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How am I using inquiry-based learning to improve my practice and to encourage higher order thinking among my students of mathematics?

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Abstract

In this paper, I describe and explain how I enquired into my own practice as a teacher of mathematics in a post-primary school. I engaged in an action research study as I explored how I could use inquiry-based learning (IBL) to encourage higher order thinking among my students of mathematics. I did this through two cycles of action research. In cycle one my focus was on introducing IBL into my lessons. The focus of cycle two was on improving the students' ability to write-up their inquiries. Through the cycles of the enquiry, I gained a deeper understanding of the values embodied in my practice as a teacher. I used these values as my living standards of judgement by which I judged my practice. During the research period I successfully integrated the levels of inquiry as advocated by the European Seventh Framework project 'Pathway' into my teaching and used the SOLO taxonomy as a way of assessing higher order thinking. In my study, I show how my students engaged in the inquiry-based learning process as I asked, researched and answered the question 'How can I use inquiry-based learning to improve my practice and to encourage higher order thinking among my students of mathematics?' Through the research process, my own learning and that of my students has been transformed and this gives me enormous satisfaction.

Keywords: Higher order thinking; Inquiry-based learning; Action research; Living theory; Mathematics, Statistics, CensusAtSchool.

1. Introduction

1.1. Rationale for my action research enquiry

One of my fundamental objectives as a mathematics teacher is to foster a more positive attitude to the subject and to make learning mathematics a less daunting experience for my students. I would like my students to enjoy studying mathematics and to want to spend time improving their mathematical skills.

I value perseverance in problem solving and I encourage a positive attitude to mistakes and difficulties in my students. I also value my students taking responsibility and accountability for their own learning of mathematics. As I embarked on the research process, I was concerned that my students were not persevering with problem solving and were not taking ownership of their own understanding of mathematical methods and concepts. I was also aware of the National Council for Curriculum and Assessment's view on Mathematical skills as essential for students' everyday lives and their future working lives (NCCA 2005, 2006, 2008). I observed that when my students came across a problem that they found difficult or required higher order thinking they tended to give up and wait for me to explain. I want my students to consider problems more rigorously and weigh up all the possible solutions rather than giving up after the first attempt. Stated plainly, I want my students to apply higher order thinking to their work.

After deep introspection I came to recognize my didactic teaching methods negated my educational values. In my teaching I was feeding the students information and demonstrating skills that they had to then try to imitate. Paulo Freire describes this as the 'banking concept of education'. I assumed that my students could understand methods and learn skills for which they could see no real life application. I was not affording the students the opportunity to take ownership of their learning by constructing their own meaning from their experiences in the classroom.

1.2. My educational context

I work in a multi-denominational, co-educational post-primary school in North County Dublin. It is a newly established school. The school opened its doors to our first set of students at the end of August 2009. As I undertook this study in Spring/Summer 2012 the school was in its third academic year and had an enrolment of approximately 290 students. The student body consisted of first, second and third year students. The male students outnumbered the female students by more than three to one.

I have worked as a teacher of mathematics and information and communications technology (ICT) for a total of seven years, three of which have been spent in the school I am working in at present.

1.3. Reform of Mathematics Education in Ireland

After the Leaving Certificate results were issued in 2005, concerns about mathematics at post-primary level that were expressed in national newspapers reflected a general unrest about the subject at post-primary level. Among the headlines in the national newspapers were the following comments:

> "Poor maths results just don't add up"
> (The Irish Times, 12 August 2005)
> "Overhaul of Leaving Cert Maths urged by key group"
> (The Irish Times, 16 August 2005)
> "High rates of failure in Leaving Certificate maths and science"
> (The Irish Times, 17 August 2005)
> (NCCA, 2005)

Furthermore, in the 2003 PISA tests Irish students ranked 20th out of 40 countries in mathematical literacy. This contrasts starkly with Irish students' ranking in reading literacy, which is 5th of 39 countries (PISA).

As a result of these issues with post-primary mathematics education in Ireland the National Council for Curriculum and Assessment (NCCA) published the "Review of mathematics in post-primary education – report on the consultation" (2006). They consulted with teachers, post-primary and third-level students, parents, lecturers and school principals in order to compile this report. A dominant theme in the consultation feedback was the need to make mathematics more related to the lives of students. Two main approaches were advocated for this:

- introducing mathematical concepts in real-life contexts so that it leads from the concrete to an appropriate level of abstraction;
- giving examples of ways in which mathematics is applied in the real world.

Project Maths is a curriculum and assessment project in post-primary mathematics that began in 2008, arising from the NCCA review of mathematics education (2005, 2006). The aim of Project Maths is to increase the number of students taking Higher Level mathematics at Leaving Certificate. In this new curriculum students can experience mathematics in a new way, using examples and applications that are meaningful for them. Project Maths allows students to appreciate how mathematics relates to daily life and to the world of work. Students can develop skills in analysing, interpreting and presenting mathematical information, in logical reasoning and argument, and in applying their mathematical knowledge and skills to solve familiar and unfamiliar problems (Project Maths Development Team 2008).

As I began to teach the Project Maths curriculum I realised that in order for my students to truly recognize the value of mathematics, they need to understand the role of mathematics in the real world, outside the classroom. I began investigating ways that I can make learning mathematics a more meaningful experience for my students. I drew on my experiences in the Project Maths workshops and my experiences as a student on the Masters in Education and Training Management (eLearning) programme at Dublin City University (DCU). I came to the conclusion that adopting an inquiry-based approach could help my students appreciate and understand mathematics because it enables students to construct knowledge for themselves and it draws on real life contexts. Inquiry-based learning (IBL) is where students are engaged in essentially open-ended, student-centered, hands-on activities based on real life problems (Colburn, 2000).

1.4. The European Seventh Framework Pathway Project

I was able to access the inquiry based learning documentation and participate in the Pathway workshop in the initial stages of carrying out this study. A two-day workshop was held in Dublin City University (DCU) on 13th and 14th February 2012 as DCU is one of the Pathway project partners. This particular workshop event was organised by Dr. Margaret Farren. A number of other Inquiry Based Science Education (IBSE) workshop sessions were planned by Pathway Ireland in order to share leading practice in IBSE. This workshop was entitled “Discovering and Promoting Inquiry in the Sciences through Computational Thinking” and it was led by Robert M. Panoff, Ph.D., President and Executive Director of Shodor and the National Computational Science Institute.

I found the workshops to be very beneficial in developing my understanding of inquiry-based learning. In these workshops I learned about the different types of inquiry, inquiry through computational thinking, online resources for use in IBL, inquiry through modelling and developing and assessing inquiry through small group projects. In addition to lecture-style sessions, these workshops afforded the participants the opportunity to experience being a student in an inquiry-based setting (Farren, Crotty, Owen & McTiernan, 2012).

2. Inquiry-based learning, higher order thinking and mathematics

2.1. Inquiry-based learning

Inquiry-based learning is emerging as a popular approach to teaching and learning in many fields, particularly in science and mathematics (Hayes, 2002; Phelan, 2005 and Towers, 2010). Henningsen & Stein (1997) contend that without engaging in active processes during classroom instruction, students cannot be expected to develop the capacity to think, reason, and problem solve in mathematically appropriate and powerful ways. Connections with students’ prior knowledge and experience also play an important role in engaging students in high-level thought processes (Henningsen & Stein, 1997 and Abu-Febiri, 2002).

Hayes (2002) notes that defining inquiry-based learning precisely is quite difficult and that historically, definitions of IBL have ranged from traditional hands-on learning to student research. With this in mind, I have chosen two definitions of IBL to give a broader description of IBL.

Wilke and Straits (2001, cited in Coombs and Elden, 2004) emphasize the importance of the student’s existing knowledge in IBL. They define IBL as learning occurring when the learner constructs an understanding of new information by associating it with prior knowledge in an organized and systematic way. Within this context, IBL is a student-based exploration of real-life problems using the processes and the tools of inquiry.

Kahn and O’Rourke (2005) describe IBL as a broad umbrella term to describe approaches to learning that are driven by a process of inquiry. In their definition of

IBL the tutor establishes the task and supports or facilitates the process, but the students pursue their own lines of inquiry, draw on their existing knowledge and take responsibility for analysing and presenting their ideas appropriately.

IBL draws on constructivist ideas of learning. Constructivism's central idea is that learning is an active process in which learners construct new ideas or concepts based upon their experiences and prior knowledge (Kanselaar, 2002). Similarly, IBL is a student centred approach that encourages participants to draw on prior knowledge and experience in exploring their inquiries (Kahn and O'Rourke, 2005). In IBL the student is responsible for constructing their own meaning and understanding from the learning activities.

2.2. Levels of inquiry

Pathway proposes a four-level model (adapted from the National Research Council 2000) that illustrates how inquiry-based learning can range from highly teacher directed to highly student directed. The levels of inquiry in these models are structured inquiry, guided inquiry, open inquiry and coupled inquiry respectively. The following table offers a brief description of each level of inquiry:

Table 1. Levels of Inquiry

Level of Inquiry	Description
Structured	Strongly teacher-directed. Students follow their teacher's direction in pursuing a scientific investigation to produce some form of prescribed product, e.g. they investigate a question provided by the teacher through procedures that the teacher determines, and receive detailed step-by step instructions for each stage of their investigation.
Guided	More loosely scaffolded. Students take some responsibility for establishing the direction and methods of their inquiry. The teacher helps students to develop investigations, for example offering a pool of possible inquiry questions from which students select, and proposing guidelines on methods.
Open	Strongly student-directed. Students take the lead in establishing the inquiry question and methods, while benefiting from teacher support. For example, students initiate the inquiry process by generating scientific questions and take their own decisions about the design and conduct of the inquiry and the communication of results.
Coupled	A combination of two types of inquiry, for example a guided inquiry phase followed by an open inquiry phase.

Adapted from Pathway

At the open inquiry level students have the most authentic possible opportunity to act like scientists or mathematicians, deriving questions, designing and carrying out investigations, and communicating their results. This level requires the most reasoning skills and the greatest cognitive demand from students (Bell et al, 2005). Banchi and Bell (2008) contend that it is only appropriate to facilitate students conducting open enquiries when they have demonstrated that they can successfully design and carry out investigations at the structured and guided levels of inquiry. This includes being able to record and analyze data, as well as draw conclusions from the evidence they collected.

2.3. Inquiry-Based Learning and Higher Order Thinking

Problem solving, inferring, estimating, predicting, generalising and creative thinking are all considered to be higher order thinking skills (Miri et al, 2007). Many researchers believe that fostering higher order thinking among students of all ages is an important educational goal and that higher order thinking is an important element of life success (Gough, 1991; Marzano, 1998; Zohar et al, 2001; Sousa, 2008; Lord and Baviskar, 2007). Miri et al (2007) assert that our ever-changing and challenging world requires students, our future citizens, to go beyond the building of their knowledge capacity and need to develop higher order thinking skills.

Bloom's taxonomy categorised and ordered thinking skills and objectives according to six cognitive levels of complexity (Bloom, 1956). The idea is that some types of learning require more cognitive processing than others. The lowest three levels of cognition in Bloom's taxonomy are knowledge, comprehension, and application and are considered to be lower-order thinking skills. The highest three levels are analysis, synthesis, and evaluation and are thought to be of a higher order, and require different learning and teaching methods than the learning of facts and concepts (Krathwohl, 2002). The following table outlines some of the thinking skills associated with the six categories within Bloom's taxonomy:

Table 2. Bloom's Taxonomy

Level in Bloom's Taxonomy	Associated Thinking Skills
Knowledge	define, describe, recall, recognize;
Comprehension	explain, extend, interpret, summarise;
Application	construct, demonstrate, modify, prepare, solve;
Analysis	compare, contrast, distinguish, identify, illustrate;
Synthesis	categorise, devise, design, generate, organize, reconstruct, relate;
Evaluation	appraise, compare, conclude, contrast, interprets, justifies, supports;

Adapted from Bloom, 1956; Krathwohl, 2002 and Lord and Baviskar, 2007

In 2001 Anderson and Krathwohl adapted and revised Bloom's taxonomy. With the dramatic changes in society and education over the last five decades, the revised Bloom's taxonomy provides an even more powerful tool to fit today's teachers' needs. The structure of the revised taxonomy provides a clear, concise visual representation of the alignment between standards and educational goals, objectives, products, and activities (Forehand, 2005). The following is an amended taxonomy of thinking skills:

Table 3. Revised Taxonomy

Level in Revised Taxonomy	Description
Remembering	Retrieving, recognizing, and recalling relevant knowledge from long-term memory;
Understanding	Constructing meaning from oral, written, and graphic messages through interpreting, exemplifying, classifying, summarizing, inferring, comparing, and explaining;
Applying	Carrying out or using a procedure through executing, or implementing;
Analyzing	Breaking material into constituent parts, determining how the parts relate to one another and to an overall structure or purpose through differentiating, organizing, and attributing;
Evaluating	Making judgments based on criteria and standards through checking and critiquing;
Creating	Putting elements together to form a coherent or functional whole; reorganizing elements into a new pattern or structure through generating, planning, or producing.

(Anderson and Krathwohl, 2001, p.67-68)

In order to assess levels of higher order thinking in students' work it is important to examine the relevant framework. . The SOLO taxonomy (Biggs & Collis, 1982) is a hierarchy of learning evaluation based on both the learning quantity and quality. This model can be used to effectively measure different kinds of cognitive learning outcomes within a wide range of subject areas (Kanuka, 2005 and Atherton, 2011). The five levels are as follows, in increasing order of structural complexity:

Table 4. SOLO taxonomy

Level in the SOLO Taxonomy	Description
1. The Pre-Structural Level	The student does not have any kind of understanding but uses irrelevant information or misses the point altogether.
2. The Uni-Structural Level	The student can deal with one single aspect and make obvious connections.
3. The Multi-Structural Level	The student can deal with several aspects but these are considered independently and not in connection.
4. The Relational Level	The student understands relations between several aspects and how they might fit together to form a whole.
5. The Extended Abstract Level	The student shows profound understanding and can apply this understanding to wider contexts and new applications.

Adapted from Biggs & Collis, 1982, p.17-31 and Kanuka, 2005

3. Methodology

3.1. Action Research

I have found action research to be a reflective, highly rigorous approach to research. Berg (2004, p.197) asserts that “it encourages people to formulate accounts and explanations of their situation and to develop plans that may resolve these problems.”

What distinguishes the living educational theory approach form of action research from other forms of action research is that it is grounded in the ontological ‘I’ of the researcher, and the researchers organise their thinking in terms of what they are experiencing at the moment. (McNiff & Whitehead, 2006, p.41-42; Barry, 2012; Farren & Crotty, 2010 and Laidlaw, 2008). The authors write that “studying our practice and its underpinning assumptions enables us to develop a creative understanding of ourselves and our own processes of learning and growth” (p.59). It is a research approach for improving one’s practice and generating knowledge from questions of the kind ‘How do I improve what I am doing?’ (Whitehead, 2008). My research question was focused on ‘How do I Encourage Higher Order Thinking through the use of Inquiry Based Learning?’ Whitehead (1989) asserts that individuals can create their own theory as descriptions and explanations of their own learning as they live their life of enquiry. Throughout the course of the Masters programme we were encouraged to create our own theories, by embodying our educational values in our practice. The basis of this approach to research is that a practitioner exists as a ‘living contradiction’, which means that a practitioner is holding certain values while denying them in practice (Walton 2008). In carrying out this research I was compelled to address the contradictions of my values in my own practice.

The Multimedia and Educational Innovation module on the Masters programme encouraged us to use our imagination to create educational multimedia resources such as videos, comic strips, podcasts and vodcasts that could be used in our teaching. In learning the skill of multimedia production and visual representation we were able to communicate through multimodal forms the knowledge that we were generating (Crotty, 2012). I used a reflective journal to record my reflections and observations after each lesson during the research period. In my reflective journal I aimed to not only write about what I did but also write about what I learned. I recorded my lessons during the research period on video, with a view to making further observations and reflections. I documented these videotape observations and reflections in my reflective journal. I photographed all the project work as evidence. I assessed if there is any evidence of higher order thinking in the students' work. The Biggs & Collis' SOLO taxonomy (1982) offered me a means of measuring higher order thinking.

3.2. Ethical Considerations

I endeavoured to ensure that all of the students participating in my study are kept anonymous. I have not identified the name of the school in the research. The names of students participating in the study have been changed in order to ensure their anonymity. In undertaking my research I was mindful that I have a duty of care to my students. My role as a teacher supersedes my role as a researcher. I received ethical approval from parents, the Principal and the Board of Management of the school. I gave out a plain language statement explaining my research to the students and parents or guardians of the participating students. I received informed consent from the Principal, Board of Management and all of the participating students and their parents or guardians.

4. Implementation and Evaluation

4.1. Introduction

I saw the need to make my lessons more activity orientated and engage my students more by relating to their experiences and interests. The literature of Prawat (1996), Henningsen & Stein (1997), Jarworski (2006) and Libman (2010) indicates that classroom activities should be based on real life situations so that the students can appreciate the applications of mathematics in everyday life and in their future working lives. My experiences at Project Maths workshops, Pathway workshops and as a MSc student and my review of the literature have informed my belief that adopting an inquiry-based approach could help my students appreciate mathematics and apply a higher level of thinking to their work because it engages students in investigating real world questions and it enables students to discover knowledge for themselves.

My study is focused on statistics. Traditional methods of statistics teaching have come under serious criticism because of their failure to help students achieve sufficient in-depth understanding of statistical concepts and principles so as to be able to use them in new situations (Libman, 2010). Research carried out by Libman (2010) indicated that statistical investigations that are based on real-life data collected by the students meant that the students were more engaged and they were drawn more deeply into thinking critically about the information. Libman (*ibid*) remarked that a real data approach seems even more valid when we are talking about applied academic studies such as statistics, whose very objective is to enable students to conduct inquiry through intelligent use of statistical methods.

Gaining a deep understanding of statistics, which will enable the student to properly apply what he or she has learned, requires an approach to learning that allows the learner to investigate freely, in realistic circumstances and meaningful contexts. This involves two requirements: personal investigation, and complex and meaningful context (Libman, 2010; Singer and Willett, 1990). Allowing students to learn in context dictates teaching approaches that require the learners to do their own investigating and cope by themselves in order to create meaning and statistical understanding (Prawat, 1996; Marriott et al, 2009).

I invited my first year Junior Certificate mathematics class to join me in this research. The class comprises of twenty-three students, five girls and eighteen boys. The average age of the students at the time of the research was thirteen. The class consists of a vast array of abilities, ranging from students who have difficulty adding fractions to those who can grasp abstract concepts in algebra. They are currently studying the Project Maths common level first year introductory course. I teach this class daily during the school year for a single class period, which is 35 or 40 minutes long depending on the time of day.

Cycle one of the research took place over eleven consecutive class periods in March 2012. The second cycle took place over fourteen consecutive class periods in April and May 2012. The branch of statistics we explored in these cycles was data handling (Figure 1). The new statistics curriculum for Project Maths, which is outlined in the "Teacher Handbook for Junior Certificate Strand 1: Probability and Statistics" (Project Maths Development Team 2010) requires the students to understand the data handling cycle.

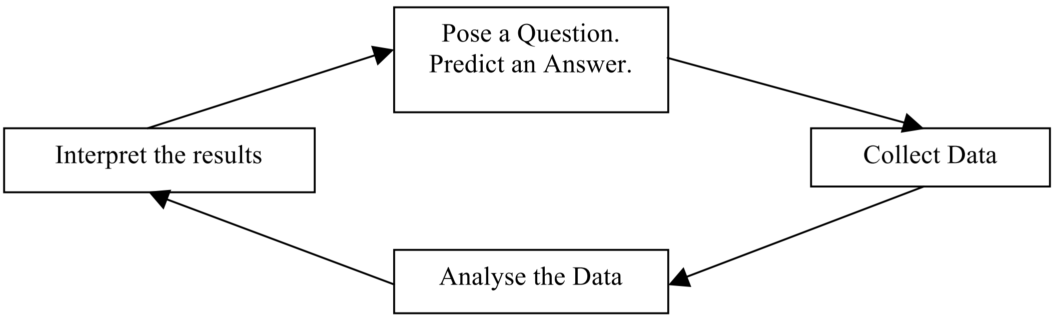


Figure 1: The Data Handling Cycle

4.2. Cycle One

Cycle one of the research took place over eleven consecutive class periods in March 2012. As both the students and I, the teacher, are novices to inquiry-based learning I decided to employ a guided inquiry approach in this cycle and adapt this approach to suit my needs as a mathematics teacher. My review of the literature informed this choice. Sweller (1988) and Kirscher et al (2006) contend that novices to inquiry-based learning need a lot of teacher guidance and support.

Video 1: Scaffolding for Cycle One (Rooney, 2012a)

I dedicated one lesson on the 27th March 2012 to teaching the students about planning a survey and facilitating the students working in groups to plan their group surveys. I tried to structure the lesson so that the students were very clear on what I wanted them to do. I delivered a PowerPoint presentation (Presentation 1) to teach the students about data handling with specific emphasis on the planning stage of data handling (Video 1, Rooney, 2012a).

I then split the class into groups of three and four and handed out worksheets that I had designed to help the students to plan their group inquiries (Worksheet 1). I offered each group a variety of tools of measurement to choose from in an effort to help them to decide what they would like to investigate. I offered them a choice of a timer, a measuring tape, a ruler, a protractor, weighing scales or a thermometer. At the end of the lesson each group shared the questions that they wanted to pose with the rest of the class. Their homework was to plan their own individual surveys and to plan what data to collect and how they would collect that data (Worksheet 2).

There were some early indications of higher order thinking in the students' activities, which I described in my journal entry on the 27th March 2012. (Journal 1) However the completed group worksheets (Worksheet 3) that the students were required to fill out do not reveal much analytical thinking and evaluation. Most of the questions were answered with one-line responses.

In the proceeding lesson the students shared their individual questions with each other and offered constructive criticism to each other. Peer interactions are beneficial to assist students to clarify and focus their statistical questions (Allmond & Makar, 2010; Chin & Osbourne, 2008; Chin, Brown, & Bruce, 2002 and Lowrie 2002). There were several problems with their questions. I described the difficulties we encountered in my journal entry on the 28th March 2012 (Journal 2). Overall the quality of research questions that the students came up with was poor and there was very little evidence of higher order thinking (Appendix 2). Also the students seemed to have difficulty in finding the flaws in each other's questions.

At this point I decided to abandon the individual inquiries. This is mostly due to time constraints. I only had two lessons remaining with the class before the Easter holidays started. Also this would allow us to focus all our attention on the group work inquiries. An ongoing issue for me, that I wrote about in my reflective journal (Journal 2) was that my lessons remained teacher-dominated. The work of several authors such as Colburn (2000), Hmelo-Silver (2004) and Lord and Baviskar (2007), emphasize the importance of a student-centred classroom.

The objective of the lesson on the 29th March 2012 was to allow the students to carry out the data collection phase of their group investigations. The only way I could describe this lesson was organised chaos. However, overall I was happy with the lesson and I was satisfied that I achieved my aim of making the lesson more student-centred.

Video 2: Student Enjoyment in Cycle One (Rooney, 2012b)

It was evident to me that the students really enjoyed this lesson. At one stage Jack said to me “Ours is really fun, Miss” referring to his survey (Video 2, Rooney, 2012b). When I looked at the recording all of the students were engaged, active, interested and in some cases a little over-excited (Video 2, Rooney, 2012b).

I believe that a key factor in the success of this lesson was the time we spent on the planning stage. This meant that the students knew exactly what they were doing and how they were going to carry it out. The writings of Sweller (1988) and Kirschner et al (2006) underline the need for teacher support and guidance for novices to inquiry-based learning influenced my decision to dedicate significant time to planning the inquiry. I helped the students develop the investigations and I gave them guidelines but the students were responsible for establishing the direction and methods of their inquiries.

I observed indications of higher order thinking as the students generated data for their inquiries, which I described in my journal entry on the 29th March 2012 (Journal 3) These activities fit into the higher levels of Anderson and Krathwohl’s amended version of Blooms taxonomy of thinking skills (2001), specifically evaluating and creating.

Video 3: Students Discussing Data Cycle One (Rooney, 2012c)

A key objective of the new mathematics curriculum, Project Maths, is to enable students to develop their skills in communication (NCCA 2007 p.5). The purpose of the lesson on the 30th March 2012 was to discuss how the investigations went in the previous lesson. I asked each group to tell the class and I about their inquiry. I recorded the students on video as they spoke about the data they collected and explained their conclusions (Video 3, Rooney, 2012c). I observed that the students were engaged and eager to share their results and conclusions. There were signs of higher order thinking in the class discussions, which I described in my reflective journal on the 30th March 2012. (Journal 4)

However, when I collected the students' copies to read what they had written for their conclusions I was very disappointed. Although the students were able to speak eloquently and at length about their investigations, they wrote very little in their written conclusions. (Appendix 2)

Video 4: Feedback from Students on Cycle One (Rooney, 2012d)

In order to get the students' first impressions of IBL, I asked three of the participating students that I have for a Resource class, Brendan, Jamie and Amy to talk to me about their experiences. I chose these students because my Resource class group are mixed in ability and gender so they represented the overall class well. Also because I see these students more often than the rest of the class, I have built a good relationship with these students and I felt I could elicit honest and open feedback from these students.

The feedback was very positive. Jamie said, "It was class" (Video 4, Rooney, 2012d). They all concurred that when they do it themselves they actually get it, "We understand." "We want to do it well." (Video 4, Rooney, 2012d, Focus Group Meeting Reflections 1) The feedback from the students and the evidence from the video recordings illustrates that the students enjoyed directing their own investigations.

Video 5: Students' Thoughts on Scaffolding (Rooney, 2012e)

The initial lessons were teacher dominated as I tried to prepare my students for inquiry. The later lessons in cycle one were more student centred. This faded approach to scaffolding worked well. Scaffolding methods are most useful to fade guidance during inquiry-based learning (Anderson, 1989; Hmelo-Silver, 2004; Hmelo-Silver et al 2007). Hmelo-Silver (2004) explains the process of fading as the teacher acting as a facilitator of learning and scaffolding student learning through modelling and coaching, and progressively fading their scaffolding as students become more experienced with IBL. The teacher or facilitator is responsible both for moving the students through the various stages of IBL and for monitoring the learning process. The feedback from the focus group students supported this. Jamie and Amy agreed that they wanted me to teach them the skills and knowledge first before they start their inquiries (Video 5, Rooney, 2012e, Focus Group Meeting Reflections 1).

In terms of the students' understanding of statistics, the use of real data meant that the students were able to draw meaningful conclusions about the data. Because they were working with real data that concerned themselves, the students were more interested and thus were able to make insightful interpretations and apply a higher level of thinking to the analysis of the data. My reading of the literature supports this finding. According to Singer and Willett (1990) and Libman (2010) students find real data intrinsically interesting.

4.3. Reflection on Cycle One

I was starting to see more congruence between my educational values and my practice as a mathematics teacher. I identified at the beginning of the research process that I value student engagement, self-directed learning, students taking responsibility and accountability for their own work and a positive attitude towards the learning of mathematics in my students. The key improvement to my practice I could identify at the end of cycle one was increased student interest and engagement as illustrated in the students' feedback (Video 4, Rooney, 2012d), the students' enthusiasm in their classroom activities (Video 2, Rooney, 2012b) and their eagerness to share the results of their inquiries (Video 3, Rooney, 2012c). The students were self-directed in negotiating with their group members to plan and orchestrate their inquiries (Video 2, Rooney, 2012b). I also succeeded in allowing the students to take ownership of their own learning in the classroom by facilitating a student centred classroom (Journal 3). However, because they were sharing responsibility for the inquiries with their group members, I did not encourage the students to take responsibility and accountability for their own work.

One of the main stimuli behind the research was my desire to encourage higher order thinking among my students. Although there was some evidence of higher order thinking in the class discussions (Video 3, Rooney, 2012c) and the students' activities (Video 2, Rooney, 2012b), I had yet to ascertain any concrete evidence of higher order thinking in their written work. Similarly, I encountered problems in asking the students to pose their own questions. Research acknowledges that writing good statistical questions is problematic for students (Arnold, 2008 and Wild & Pfannkuch, 1999). It is important to ensure that students have sufficient interest, knowledge or experience in a topic to pose meaningful questions (Arnold 2008, Chin & Kayalvizhi 2002). It was at this point that I considered CensusAtSchool. CensusAtSchool is an online questionnaire for students and the questions are based on teenage interests and experiences (Townsend, 2006 and Marriott et al, 2009). The worldwide database, which contains well over a million responses, can be sampled over the Internet for use in creating teaching and learning materials (Connor, 2002). I believed that I could employ CensusAtSchool as a means of helping the students to come up with interesting and sensible questions for their individual inquiries.

At the end of my first cycle of action research I reflected that inquiry-based learning is time consuming. I underestimated the time it would take to carry out the planned activities, which led to my decision to abandon the students' individual inquiries. I now recognised that inquiry-based learning takes time and that I needed to be more flexible with the time I allocated to activities. It was clear to me, going in to cycle two, that inquiry-based learning requires rigorous planning and preparation by the teacher. I had dedicated considerable time to planning and preparation in cycle one. However, I could see that if I had been better prepared at certain stages, such as pre-empting the students' difficulties in posing sensible questions and providing more guidance at this stage, things could have run more smoothly.

4.4. Cycle Two

My focus in cycle two was on the students' written work. I planned to use two methods in order to encourage the students to put more effort into their written conclusions. Firstly, I would try to motivate the students by offering prizes for the top projects and weighting the marks for their projects in favour of the written parts. Secondly, I would try to ensure that the students were clear on what I expected from them, by preparing a sample project and setting clear criteria for their projects. Students are more likely to put forth the required effort when they clearly understand the task and the learning goal and know how teachers will evaluate their learning (Marzano, 1992, cited in McTighe & O'Connor, 2005).

As the students had experienced a guided inquiry approach in cycle one and were no longer novices to inquiry-based learning, I decided to adopt a more open inquiry approach in this cycle. Banchi and Bell (2008) contend that it is only appropriate to facilitate students conducting open enquiries when they have demonstrated that they can successfully design and carry out investigations at the structured and guided levels of inquiry. At the open inquiry level the student is responsible for all aspects of the inquiry (Bell et al, 2005).

I combined a guided inquiry approach with an open inquiry approach. At the beginning of the cycle, during the data generation stage and setting up for the project work, the inquiries were more guided. During the project work and presentation stages the students made all the decisions about their inquiries and how they presented their results. Pathway's view is that combining two types of inquiry is called a coupled inquiry.

In cycle one the students had great difficulties with posing a question to investigate. To address this I decided to use the CensusAtSchool online questionnaires in cycle two to help the students to come up with better questions. There are a significant number of measurements required by the CensusAtSchool questionnaire (Appendix 1) so I dedicated one lesson to filling out a hard copy of the questionnaire. My hope was that this would help to speed up the process of filling it in online. This activity took longer than I predicted – we spent one and a half lessons completing the hard copies of the questionnaire, 26th and 27th April. I wrote in my reflective diary on 26th April 2012 (Journal 5).

Video 6: The Bell Interrupts Filling in Questionnaire (Rooney, 2012f)

Once the hard copies of the questionnaires were completed we moved to the computer room so that the students could begin filling out the online questionnaires. This activity also took longer than anticipated (Video 6, Rooney, 2012f). I had predicted that we would finish the questionnaires on the 27th April but we had to return to the computer room for the following lesson on the 30th April 2012 to complete the task. In the CensusAtSchool lessons some classroom management issues arose, which I articulated in my journal entry on 27th April (Journal 6), I realised that I needed to anticipate this inactivity and ensure that the students are kept on task so that they are not afforded the opportunity to become unsettled.

Once the online questionnaires were completed I brought the students back to the classroom. The students worked on their projects on Tuesday 1st May and Wednesday 2nd May. Before these lessons began I spent some time setting up the room. I organised the desks so that the students could sit in groups of four. I put white paper, graph paper, scissors, glue and a set of coloured markers on the desks for each group to share. Research shows that this set-up can provide pupils with opportunities to explain and evaluate their own work in a peer group setting (Carr, 2010).

Video 7: Scaffolding for Cycle Two (Rooney, 2012g)

I felt that it was important, based on my experiences in cycle one, to explain to the students exactly what I expected from them. I went through the project instructions on a PowerPoint presentation (Video 7, Rooney, 2012g, Presentation 2) and I showed the students a sample project that I had prepared. (Appendix 3) Then I handed out instructions (Appendix 4), coloured card and a class dataset (Appendix 5) from the completed CensusAtSchool questionnaires to each student. I also handed out CensusAtSchool questionnaires so that the students could understand the class dataset. I set the students to work on their own projects and I circulated the classroom and offered guidance and encouragement where it was needed.

Video 8: Student Enjoyment in Cycle Two (Rooney, 2012h)

I found that the grouped seating worked very well for these lessons. I wrote in my reflective journal that the students were self-directed (Journal 7). They negotiated with each other and shared the equipment. Overall, I believe that the class was focused on the task. The students seemed to enjoy the project work and several students stayed back after the bell had gone to continue with their projects. In fact, when I looked at the recording (Video 8, Rooney, 2012h), I was astonished to see that when the bell sounded nobody moved, even though it was the last class of the day. They seemed to be in no rush to leave, which is certainly not the norm. The students spent two lessons (1st and 2nd May 2012) completing their projects in class time and several students came back at lunchtime and after school to work on their projects.

I tried to encourage the students to give more consideration to their written conclusions, as this was an issue in cycle one. I put up a marking scheme that weighted the marks so that the conclusion would be considered an important part of the project:

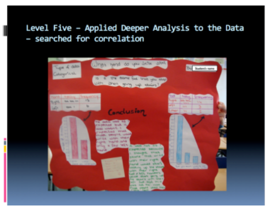
Tables: 10 marks
Charts: 10 marks
Design: 10 marks
Conclusion: 20 marks
Presentation: 20 marks

Bennett and Desforges (1988) and Sousa (2008) assert that if students are given challenging tasks that encourage the students to think at a higher level, then students' cognitive processing during task implementation stands a better chance of remaining at a high level.

Figure 2: Video stills of the students presenting their projects to the class

The objective of the final two lessons of cycle two was to allow all the students to present their projects (Figure 2). According to the National Research Council in the US (1996) one of the fundamental abilities of inquiry is to communicate and defend a scientific argument. Barrow (2006) argues that students should refine their communication skills by giving oral presentations that involve responding appropriately to critical comments from peers.

I gave the students one minute each and I timed them on a stopwatch. I questioned the students and I tried to encourage them when they were giving their presentations. The students listening seemed interested and also asked questions about each other's work. I recorded my observations in my reflective journal (2nd May 2012). (Journal 8)



Presentation 3: SOLO Taxonomy Evaluations (Rooney 2012)

I was impressed with the work the students put into their projects (Presentation 3). At the end of the presentations, I gave prizes to the best five projects, according to the marking scheme I set out. I gave the prize-winners Olympics mugs filled with sweets because I felt it was in keeping with the theme of the CensusAtSchool survey.

Video 9: Talking About IBL in Other Subjects (Rooney, 2012i)

In an effort to get feedback I asked three students, Brendan, Jamie and Neil, that I teach Resource mathematics to, if I could talk to them about their experiences in carrying out the projects (Focus Group Meeting Reflections 2, Video 9, Rooney, 2012i). The feedback was very positive. They said they really enjoyed doing the projects. Neil said he preferred subjects that allowed him to be creative and make things. All three students agreed that they would like if they could do project work in all their subjects.

I asked them if they preferred the individual projects in cycle two or the group work projects in cycle one. Jamie and Neil said that they preferred doing the projects on their own because they were responsible for all aspects of the projects and they did not have to negotiate with teammates (Focus Group Meeting Reflections 2, Video 9, Rooney, 2012i).

I was also interested in finding out if they felt that they had learned anything in doing the projects. All three students asserted the project work helped their understanding of data handling. Jamie said that it helped him to learn about the different types of data and how to draw tables and charts properly (Focus Group Meeting Reflections 2, Video 9, Rooney, 2012i).

4.5. Validating the Evidence

In order to validate our evidence we were required to take part in a validation meeting using Habermas' (1976) criteria to judge the legitimacy of our knowledge claims:

- A statement is true;
- A speech act is comprehensible;
- The speaker is authentic;
- The situation is appropriate for these things being said.

My claims to knowledge were critically evaluated formally at validation meetings with my fellow Masters students in DCU and with my supervisor, Dr. Margaret Farren.

4.6. Evaluating Higher Order Thinking Skills in the Students' Work

Video 10: Validating my SOLO taxonomy evaluations (Rooney, 2012j)

I examined the students' written conclusions to see if they could explain the data they had collected and if they had come up with good reasons for their results and shown a deep understanding of statistics (Presentation 3). I also looked at their graphs and tables to see that they were accurate and correctly labelled and that they corresponded with their written conclusions. For each project I assessed the level of understanding of statistics demonstrated by the student using Biggs' SOLO taxonomy (*ibid*). I justified my assessments at my final validation meeting on the 28th May 2012 (Video 10, Rooney, 2012j).

Table 5. SOLO taxonomy evaluations

Level of SOLO Taxonomy	Number of Students
Prestructural	1
Unistructural	1
Multi-structural	3
Relational	7
Extended Abstract	8

4.7. Reflection on Cycle Two

Using CensusAtSchool to generate data, although problematical at the initial stages, proved very successful. The students did not experience the same difficulties in coming up with reasonable questions as they did in cycle one. Also the quality of written work was much improved, when compared with their efforts in cycle one. This could be down to the students' interest in the data or the motivation of winning a prize or a combination of both.

The students enjoyed carrying out their inquiries and were thoroughly absorbed by their work. They were self-directed and self-regulated. During this cycle the students were challenged to engage at a higher level of inquiry (open inquiry). The students responded to this challenge and impressed me greatly with the level of effort that they put into their projects and the levels of understanding that they demonstrated in their work.

At the end of cycle one I felt that there remained some disagreement between my educational values and my practice. I had failed to facilitate the students taking responsibility and accountability for their own work, as they shared responsibility for the inquiries with their group members. In cycle two this was resolved as the students were responsible for all aspects of their individual inquiries and they could not rely on fellow group members. A further issue that emerged in cycle one was the poor quality of the students' written work and the lack of evidence of higher order thinking skills in their written work. My analysis of the students' work in cycle two using the SOLO taxonomy indicates clear evidence of higher order thinking. As I concluded my second cycle of action research, I could now see that I was now living more in the direction of my educational values.

4.8. My Core Values

Early in the research process I quickly identified that I value higher order thinking, student engagement, self-directed learning, students taking responsibility and accountability for their own work and a positive attitude to the learning of mathematics in my students. However these are not my core values that drive and motivate me as a human being and a teacher. In an effort to identify my core values, I read back through all my journal entries and I looked at my video recordings. The three core values that emerged glaringly to me from my writing and my interactions with the students in the video recordings were responsibility and accountability, inclusion and love.

Video 11: Articulating My Value of Responsibility and Accountability (Rooney, 2012k)

Responsibility and Accountability: I recognize that as a teacher, I am in a position of influence and I can negatively or positively impact on my students' learning experiences in mathematics. One of my key objectives is to foster a positive attitude to mathematics in my students and to make learning mathematics a less daunting experience for my students. In my teaching, I endeavour to make learning mathematics an enjoyable and engaging experience. I hold myself responsible and accountable for my students learning and enjoyment of my subject. In the final validation meeting on 28th May 2012 I explain why this is one of my core values (Video 11, Rooney, 2012k). Throughout this study I dedicated significant time to preparing the lessons and scaffolding the learning for my students (Video 1, Rooney, 2012a, Video 7, Rooney, 2012g). I also tried out the classroom activities in an effort to pre-empt any difficulties that the students may encounter (Journal 7).

Inclusion: Inclusion is about ensuring that all the students feel respected and valued. I understand that some students have difficulties with mathematics and I try to ensure that all the students can engage and participate actively in my lessons. In cycle two I tried to ensure that every student had a completed project. Unfortunately there was one student who did not seem to enjoy the project work. Brendan has several learning difficulties – he has been diagnosed with dyspraxia and dyslexia and he was recently diagnosed with autism spectrum disorder. He had great difficulties with this project and did not seem engaged with the task. I wrote in my reflective journal on 2nd May 2012. (Journal 8)

In the next lesson (Thursday 3rd April) I asked Cian, who had been absent for the previous two lessons and thus did not have a project of his own to work on, to help this student to finish his project. Thankfully this seemed to work well and by the end of the first presentations lesson Brendan had completed his project.

Love: I love the work that I do as a mathematics teacher and I care about my students. I appreciate the beauty of mathematics and I try to ignite a passion for mathematics in my students. A conversation with Dr. Jack Whitehead prompted me to acknowledge the 'life-affirming loving energy' that I feel in my practice as a teacher. I see it clearly in my video recordings. In cycle one when we were discussing the results of the group activities I could hear in my voice the fondness I have for my students (Video 3, Rooney, 2012c). In the feedback sessions with my focus group the students were relaxed and open with me, which is indicative of the good relationship I have built with my students (Video 4, Rooney, 2012d, Video 9, Rooney, 2012i).

My embodied values of responsibility and accountability, inclusion and love became my living standards of judgement (Whitehead & McNiff, 2006, p.150). In presenting my claims to knowledge to be validated in my final validation meeting on 28th May 2012. I used my core values that emerged in the course of the enquiry as my living standards of judgement. These values are responsibility and accountability, inclusion and love and I used video clips, students' work and journal excerpts to demonstrate how I am fulfilling them. I also demonstrated how these values had an influence for good on my students' learning. (Video 10, Rooney, 2012j, Video 11, Rooney, 2012k)

5. Conclusion

5.1. My Learning

This study has greatly improved my understanding of how to integrate inquiry-based learning into my teaching. I have not only gained a working knowledge of the difficulties that may be encountered along the way but also first hand experience of the benefits that may accrue. The conclusions I have drawn and my key learning points are as follows:

- Inquiry-based learning requires rigorous preparation;
- Inquiry-based learning takes time;
- Motivation is key to encouraging higher order thinking;
- Inquiry-based learning helps to encourage higher order thinking;
- The students enjoyed inquiry-based learning more than traditional didactic approaches.

During the research process I also came to acknowledge the core values that are implicit to my practice as a teacher. These core values are responsibility and accountability, inclusion and love. I gained a deeper understanding of my practice and I can now see that I am living more in the direction of these embodied values.

5.2. Final Thoughts

Inquiry-based learning changed the way that my students learn mathematics. There was clear evidence of higher order thinking in their project work. They were engaged, self-directed and took responsibility and accountability for their own work. The video evidence which is integral to the form of practitioner-research promoted on the MSc. in Education and Training Management (eLearning) programme clearly shows that my students enjoyed IBL and demonstrated a positive attitude to the learning of mathematics in their activities. In that sense, I could say that my research was successful. However, I feel that the real success was in the journey and not the destination. In carrying out the research I was compelled to look at myself and my practice as a teacher with honesty. I acknowledge the love and passion I hold for my job as a teacher, my subject and my students. I now have a much deeper understanding of my implicit values and how they influence and motivate my practice as a mathematics teacher.

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