). But often this kind of lab only verifies facts that are already known and, thus, results in no discovery, dulling students’ innate curiosity and giving them little opportunity to learn how science works. By contrast, an inquiry-based approach allows students to act as scientists. By devising their own hypotheses, designing and conducting their own experiments, and analyzing and presenting their results, students can improve their reasoning skills and ability to think innovatively. Practicing similar activities as scientists also helps students gain a deeper understanding of scientific inquiry. (p.228)

Bruner adds to the discussion by affirming that inquiry approaches in science not only allow for more authentic experiences of the nature of science, but adds that when “you make science classrooms more like the quirky worlds of working scientists—full of the humor of wild hypothesis, the exhilaration of unconventional procedure—the dividends in better performance are quickly evident” (p. 132). The inquiry allowed my students to experience that “not all that is learned through science is orderly and predictable. ... Real science, like any human activity, tends to be a little messy around the edges” (Martin, et al, 2009, p. 10).

**Alternative Approaches to Laboratory Assessment and Evaluation**

This portion of my thesis will focus on how creating the Comic Life lab write-up and the Broader Application PowerPoint presentation reinforced my students’ learning outcomes and challenged them to apply their newly acquired knowledge in new and more meaningful ways.
For the purpose of this discussion I will be using the following working definitions for the terms assessment and evaluation. The term assessment will refer to the formative, ongoing reflective appraisal of the research teams’ efforts and the products of those efforts as well as their budding shared and individual understandings of the concepts of osmosis and diffusion. In contrast, evaluation will refer to summative appraisals that will result in the assignment of a numerical value to the end products of the research groups’ and individual students’ efforts.

**Comic Life**

**My Story**

Presenting my idea of the Osmosis/Diffusion Inquiry to my students and having them agree to give it a try was easy. Coming up with a way for research teams to document and present their inquiries in a fashion that would allow their work to be shared with their classmates and that I could use to formally assess their learning, was not quite as easy. Having the teams produce a traditional-style lab write-up was a possibility; however, this idea was not sitting well with me. The traditional format seemed uninspired, somewhat pedestrian, and rather rigid alongside the inquiry which I was hoping would be a far more thought-provoking, unique and creative process. In addition, I knew that documenting their work by pen and paper would become quite tedious for my students and would likely result in reams of not overly interesting and perhaps not very insightful procedural steps which I would then have to assign a grade to.

Fortunately, just days prior to launching into the Osmosis/Diffusion Inquiry, a fellow grad student introduced me to the Comic Life computer program—an easy to use program that utilizes personal digital photos to create comic books. Upon introduction to Comic Life I felt that this approach would be an interesting and appropriate way for the research teams to document and present their inquiries. When I suggested the idea to my students they were again eager and willing to give it a try.

**Students’ Stories**

Almost as soon as the research teams began their inquiries I began to see a level of engagement and learning not witnessed during the traditional version
of the lab activity. Knowing that I wanted my students to have the opportunity to describe their work and their understanding of the concepts of osmosis and diffusion in as creative, self-directed and as meaningful a manner as they had approached their inquiries I decided to have the teams use Comic Life to create comic book lab reports which would tell the story of their inquiry.

The creation of the comic book was more involved and time consuming than a traditional lab write-up. The entire comic had to be created on the students’ home computers using a thirty-day free trial, as the program was not available on the school’s computers. With this in mind, I was interested in receiving student feedback as to whether or not they found value in reporting their work in the form of comic book rather than through the traditional lab write-up. Here is some of their feedback regarding the comic book inquiry reports.

As I read through the students’ responses regarding the Comic Life lab report it became evident that students viewed the making of the comic book lab report as a creative endeavor. Quite the opposite experience to preparing a traditional lab report, which some believed to be a mindless endeavor with a propensity to foster laziness in students. Steve states:

I think one main advantage about using Comic Life over a traditional lab write-up is how it affects the laziness of students. When writing out a standard lab write up, students often get lazy and bored while writing out the materials and directions, so much so that they get lazy on the part that really matters—the discussion questions.

Steve’s comment sheds light on why I often have traditional lab reports handed in which are void of any form of discussion or analysis of the findings. I
speculate that the mind numbing process of copying word for word from the *script* provided by the teacher leaves some students in a poor frame of mind to actually apply themselves during the aspects of the lab write-up that require more mindful attention.

Figure 1 - Example One of Student Lab Report with Comic Life

Adam’s response reinforces what Steve has said about laziness by providing examples of shortcuts students might take when preparing a traditional lab write-up:

The use of *Comic Life* gave us students a great way of showing off our creative sides. ... It also shows the teacher that the student knows what they’re doing so that they couldn’t just copy off someone else’s lab write-up or just scribble down a bunch of nonsense.
With regard to the link between assessment and the quality of learning, Novak, et al (2005) write that, “High-quality assessment can facilitate high-quality learning, but unfortunately, poor assessment can deter or prevent high quality learning and may reward performance that is deleterious to the learner in the long run” (p. 1). As a science teacher I have seen what Adam and Steve write about numerous times. The blatant copying, the large number of unanswered discussion questions, and the general poor quality of many traditional lab reports that I was correcting, were all reasons why I did not want the efforts of the student research teams to culminate in a traditional lab write-up.

Courtney’s response concurs with Adam’s as she speaks to Comic Life’s ability to engage teams in a creative, unique, and reflective process writing that:

The best part of creating the comic was that we were able to use our imaginations to create a story to go along with our experiments. When comparing this with a traditional lab write-up I would have to say that the comic book wins. I find that when simply writing out lab experiments I lose interest and do not find any significance in my findings.

Andrea states that:

Doing a formal lab write-up is very similar to that of recipe style lab instructions. Both have strict rules and guidelines that we have to follow. By allowing us to use the Comic Life program to present our findings, we were able to carry on with the freedom of figuring out things for ourselves, and at the same time, doing it in a fun manner. ... We ... had to talk about what we experienced ... [and] we really had to understand what we made happen before we could even try starting to explain it to someone else.
By stating that her team was able to “carry on with the freedom of figuring out things for” themselves, Andrea provides us with the understanding that her team’s inquiry did not end with the conclusion of the experimental portion of their work. Andrea continues by stressing that the creation of the comic book required them to really examine their understanding of the concepts and their procedural steps, as they had to make sure that they knew what had occurred during their inquiry before they could even start to explain it in the comic book.

Michelle echoes this sentiment stating:

I found it was a great deal more exciting to share my experience through the Comic Life program, in comparison to that of a lab write up. It was also easier to recall what my group had done in the course
of the lab as it was documented using photographs, and I was able to see the development of the lab as it progressed. I found this was a valuable method of reporting our information as we were able to present the information in an informal and fun manner. ... I think it is important to enjoy what you are doing in a class because I find that one often does a better job when the task at hand is enjoyed. ... Putting the comic book together allowed me to ... [do the lab] ... a second time. ... I felt that each time I began working on the comic book I was reliving the lab. ... although the second time only involved photographs. This was beneficial to me as it allowed me to continually recall what we had done, and it forced me to accurately describe our processes.

Michelle explains that working on the comic book was not only exciting and fun, but that gave her the opportunity to do the lab for a second time. Reviewing the photographs taken during the inquiry provided herself and her teammates the opportunity to relive the lab as they strove to accurately describe what they had done experimentally.

Michelle was not the only student who reported that using photographs of her team’s experiments helped her to recall and better understand their work. When reflecting on her experience of using Comic Life to document her team’s work Tara writes that:

I enjoyed using Comic Life better than the usual lab write-ups because it was less writing. Sometimes it helps to have fewer words and more graphics when you’re learning ... because it’s more to the point and easier to remember, it sticks in your head better!

Even though Michelle and Tara are not experts in the field of the mind or intelligence, their awareness of the impact that photographs had on their
ability to construct knowledge and recall information is in line with that of
cognitive scientist Donald Norman. Wandersee (2005) writes that:

Donald Norman ... claims that “cognitive artifacts” (units of key
information abstracted into representational form) comprise the basis of
human intellectual power. Since the majority of photographs taken
involve human choice, judgment, and framing ... photographs might be
considered “experiential artifacts” ... that allow biology students to
experience objects and events as if they were there, to see critical
features, to become informed about things that are otherwise
inaccessible to them, to reason about these objects, and sometimes to
make new discoveries using them. (p. 132)

If photographs, taken by a third person, of objects and events that exist or
have occurred elsewhere can provide biology students with the type of learning
opportunities described above, then one can only imagine the educational
impact that encouraging students, like Michelle and Tara, to create their own
experiential photographic artifacts could have on deepening the quality of the
students’ learning experiences.

Natalie’s feedback takes the discussion of photography as a learning tool
even further, telling us that creating the comic book bolstered her personal
learning style:

The way we presented our findings helped me to continuously learn
and visually remember our lab experiments. [Traditional lab write-ups]
don’t give a continuous visual image. I thought this was extremely
valuable as I am a visual learner and I always had an image to look
back on and relate to.

Presenting a graphic account of her team’s work was valuable to Natalie
as reviewing the photographs they had taken allowed her to continue to learn.
Keeping Michelle’s, Tara’s, and Natalie’s words in mind it is interesting to read
and draw parallels between what Wandersee (2005) says are the educational
impacts that life science photographs can have on student learning and what
the students have said their experiences were. He writes that photographs can:

1. Serve as a “shared workspace” for thinking about biological questions
   and issues
2. Provide external memory storage that maintains an accurate view of
   objects and events, and stores more information than human memory
   alone can store
3. Capture (freeze in time) the special arrangement of objects or events
   of interest
4. Provide the imagery necessary to anchor relevant concepts,
   principles, and theory in long-term memory
5. Serve as a primary, complementary, or redundant communication
   channel for learning biology. (p. 132)

Reading this list it is obvious that the students were quite right in
crediting the use of photographs with their enhanced ability to relive their
inquiry, to construct more meaning from it and to remember specific aspects of
it, but what is not so obvious is why. For insight into this phenomenon we can
look to the principle of dual coding which Wandersee (2005) explains “is the
principle which proposes that texts are processed and encoded in the verbal
systems [of the cerebral cortex] whereas pictures of graphics are processed
both in the image and verbal systems” (p. 132-133). This principle of dual
coding is the basis of a theory proposed by psychologist Allan Paivio that
explains how visual experiences are able to enhance learning (Wandersee,
2005). Paivio’s “research has shown that pictures contain information that is
not contained in text, that information shown in pictures is easier to recall
because it is encoded in both memory systems, not just text” (Wandersee,
2005, p. 133).
Mark’s response reiterates what others have said regarding the tedious, unimaginative nature of the traditional lab write-up, but he also brings forth the idea of the comic book as a narrative that opened the doors to the possibilities of both reflection on and assessment of the work:

The purpose of the Comic Life program is to tell a story. ... This process is much more effective than a formal lab write-up, which becomes tedious when the method is overdone. ... Personally, I found this method to be a valuable approach to analyzing the lab. Using the “storybook” allows the “characters” ... to reflect on their experiences. ... By doing this we can see where we were successful and determine some of the areas we were not so successful in.

Mark and his teammates, not only used the creation of the comic book as an opportunity to reflect on their experiences, but they also used it as an opportunity to engage in some self-assessment of their work. In their comic book they were able to note aspects of the inquiry they thought were successful and others they felt were less so.

Bruner (1996) describes narrative as a way of thinking, as a method for organizing knowledge, and as an instrument in the process of education, especially in science education. He goes on to say that, “A story has two sides to it: a sequence of events, and an implied evaluation of the events recounted” (Bruner, 1996, p. 121). Lewis (2007) summarizes these ideas stating that, “Narrative is at once a source of knowledge and a fundamental means of conveying that knowledge and experience” (p. 2). In light of the Bruner’s and Lewis’ words, it is important to note the high level of insight demonstrated by
Mark, as he reflects on the analytical and evaluative potential of storytelling as a learning strategy.

Figure 3 - Example of Student Lab Report showing details of Lab work with pictures and text

In addition to the reasons I stated in “My Story” at the beginning of this section, I chose to use Comic Life because I found the idea of students documenting their own work through photography to be quite intriguing. I have always used images as teaching tools, thinking as Wandersee (2005) does, “that a well chosen image can communicate ... [ideas] about the about the living world much better than words do” (p. 129). For years I have documented my students’ learning through photographs that I have posted for them to view and reflect on, but prior to being introduced to Comic Life I had not thought to
have my students take control of the camera. While I knew the research teams would be using their photographs to document and share their work with others, I had not anticipated the educational impact that the photographs would have on the learning experiences of the team members themselves. Student feedback regarding the use of Comic Life, allows us to appreciate that the creation of the comic book lab report was a deeply engaging and mindful exercise that allowed for self-assessment and the continued construction of knowledge.

**The Genesis of the Broader Application**

**My Story**

With Comic Life being seen as an acceptable means of communicating what the research teams had done I now had to figure out what to do about the discussion questions. Traditional lab activities’ discussion questions usually provide students with the opportunity to reflect on procedural steps and sometimes ask questions which challenge students to apply what they have learned in the lab to real life situations. By the time I had the opportunity to focus on this aspect of the inquiry my students were already so deeply involved in exploring how the materials worked together and designing experiments, that the thought of asking them to answer the original discussion questions seemed pointless. In fact the idea of asking them to answer any block of teacher generated questions seemed quite anticlimactic considering what they were accomplishing within their teams.

Then I had an idea. What if each team had to research and share, with their classmates and myself, a process within living tissue (plant or animal) that depended on either osmosis or diffusion to occur? I asked for my students’ attention, proposed my idea, they agreed to it and we now had the final aspect of the inquiry—the Broader Application. The next day a few students volunteered to help me create the evaluation rubrics which would be used to assign a final grade to both their comic books and the Broader Application and I now had a formal way of evaluating the research team’s knowledge and providing them with feedback.
Students’ Stories

In addition to the obvious immediate benefits of mindful learning, another benefit is the fact that material learned through mindful methods does not remain frozen “in one rigid perspective” (Langer, 2000, p. 222). As a result, Langer notes that the information is more readily available for students to use in relevant ways outside of the context in which it was learned (p. 222). This transferability of knowledge has not been shown to be characteristic of information obtained through traditional lab activities.

To illustrate this point the following is Adam’s reflection on his experience with chemistry lab activities compared to his experience with the Osmosis/Diffusion Inquiry. Adam writes:

One of the things that bothers me about chemistry [lab activities] is that we learn what the chemicals do when mixed but we don’t learn what the purpose or reason why these chemicals would be mixed in the first place. This lab experiment allowed us to discover things on our own, and then apply it to real life, so we fully understand the reason for us doing the experiment. Through the broader application I learned that osmosis and diffusion are used in almost all living organisms such as: frogs, slugs, plant roots and the blood stream.

Appreciating how demanding researching, creating the PowerPoint and presenting the Broader Application was compared to answering and handing in a few discussion questions, I again wanted my students’ feedback. I asked my students to reflect on whether or not the challenge of researching, creating and presenting a Broader Application helped to deepen their understanding of the concepts of osmosis and diffusion. As they did so, many students again compared the inquiry to traditional lab activities.
Steve contrasts his approach to completing discussion questions, with the approach necessitated by the Broader Application stating:

Instead of simply doing what was required of us in the [traditional] lab and rambling off half thought out answers in discussion questions, we were forced to understand why osmosis and diffusion occurred so we had a hope of presenting any real information on the PowerPoint.

Peter’s statement led me to infer that he views traditional labs as unengaging, obligatory tasks with little educational value.

Michelle comments on the transferability of information gleaned from traditional labs compared to the information she acquired during the inquiry adding:

In [traditional] labs, I often find that the conclusions are hard to relate to topics that are either relevant or applicable to me... so this lab was interesting because I had to apply it to daily life.

Figure 4 - Example of a Student Summary of Laboratory Experience
Statements such as these make me stop and wonder how many other students see traditional lab activities as they do; as perfunctory activities whose meaning and purpose is vague and whose products are of no real consequence.

Reading the comments made by Steve and Michelle regarding the Broader Application, I sense a different attitude towards this task. Steve reflects that in order for his team to present factual information he and his teammates had to make sure that they understood why osmosis and diffusion occurred—a commitment to learning and understanding not present when he spoke of answering traditional discussion questions. He also adds:

... having to apply the lab did challenge us to further investigate the concepts of osmosis and diffusion. ... Having to do additional research also provide ... information into the topic that I would not have known otherwise.

Michelle comments that:

Having to apply my new knowledge of osmosis and diffusion to a real life example helped deepen my understanding of the concepts. ... I enjoyed the freedom of researching a topic that I found personally interesting, as it enabled me to tailor my ... learning. ... In my research, I was forced to think logically about all the ways in which osmosis and diffusion apply in my life. ... When I am able to apply information directly to myself, I find I am able to retain the information for a longer period of time [and] I find that I am able to understand it better.

Michelle’s comments allow us to appreciate that creating the Broader Application presentation allowed her to internalize the learning process. Her motivation to delve deeper into the concepts of osmosis and diffusion and
apply her knowledge was empowered by positive feelings of enjoyment, choice, interest, understanding and personal relevance. Novak, et al (2005) provide insight into what Michelle experience stating, that knowledge stored in the human brain is associated to some degree with feelings. Subsequently, “successful application of knowledge depends not only on how much knowledge we have and how we organize it, but also on the feeling we associate with our knowledge” (Novak, et al, 2005, p. 9).

Allie’s reflection is a bit different from the others as it gives us some insight into her personal journey towards constructing an understanding of the concept of diffusion. Allie shares that:

*When I first started I didn’t know what diffusion was and when we did the lab I started grasping the idea. But when I started the PowerPoint everything kind of clicked, and it started making sense. To me it personally makes more sense if something is related to real life situations, and if I’m interested in learning about it. While doing the PowerPoint I had to apply my knowledge of diffusion to Diabetes, and it made me have to think and I know that it will stay longer with me because I had to do it on my own.*

At the onset of the inquiry Allie did not know what diffusion was and by the close of the experimental portion she had just begun to grasp the concept. Allie reports that it was not until she began to research her team’s Broader Application that the information she was gathering throughout the inquiry really started to come together and make sense to her. Allie’s experience illustrates that students who engage in meaningful learning are able to relate information gathered from a variety of sources and integrate it with what they
already know in an attempt to make meaning of it (Novak, et al, 2005).

Without the inclusion of the Broader Application it is possible that Allie would have concluded the inquiry with a less developed understanding of diffusion.

Figure 5 - Student Slide from a Power Point Presentation.

The comments made by Steve, Michelle, and Allie are evidence of learners who are interested in making meaning out of what they are doing in the classroom. Novak, et al (2005) states that, “Meaningful learning occurs when the learner seeks to relate new concepts and propositions to relevant existing concepts and propositions in his/her cognitive structures” (p. 3). In order for this development to occur these students tell us that they must be able to connect what is happening in the classroom to what they already know and have experienced in their everyday lives. In other words, their learning experience must be meaningful in order for meaningful learning to occur.
I share the epistemological belief “that all knowledge is constructed [or reconstructed if needed] from concepts and the relationships between concepts” (Novak, et al, 2005, p. 2). Bruner (1996) simply, but brilliantly states that coming to know something “includes conversation plus show-and-tell plus brooding on it all on one’s own” (p. 116). Student reflections regarding the educational impact of creating the comic book lab report and researching and presenting the Broader Application demonstrate what Novak, et al and Bruner maintain—that by giving students the time, encouragement, and the inclination they are able to construct for themselves new connections between concepts while at the same time reconstructing faulty conceptual frameworks. With each new link created, my students were able to build a more complex web of connections between their deeply engrained knowledge and these newer, less fixed understandings, thus increasing the chances that they would be able to retain and recall the information in the future.

It is clear that the Broader Application served as a way for students to both deepen their understanding of the concepts of osmosis and diffusion and bring relevance to their work. In addition the Broader Application also served as a tool by which I could evaluate the groups’ knowledge. Bruner (1996) states that, “One of the great triumphs of learning ... is to get things organized in your head in a way that permits you to know more than you ‘ought’ to” (p. 129). If students could organize and make sense of what they had observed during the experimental portion of the inquiry, find a real life examples of osmosis and
diffusion and use their understanding to accurately explain phenomena then I had evidence that they understood the concepts.

From past experiences with student inquiries I knew that it was best to try not to influence my students’ work. Even though I allowed myself to hover and assess student understanding through informal questions and conversations about their work, I was careful to not give advice or make suggestions about what they should do. Instead I took on the role of inquisitive observer, as I knew that the nature of the Osmosis/Diffusion Inquiry necessitated the need for informal student-initiated, self-, peer- and group-assessment. In reality, the success of the inquiry was both driven by and dependent upon the fact that students were engaged in a constant cycle of doing, observing, critiquing, assessing and reconsidering their own work and understanding as well as that of their research team as a whole. It was by engaging in this cycle that they were able to construct their knowledge of osmosis and diffusion that they would later use to explain the process of focus in their Broader Application. In other words, it was the cyclic process of assessment that allowed my students (both as individuals and as members of a team) to recognize their shortcomings in understanding, make adjustments to their experimental design, reconsider possible misconceptions, and apply their knowledge in meaningful ways.

Evaluation of the Comic Book lab write-up and the Broader Application presentation was done by myself using marking schemes that I created in partnership with my students (See Appendixes B and C). Initially a few students volunteered to help me to create them. Once we had drafts that we were
happy with we shared them with the rest of the class and some revisions were made. My students and I also felt that it was important to carry out peer evaluations of research team members. To that end, the peer evaluation was also created collaboratively (See Appendix E).

The Independent Wrap-up Assignment

The final aspect of evaluation for the Osmosis/Diffusion Inquiry activity was The Independent Wrap-up Assignment (See Appendix F). My initial intentions for this particular evaluation were two-fold: first for it to serve as a tool for collecting my research data for this paper, second to check for individual student understandings of the concepts of osmosis and diffusion. However, once I saw the value that it held for my students as an opportunity to engage in personal thinking about how they, as an individual, learn best I continued to use it as the final evaluation of the inquiry.

As the final aspect of this section on assessment and evaluation it is both prudent and appropriate to return to the words of my students. The last section of the Independent Wrap-up Assignment required my students to comment on (assess) their overall experience with the Osmosis/Diffusion Inquiry activity. Here is some of what they had to say.

Students’ Stories

Natalie

Amazing! This for me was extremely beneficial! I personally feel that for the first time in a long time I was able to complete a project well! There aren’t any other times during my high school life where I have felt okay with trial and error, along with little stress when completing a large project. This not only taught me the scientific aspects behind osmosis and diffusion but that the members you choose in a group are crucial. I would like to see
more science teachers take risks, and for once, let students explore their personal knowledge in their own ways.

**Adam**

Overall, I felt that participating in the inquiry was a very good and rewarding learning experience for me. I, along with my group members, was free to discover many ways of demonstrating osmosis and diffusion in a variety of creative ways. After we had successfully demonstrated osmosis and diffusion we were instructed to make a PowerPoint presentation on a broader application. ... We were able to use anything we could think of as long as we were able to demonstrate osmosis or diffusion in it. This was an excellent ... experience because there has been many occasions where teachers will tell you to make a presentation based on something that I really don’t care about, but this allowed us to choose something that we actually enjoyed researching. ... I thoroughly enjoyed this assignment; in fact it didn’t even feel like an assignment. This was one of the very few school assignments that I learned a lot and had fun doing at the same time.

Throughout the Independent Wrap-up Assignment students used words such as loved, exciting, fun, proud, relaxed, and motivated to express how and what they were feeling during the inquiry process. Novak, et al (2005) shed some light on the role that feelings play in one’s ability to learn:

> In so much of school assessment, emotion plays little or no role; strong feelings may even prove a liability ... emotions or feelings motivate. We seek to do those things that make us feel good, and we avoid those things that make us feel bad. If one of our goals is to make students more creative, more motivated to do something positive with their lives, then we face the challenge of using evaluation strategies that reward high levels of meaningful learning. (p. 9)

By reading the students’ comments about their experiences with the Osmosis/Diffusion Inquiry, it would seem reasonable to conclude that it not only elicited high levels of meaningful learning, but also provided assessment strategies and evaluation tools which could appropriately measure the learning.
Figure 6 - A Final Expression from the Student Data
CHAPTER 5: IMPLICATIONS AND CONCLUSIONS

Different Degrees of Inquiry

One focus of this thesis has been to share my journey as I created and introduced inquiry-learning activities into my teaching practice. Even though I consider the Osmosis-Diffusion Inquiry to be the most transformed inquiry activity I engage my students in (as every aspect of its traditional counterpart has been turned inside-out, making the investigation student-driven from beginning to end) some of the inquiry activities that I have created and used with my students are not. Depending on the learning objectives that are the focus of the inquiry in conjunction with the complexity of the procedural steps and attention to student safety it is necessary for some activities to be partial-inquiry activities. In fact, it should be recognized that the degree of structure provided by traditional labs can be especially valuable “at times, such as at the beginning of the school year, or when time is at a critical shortage, or when students have not had prior experience in designing labs on their own, or even when safety is an important issue, it may be more appropriate to provide students with a directed, hands-on laboratory experience” (Llewellyn, 2005, p. 91). Therefore, the purpose of this section is not to argue that science teachers should stop using traditional labs altogether, but rather to provide some guidance to teachers who are interested in transforming some of their existing traditional labs into investigations which take on a more inquiry-oriented approach.

Llewellyn (2005) cites the work of Colburn who wrote that:
... you don’t have to abandon these [cookbook] activities to make your teaching more inquiry-based. There is a middle ground between activities that are teacher directed and those that are almost totally student centered.’ The teacher’s understanding of instruction plays a key role in modifying labs. By making minor changes to the format and structure of the lab, teachers can provide a transition into inquiry-based learning, with more empowerment being granted to the students and with students developing more responsibility for their own learning. (p. 92)

Before a teacher can begin to transform her traditional activities into those with an inquiry focus she must possess an understanding of what inquiry learning involves.

According to the NRC [National Research Council], K-12 teachers of science must know that inquiry involves (a) the cognitive abilities that their students must develop; (b) an understanding of methods used by scientists to search for answers to their research questions; and (c) a variety of teaching strategies that help students to learn about scientific inquiry, develop their abilities of inquiry, and understand science concepts. (Barrow, 2006, p. 268)

To this end the NRC has created a table (see Table 2) in which statements describing traditional lab activities are juxtaposed against statements describing activities that promote inquiry learning. Using these statements science teachers could evaluate the compatibility of their own perspectives regarding the three domains of inquiry learning with those of the science reform movement (Barrow, 2006). This information could be particularly useful for teachers who want to better understand what is required in order for an activity to be considered inquiry learning.

The next table (see Table 3) created by Anderson (2001) is “an example of a descriptive framework used to categorize two different orientations (i.e., ones similar to inquiry and non-inquiry orientations)” (p.4). It was “developed
Table 2 - Changing Emphasis to Promote Inquiry (after Barrow, 2006, p.270)

<table>
<thead>
<tr>
<th>LESS EMPHASIS ON</th>
<th>MORE EMPHASIS ON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activities that demonstrate and verify science content</td>
<td>Activities that investigate and analyze science questions</td>
</tr>
<tr>
<td>Investigations confined to one class period</td>
<td>Investigations extended over periods of time</td>
</tr>
<tr>
<td>Process skills out of context</td>
<td>Process skills in context</td>
</tr>
<tr>
<td>Emphasis on individual process skills as observation or inference.</td>
<td>Understanding multiple process skills—manipulation, cognitive, procedural</td>
</tr>
<tr>
<td>Getting an answer</td>
<td>Using evidence and strategies for developing or revising an explanation</td>
</tr>
<tr>
<td>Science as exploration and experiment</td>
<td>Science as argument and explanation</td>
</tr>
<tr>
<td>Providing answers to questions about science content</td>
<td>Communicating science explanations</td>
</tr>
<tr>
<td>Individuals and groups of students analyzing and synthesizing data without defending a conclusion</td>
<td>Groups of students often analyzing and synthesizing data after defending conclusions</td>
</tr>
<tr>
<td>Doing few investigations in order to leave time to cover large amounts of content</td>
<td>Doing more investigations in order to develop understanding [sic], ability, values of inquiry and knowledge of science content</td>
</tr>
<tr>
<td>Concluding inquiries with the results of the experiment</td>
<td>Applying the results of experiments to scientific arguments and explanations</td>
</tr>
<tr>
<td>Management of materials and equipment</td>
<td>Management of ideas and information</td>
</tr>
<tr>
<td>Private communication of student ideas and conclusions to teacher</td>
<td>Public communication of student ideas and work to classmates</td>
</tr>
</tbody>
</table>

to describe classrooms ... where ... teachers were identified as teaching in accordance with the approaches of the new national standards in science” (Anderson, 2001, p.4). Using Table 3 educators could note the statements which pertain to their current teaching practices and thus quickly establish for themselves where their lessons fall within the traditional to reform pedagogy.
Table 3 - Traditional-Reform Pedagogy Continuum (after Anderson, 2002, p. 5)

<table>
<thead>
<tr>
<th>PREDOMINANCE OF OLD ORIENTATION</th>
<th>PREDOMINANCE OF NEW ORIENTATION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Teacher Role:</strong></td>
<td></td>
</tr>
<tr>
<td><strong>As dispense of knowledge</strong></td>
<td><strong>As coach and facilitator</strong></td>
</tr>
<tr>
<td>Transmits information</td>
<td>Helps students process info</td>
</tr>
<tr>
<td>Communicates with individuals</td>
<td>Communicates with groups</td>
</tr>
<tr>
<td>Directs student actions</td>
<td>Coaches student actions</td>
</tr>
<tr>
<td>Explains conceptual relationships</td>
<td>Facilitates student thinking</td>
</tr>
<tr>
<td>Teachers knowledge is static</td>
<td>Models the learning process</td>
</tr>
<tr>
<td>Directed use of textbook, etc.</td>
<td>Flexible use of materials</td>
</tr>
</tbody>
</table>

| **Student Role:**              |                                |
| **As passive receiver**        | **As self-directed learner**   |
| Records teacher’s information  | Processes information          |
| Memorizes information          | Interprets, explains, hypoth.  |
| Follows teacher directions     | Designs own activities         |
| Defers to teach as authority   | Shares authority for answers   |

| **Student Work:**              |                                |
| **Teacher -prescribed activities** | **Student-directed learning** |
| Completes worksheets           | Directs own learning           |
| All students complete same tasks | Tasks vary among students     |
| Teacher directs task           | Design and direct own tasks    |
| Absence of items on right      | Emphasizes reasoning, reading and writing for meaning, solving problems, building from existing cognitive structures, and explaining complex problems |

continuum.

Both Table 2 and Table 3 could prove valuable for teachers who are interested in comparing their current teaching practices and beliefs with those that are being called for by the current science education reform efforts.

These tables could provide teachers with the inspiration and the know-how to
(a) determine the level of inquiry within a particular activity, (b) convert some of their traditional labs into inquiry learning opportunities, and/or (c) create new activities that could provide students with inquiry learning opportunities.

**Transitioning from Traditional Labs toward Inquiry Learning**

I feel that the need for a transition from traditional lab activities to those that require full inquiry is necessary and should be carried out in a thoughtful and reflective manner. As a teacher who, over the past five years, has moved away from traditional types of lab activities towards full-inquiry approaches, I know that the progression does not occur in one easy step, with the one perfect activity.

Traditional lab activities hold certain degree of comfort that can be depended upon. When engaging my students in the structured, predictable, mono-didactic learning experiences of traditional labs I always knew what materials were needed, the safety precautions that had to be addressed, the procedural steps that I would have to demonstrate in advance, and exactly which discussion questions I should troubleshoot to head off any confusion. Leaving behind the comforts of these *knowns* can be difficult which is why using partial-inquiry activities to transition from traditional lab activities to full-inquiry activities can be helpful.

Handing over the reins to my students and allowing them to direct their own learning meant that I had to understand that they would take-up those reins and carry on and it also meant that my students had to trust that I was not abandoning them. In doing so I had to learn to walk away and they had to
learn that they did not need me to tell them what to do. Over the past five years, I have come to realize that no matter how convoluted my students’ approach to an inquiry lab activity may appear to me that it is through these unique approaches that they are able to construct their own knowledge. I still find that I sometimes have to physically remove myself from my students’ busyness so that I don’t jump in and ruin the opportunities for discovery that they are creating for themselves.

Exploring the Potential for Different Student Products

As I have already stated, not all curriculum objectives can or need be taught using the inquiry approaches, however, aspects of the Osmosis/Diffusion Inquiry could still be incorporated into a more traditional lesson. For example, students following the procedural steps of a traditional lab activity could still record their work and findings using digital photography and create lab write-ups using Comic Life. In addition, traditional discussion questions could be replaced with or enhanced through the addition of a broader application type of extension assignment. Even these small changes to a traditional lab activity would require students engage in their work, as they would no longer be able to mindlessly follow procedural steps without thinking about the rationale behind them or record observations without questioning the significance of them.

Creating Communities for Change

Over the past five years I have had a number of different experiences that have influenced me and have enabled me to grow a science teacher. This
growth can be attributed to my increased exposure to literature regarding science education, discussions with fellow educators within the science education graduate classes, my participation in the CRYSTAL Project action research group, and my own willingness to make significant changes to my teaching strategies and to reflect upon the impact that these changes have had on student learning outcomes.

Prior to becoming a graduate student I certainly did not read research literature about teaching science. In fact, even though I knew that studies focusing on learning theories and student outcomes were occurring, I was unaware that research specifically targeting science education was being conducted. The decision to become a graduate student and to focus my studies in the area of science education has been the most significant professional development that I have engaged in since my internship. Not only has exposure to the findings of science education research been informative, but the opportunity to discuss these findings with educators who share a similar interest for science education has proven invaluable.

An equally significant professional development opportunity that I have had for the past five years has been my participation in the CRYSTAL Project. Anderson (2002) writes that:

... collaborative working relationships among teachers provide a very important context for the re-assessment of educational values and beliefs. In this context—where the focus is the actual work of each teachers’ own students—one’s values and beliefs are encountered at every turn. It is a powerful influence. The reforming teachers in our cases did not do their work in isolation; they worked together with fellow teachers in their team or department. Crucial reform work takes place in this context.” (p. 9)
It was by participating with the diverse group of science educators involved in the CRYSTAL Project that I had the opportunity to discuss the possibility of engaging students in long-term investigations. When we began we did not use the phrase *inquiry learning*, but reflecting back on the lesson ideas I first created and shared with the group I now see that many of them (i.e. the pendulum lab, monster trucks, species at risk and weather presentations, etc.) certainly possessed characteristics in keeping with inquiry learning.

Initially the thought of having small groups of students all approaching the same or similar tasks in their own way was a bit unsettling. Worries such as, would my students stay on task long enough to accomplish the goals of the activity or when faced with difficulties would my students revolt and declare ‘she won’t even help us’ were certainly in the forefront of my mind. And so it was, during those early days as my students and I first explored *inquiry* learning, that having the support of the CRYSTAL Project members proved invaluable. Simply knowing that I had a community of educators learning alongside my students and I made it easier to shift the focus within my junior science classrooms from the *safe* teacher-centered traditional lessons and lab activities to ones which were much more student-centered, inquiry-based and unpredictable. I soon found out, however, that my students were so engaged in their inquiry learning activities that any concerns I may have had with regard to time on task, behavior management and/or concept attainment were quickly dispelled. Coming together, on a regular basis, with the other members of the CRYSTAL community gave me both the impetus and the confidence to reform
my teaching practice as well a venue to discuss the changes that I was making and most importantly, the opportunity to share stories of my students’ responses to these changes.

From my experience I have found that science teachers teach by employing familiar cookbook style laboratory activities which focus solely on science content as opposed to inquiry-based lessons which present science content and the processes of science simultaneously. Taking into consideration the incongruence between the types of laboratory activities that are primarily being employed and those that are being called for by the science education reform efforts, I would argue that it is imperative to engage teachers in professional development activities which would allow them to experience these types of investigations.

As a participant in the CRYSTAL Project I had many opportunities to share with other science teachers the inquiry-based activities that I and other members of the group had created. We conducted a series of workshops for Regina high school science teachers at the University of Regina. These workshops focused on the Sustainability of Ecosystems, Motion in Our World, and Weather Dynamics units of the Science 10 Curriculum (Saskatchewan Learning, 2005). The workshops provided participants with the opportunity to try the activities for themselves and ask questions about them and they reciprocated by recommending changes which would make the activities even better. The inquiry-activities presented at the workshops were well received as indicated by the number of teachers who took the time to attend all three
workshops. In addition to hosting our own workshops I also had the opportunity to present, with other CRYSTAL Project members, our Motion in Our World Workshop at Sciematics\(^2\) in the fall of 2010. Again many teachers attended the workshop and were interested in trying some of the activities that we presented, but our most enthusiastic endorsement came from the curriculum writer Dean Elliott, who commented on our inquiry-activities stating that, “this is exactly how the curriculum was designed to be taught”.

While I believe that teachers benefit from having the professional development time to experience inquiry-type investigations, I believe that having the time, resources and the mentorship to create inquiry-based activities for themselves would be even more valuable. My experience with designing science activities is that well thought out inquiries and investigations have subtle nuances and opportunities for learning which cannot be fully appreciated unless the teacher has played an active role in creating the activity. In addition, I find that I am much more apt to be engaged in teaching lessons that I have had a hand in generating and believe that this may be the same for other teachers. As a result, I firmly argue that professional communities, such as the one created through the CRYSTAL Project, have the greatest potential for science education reform. Not only can these types of professional groups continue to make significant strides together which impact

\(^2\) Sciematics is a provincial conference for Science and Mathematics teachers from Kindergarten to Grade 12. It is hosted by the Saskatchewan Science Teachers’ Society and the Saskatchewan Mathematics Teachers’ Society.
each of their students’ education, but through sharing in workshops and by building one-on-one mentorships even more students’ learning opportunities can be turned-inside-out.

If science teachers do in fact teach the way that they were taught, then it is reasonable to think that if we expose a generation of students to predominantly inquiry approaches to learning then the next generation of teachers will employ predominantly inquiry approaches to teaching.

Conclusion - Teaching is an Inquiry Learning Process!

Completing this research has given me the opportunity to reflect on my sixteen-year teaching journey. For years I struggled to create learning opportunities that would mindfully engage my students and would result in a deep understanding of and relevance for the concepts being presented. As a graduate student and a participant in the CRYSTAL Project I have been engaged in five years of professional development. During these past five years I have come to know and have been able to share with other educators and most importantly my students, a teaching practice which is more in line with my constructivist epistemological and pedagogical points of views; a teaching practice which is rooted in inquiry learning.

I did not venture into the world of inquiry learning on my own however, rather my students accompanied me every step of the way. In the early days of my career my students were the ones who inspired me to make changes to my teaching practice. Sometimes my inspiration came in from them just not getting it and at other times it came from their enthusiastic let’s make and
experiment recommendation to test a hypothesis. It was because of my students’ endless patience with me, as I used them as guinea pigs on which to test my various lesson incarnations, that I was able to try different things in an attempt to transform my teaching practice. It was with my students that I came to know that teaching itself is in an inquiry learning activity.

Engaging my students in a manner that afforded them the time and space to think, brainstorm, generate ideas, and create hypotheses allowed them the freedom to explore, design and conduct their own experiments—testing their own hypothesis using any approach they wanted. My students were challenged to assess their findings, compare them to hypotheses, draw conclusions, accept their findings or return to the drawing board and they were given the opportunity to rethink, refine, construct and reconstruct their understand of the processes of osmosis and diffusion in an environment that they described as fun. In other words, my students were given the opportunity to inquire.

The support that I received from my students throughout my research, whether it was through their enthusiastic participation in the inquiry itself or by way of their insightful feedback, was invaluable. It is for these reasons I feel it appropriate to end this research paper with the words of one of my student participants.

Courtney

Overall the opportunity to participate in the inquiry was a good learning experience for me. The inquiry was a new way to create a lab and I feel that not only my team but each student in the class was
able to benefit from it. Having an independent and hands on inquiry was the best way to show osmosis and diffusion in a biology classroom and in real life situations. I now have knowledge pertaining to such concepts and this knowledge I know will last. I strongly suggest more science classrooms take part in this type of lab rather than the traditional step-by-step lab. Mistakes are made fun, results are achieved and science is finally noticed in the world around us.

Figure 7 - The Student Participants have the Final Words
REFERENCES


St. Omer, L. (2002). Successful science instruction involves more than just discovering concepts through inquiry-based activities. Education, 123, 318-321. doi: 323226991


Appendix A

Inquiry Timeline

IMPORTANT: An extremely important aspect of your research team’s work is the application of your experimental findings to real world phenomena. This link between your findings and the real world phenomena must be formally presented to the class as a PowerPoint presentation.

Pre-inquiry: Introduction to Osmosis/Diffusion Inquiry

- Background Research Sheet/Our Research Question
  Sheet/Outline of Procedure/Participant Responsibilities Booklets
- Introduction to Lab Materials Provided
- Presentation of Comic Life. (http://plasq.com/comiclife/).

Day One: Background Research

- Research each of the terms on-line. It is very important that you discover the connection between the materials that you have been provided. You must discover how they will allow you to design an experiment which will allow you to investigate the concepts of osmosis and/or diffusion.

Day Two – Day Four: Lab Days & Developing a Broader Application

Day Five – Day Seven: Wrap-up/Broader Application Presentation/Comic Book

- Create your comic book → have a really fun and creative time creating a comic book lab write-up which tells the story of your research team’s experiences.

- Work on your PowerPoint presentation. Even though your presentation should provide the audience with an overview of your lab procedures, it should focus mainly on the application of your findings to the real life transport of materials across plant or animal cell membranes.

Day Eight: Presentation of Work

- Broader Application Presentations & Hand-in Comic Book Reports
Appendix B

Lab Outline:

Title: _____/1
Materials: _____/1
Lab Partners: _____/1
Procedure: _____/4
Problem/Purpose: _____/2
Results: _____/1
Tells the story of the team’s experiences: _______/5
TOTAL: _____/15

Comic Book Design:

Layout: (5 points)
- Graphic Appeal: _____/3
- Organization: _____/2
Page Design Variety: (3 points)
- None: _____/1
- Some (3-4 different designs): _____/2
- Much (4-every page is different): _____/3
TOTAL: _____/8

Information stated in the comic is accurate: _____/4

Mechanics: _____/3
Appendix C

Presentation

Information:

Overview of Lab: _____/1

Connection of Lab Results to the Broader Application: _____/2

Degree of Complexity of the Broader Application:

Simple: _____/1  Average: _____/2  Complex: _____/3

Discussion of the Broader Application:

<table>
<thead>
<tr>
<th>Marking Scheme</th>
<th>10 points</th>
<th>8 points</th>
<th>6 points</th>
<th>4 - 2 point(s)</th>
<th>0 points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content</td>
<td>Contains detailed, organized, and clear information about most aspects of the topic researched.</td>
<td>Contains organized and clear information about some aspects of the topic researched with some detail.</td>
<td>Contains information about the topic researched with little detail, may not be clear and organized.</td>
<td>Contains information about the topic researched with no detail and/or organization.</td>
<td>No attempt made to complete this aspect of the project</td>
</tr>
</tbody>
</table>

Information:

Read from Screen: ___/1  Read from Cue Cards: ___/2  From C.C. and Memory: ___/3

Presentation Skills & Dynamic Speaking:

Clarity: _____/1  Loud: _____/1  Organization of Content: _____/2

Boring (sorry): ____/1  Pretty Darn Good: ____/2  Wow! Tell me More! ____/3

Apparent Knowledge of Group Members:

One: _____/1  Most: _____/2  All: _____/3

TOTAL: _____/13
### Group Member Being Evaluated: ________________

<table>
<thead>
<tr>
<th></th>
<th>Leader/Co-leader (4)</th>
<th>Faithful Assistant (3)</th>
<th>Free Loader (1)</th>
<th>What? She/he was in the group? (0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Designing &amp; Carrying out Experiments</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Broader Application</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comic Book Lab Report</td>
<td></td>
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</tr>
</tbody>
</table>
The purpose of the Osmosis/Diffusion Inquiry is multifaceted. It has been designed: a) to have you come to a better understanding of the concepts of osmosis, diffusion and the semi-permeable nature of the cell membrane; b) to give you a genuine sense of the work that scientists engage in when they seek to find answers to their questions and the challenges they may face as they pursue those answers experimentally; c) to allow you to present your lab work in an authentic, timely and creative manner via digital photography and the creation of your comic book; and d) to give you the opportunity to take your experimental findings and demonstrate to others how they apply to living cells.

Answer the following questions as a way of reflecting on the work that you have done.

Reflecting on Osmosis, Diffusion & Semi-Permeable Membranes

1. State 2 ways in which the transport of molecules across a cell membrane is similar in both osmosis and diffusion. (2 marks)
2. In what significant way does osmosis differ from diffusion? (1 mark)
3. Why do we refer to cell membranes as semi-permeable? (1 mark)
4. Understanding that the dialysis tubing acted as model of a cell membrane state the experimental evidence that you have to show that cell membranes are in fact semi-permeable? (2 marks)
5. With regard to your inquiry, what factor determined the permeability of the "cell membrane" to different molecules? (1 mark)

Reflecting on Scientific Work

1. New knowledge is often built upon already existing knowledge. With this said reflect upon the how the quality of your background research allowed you to move forward with your experimental design or perhaps how it impeded your progress. For example, if your team’s background research proved to be thorough how did this allow you to proceed onto the experimental stages of your inquiry? If your team’s background research was lacking, what did you do? (3 marks)
2. I noticed that all of the research teams “played” with the materials before actually designing and conducting experiments with which to test their ideas. What purpose did this “play” serve for your team? (3 marks)

3. Through play you were able to discover lab procedures and the interactions between lab materials.
   A) How is this different from being told what to do as you would have been in a traditional “recipe book” style experiment where the procedure is outlined in step-by-step fashion? (2 marks)
   B) Which method do you think would allow you personally to retain and recall the new procedural knowledge for a longer period of time? (1 mark)
   C) Why? (2 marks)

4. Over the years you have likely carried out numerous science experiments in school. Some have likely been very traditional recipe book style experiments while others may have been more like the inquiry that you have just completed. In your opinion which type of labs do you think have provided you with a better opportunity for learning about both: a) the scientific concepts in question and b) the nature of scientific work? Please state why and give examples. (4 marks)

Presenting Experimental Work and Findings

1. You were given the opportunity to present your experimental work and findings in a very non-traditional format through the use of the Comic Life program. Reflect on this way of presenting your work compared to that of the traditional formal lab write-up and give your opinion as to whether or not you found value in this method of reporting and state why. (3 marks)

Your Broader Application

1. As your teacher I was very adamant that each research team apply their experimental findings to real life examples of osmosis and/or diffusion of molecules across living cell membranes. Did the challenge of applying your new scientific knowledge help to deepen your understanding of the concepts of osmosis and diffusion? Why or Why not? (3 marks)

Overall Insights

1. Each day I witnessed students coming into class and getting straight to work on their inquiries. Even though there were certainly moments of frustration, groups still seemed quite motivated to complete the task.
1. What kept your motivation high? What were you actually feeling? (3 marks)

2. What aspects of the inquiry were most frustrating for you? (2 marks)
   Which aspects were the most rewarding? (2 marks) Compare this lab activity to those that you've done in other types lab experiences.

3. Overall was the opportunity to participate in the inquiry a good or bad learning experience for you? Why? (5 marks)
Appendix F

UNIVERSITY OF
REGINA

OFFICE OF RESEARCH SERVICES

MEMORANDUM

DATE: October 15, 2009

TO: Heather Haynes-Macdonald

FROM: Dr. Bruce Plouffe
Chair, Research Ethics Board

Re: An Inquiry Approach to Science Education (File # 1050910)

Please be advised that the University of Regina Research Ethics Board has reviewed your proposal and found it to be:

☑ 1. APPROVED AS SUBMITTED. Only applicants with this designation have ethical approval to proceed with their research as described in their applications. For research lasting more than one year (Section 1F). ETHICAL APPROVAL MUST BE RENEWED BY SUBMITTING A BRIEF STATUS REPORT EVERY TWELVE MONTHS. Approval will be revoked unless a satisfactory status report is received. Any substantive changes in methodology or instrumentation must also be approved prior to their implementation.

☐ 2. ACCEPTABLE SUBJECT TO MINOR CHANGES AND PRECAUTIONS (SEE ATTACHED). Changes must be submitted to the REB and approved prior to beginning research. Please submit a supplementary memo addressing the concerns to the Chair of the REB. ** Do not submit a new application. Once changes are deemed acceptable, ethical approval will be granted.

☐ 3. ACCEPTABLE SUBJECT TO CHANGES AND PRECAUTIONS (SEE ATTACHED). Changes must be submitted to the REB and approved prior to beginning research. Please submit a supplementary memo addressing the concerns to the Chair of the REB. ** Do not submit a new application. Once changes are deemed acceptable, ethical approval will be granted.

☐ 4. UNACCEPTABLE AS SUBMITTED. The proposal requires substantial additions or redesign. Please contact the Chair of the REB for advice on how the project proposal might be revised.

Dr. Bruce Plouffe

cc: Dr. Warren Wessel – Faculty of Education

** supplementary memo should be forwarded to the Chair of the Research Ethics Board at the Office of Research Services (Research and Innovation Centre, Room 105) or by e-mail to research.ethics@uregina.ca
December 4, 2009

The purpose of this narrative study is to explore students’ learning with the researcher focusing on students’ feedback during lab projects and other classroom activities in a secondary science classes. Student feedback will be provided through written work as a part of regular classroom activities. Participants may also be interviewed at a later date in order to clarify or expand upon comments they have made.

The undersigned, ____________________________________________ agrees to participate in the program of research entitled An Inquiry Approach to Science Education to be undertaken by Heather Haynes-Macdonald as a research project for her master’s studies at the University of Regina, under the following terms and conditions:

1) The participant will be engaged in regular classroom activities and involvement in the project will not require the participant to do any extra work.
2) The researcher will not know the identities of participants until after final grades have been submitted.
3) Once final grades are submitted the identities of the participants will be made known to the researcher. At this point the researcher may ask to interview certain participants.
4) The participant has the right to withdraw his or her assistance from this project at any time without penalty, even after signing this letter of content.
5) Upon request, the participant will receive a report summary as a result of this study.
6) The participant will be entirely free to discuss issues and will not be in any way coerced into providing information that is confidential or of a sensitive nature. Even though this study’s questions are not of a sensitive nature, if illegal activity is disclosed the researcher will be obliged to report this to the appropriate authorities.
7) Pseudonyms will be used to conceal the identity of the participants in all written materials.
8) The information disclosed in written work and interviews will be confidential; however, anonymity cannot be guaranteed as there is a chance that direct quotes or stories may identify the participant to others, particularly fellow students.
9) This project was approved by the Research Ethics Board, University of Regina. If the participants have any questions or concerns about their rights or treatment as subjects they may contact the Chair of the Research Ethics Board at 585-4775 or by e-mail: Research.ethics@uregina.ca
10) The participant/student will receive a copy of the letter of consent.

I, ____________________________________________, agree to the conditions stated in this letter of consent and to certify that I have received a copy of the consent form.

____________________________________  _______________________
(Student Signature) (Date)

____________________________________
(Researcher/third party)

Contact information: Questions concerning the study can be directed to the researcher, Heather Haynes-Macdonald [redacted] or her advisor Dr. Warren Wessel [redacted].

Heather Haynes-Macdonald [redacted]
December 4, 2009

The purpose of this narrative study is to explore students’ learning with the researcher focusing on students’ feedback during lab projects and activities in secondary science classes. Students will be interviewed before, during and after lab projects that occur throughout the semester.

The undersigned, the parent/guardian of ________________________________, agrees to allow his/her son or daughter to participate in the program of research entitled Inquiry Approach to Science Education to be undertaken by Heather Haynes-Macdonald as a research project for her master’s studies at the University of Regina, under the following terms and conditions:

1) The participant will be engaged in regular classroom activities and involvement in the project will not require the participant to do any extra work.

2) The researcher will not know the identities of participants until after final grades have been submitted.

3) Once final grades are submitted the identities of the participants will be made known to the researcher. At this point the researcher may ask to interview certain participants.

4) The participant has the right to withdraw his or her assistance from this project at any time without penalty, even after signing this letter of consent.

5) Upon request, the participant will receive a report summary as a result of this study.

6) The participant will be entirely free to discuss issues and will not be in any way coerced into providing information that is confidential or of a sensitive nature. Even though this study’s questions are not of a sensitive nature, if illegal activity is disclosed the researcher will be obliged to report this to the appropriate authorities.

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10) The parent/guardian will receive a copy of the letter of consent.

I, _______________________________________, agree to the conditions stated in this letter of consent and to certify that I have received a copy of the consent form.

____________________________________  ______________________ (Parent Signature) (Date)

Contact information: Questions concerning the study can be directed to the researcher, Heather Haynes-Macdonald [Contact Information] or her advisor Dr. Warren Wessel [Contact Information].

____________________________________ (Researcher/third party)