

PHYSICS THROUGH COLLABORATION

by

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ABSTRACT

This investigation utilized collaborative strategies to look at how a more social approach to teaching physics curriculum would affect students' interest, knowledge and self-efficacy towards the science of physics. Students went on field trips to meet physicists and worked together in the regular classroom on physics concept questions through Interactive Engagement teaching methods called the 'Collaborative Group Concept Conflict Process' and 'Physics by Inquiry'. The Force Concept Inventory was used as a formative and summative assessment tool and student percentiles ranked at the top of existing data that utilizes Normalized Gain as a formula for summative assessment. It was found that students gained curricular knowledge, interest and self-efficacy towards the field of physics.

INTRODUCTION AND BACKGROUND

Project Background

School Environment & Classroom Experience

Pender Harbour Secondary/Elementary is on the Sunshine Coast of British Columbia (BC), Canada. To reach the school a 40 minute ferry ride from Vancouver BC, and a subsequent one-hour drive up highway 101 is necessary. The entire Sunshine Coast has a population of 27,759 residents with 2,642 permanent residents in the Pender Harbour area. With approximately 125 students, Pender Harbour Secondary/Elementary has a school population that is distributed between grades 7 to 12. Approximately 86% of students are Caucasian with 14% First Nations. There are 47% female and 53% male students at Pender Harbour Secondary/Elementary (Ministry of Education, 2008). The Sunshine Coast is a middle-income area, but Pender Harbour has some significant anomalies with regard to family income. Waterfront properties are sought-after in this area by boating/fishing enthusiasts from all over BC. These properties provide dwellings for a portion of the population well above the middle-income bracket. Non-waterfront properties, in Pender Harbour, are cheaper than most on the Sunshine Coast since Pender Harbour is quite a distance from any significant townships. Hence, a large proportion of students are bussed in from low-income rural settings. Pender Harbour Secondary/Elementary has adopted a breakfast program that is supported by donation. This service helps to ensure that some of the basic needs of the lower income students are met at the start of each day.

At Pender Harbour Secondary during a seven-week period from January 30 to March 15, 2012 I investigated Physics 11 instruction using a predominantly qualitative action research model. I have taught physics concepts in the past in late intermediate science classes and in Sci-Tech 11 classes, but this was my first journey into senior physics instruction. Even though I had not taught physics at the senior level I felt that my endeavor to do so was a step in the right direction for our school. During my undergraduate courses to become a Technology teacher, many areas of the Physics 11 curriculum in BC were covered. As a result of our small school population we do not offer a varied course selection. The senior science classes we offer have a diverse range of students and ability levels. I was comfortable with a diverse make-up of students in my physics classroom, as well as being a first time senior physics teacher. Eric Mazur (2010), an undergraduate physics instructor at Harvard University for many years, has stated through his thorough look into conceptual physics instruction, that a physics teacher who is not educated too far beyond his/her students may be more in tune with their learning needs.

The overriding philosophic perspective on education in the province of BC is one of teacher autonomy. I agree with an autonomous perspective as an educator and also believe that following curricular standards set out by the region in which I teach is necessary. Standards are well documented in curricular guides. I choose to interpret the *methods* of implementing standards as the area in which teacher autonomy should be exercised.

My experience in the last decade as a teacher of technology, social studies and science courses has led me to recognize that collaboration between students and their

peers, along with collaboration between students and role models in subject areas, helps connect students with the subject matter they are learning and the career options that are available after high school. The conceptual framework of my action research is concerned with looking at how to create a Physics 11 classroom that enhances learning by utilizing the social nature of collaboration, be it with classroom peers, or science role models/mentors.

Focus Questions

The focus of the study is to see if collaborative peer problem solving in the Physics 11 classroom, and field trips to initiate collaborative connections with scientists in their professional settings, motivates students to become more capable and interested in the field of physics.

- Sub Question 1: Does the use of the Collaborative Group Conceptual Conflict Process (CGCCP) as a peer teaching method help girls as well as boys understand physics concepts?
- Sub Question 2: Do collaborative teaching strategies, such as CGCCP, that focus on a more social regular science classroom help girls as well as boys enjoy learning physics?
- Sub Question 3: Does a teaching strategy such as the CGCCP and connections with scientists in the field have a more noticeable affect on girls than boys with respect to self-efficacy and interest in the field of physics?

CONCEPTUAL FRAMEWORK

British Columbia Provincial Curriculum Guides

Curricular guides in BC Canada are termed Instructional Resource Packages (IRP). The K-10 science IRP's all incorporate the idea of *peer teaching* as a classroom model for instruction (BC Ministry of Education, 2008). The Physics 11 IRP brings in the notion that “teachers should ensure that classroom instruction, assessment and resources... incorporate positive role portrayals” (BC Ministry of Education, 2006, p.9). The Technology 8-10 IRP incorporates the notion of *self and society* as a curricular organizer (BC Ministry of Education, 1995). The technology teaching curriculums combine the fields of science, technology, engineering and math (STEM) with an applied, or real world lens. Of all the sciences, physics is the one that is most thoroughly investigated in technology curriculums. This literature review takes a look at how peer teaching and positive role portrayal can be viewed as variables that, if effectively conceived, can construct necessary bridges for students between physics concepts and physics careers. This bridge should foster an understanding of how self and society may interrelate to create positive science interest, stereotypes and feelings of self-efficacy in both boys and girls in their science classes.

Ontology: Constructs of Being

Self, Society and STEM

The field of technology teaching stresses cooperative, social and real world instruction to promote parity between technical knowledge and technical

careers. Spindler suggests that to avoid stereotype threat and approach a career in the areas of STEM, girls should be directed to the real world professional environments of STEM workers. There is ample evidence to support promoting mentorship possibilities early, often and as frequent as possible in science (Glynn, Taasobshirazi, & Brickman, 2006; Goebel, 2010; Jones, 2010; Madill, Montgomerie, Armour, Fitzsimmons, Stewin, & Tovell, 1997; Spindler, 2010). The University of Alberta conducted a research project called Women in Scholarship, Engineering, Science and Technology (WISEST) as a summer research program for grade 11 girls. The project concluded that a quick one-day visit to a campus setting was effective in giving students the information necessary to decide whether or not to pursue education/career directions in science and related fields. Beyond the one-day visit, a six-week summer research environment with professionals was found to promoted a positive sentiment towards these education/career directions. It was also found that a traditional classroom lecture situation was the least effective at promoting positive feelings towards science related careers (Madill et al., 1997).

Differentiated Instruction

The different instructional needs that relate to gender in the STEM areas are well documented. (Christianson, 2010; Madill et al., 1997; Spindler, 2010). The sub field of physics is also well documented to have the least amount of interest by girls (Jones, 2010). Goebel's (2010) differentiated instructional style seems to nicely address the needs of girls in STEM and she outlines them as follows.

Specific Instruction for Girls

- Interpersonal connections when presenting material

- Consider their ideas and encourage them to verbally expand upon their thoughts
- Assign project based coursework
- Present curriculum with relevant connections to the real world and relationships
- Provide positive feedback whenever possible (Goebel, 2010)

Gender specific research in science/physics suggests that girls would greatly benefit from differentiated instruction, whereas boys are interested in STEM areas as a result of positive societal prototypes and stereotypes, and do not lose interest in these subject areas based on instructional styles with any notable significance (Taconis & Kessels, 2009; Zeyer & Wolf, 2010). Girls have been found to be noticeably more critical of their academic abilities at the high school level, be affected by poor academic performance and diminished ambitions during the adolescent years, and also fall victim to stereotype threat in the STEM areas (Taconis & Kessels, 2009; Jones 2010; Goebel, 2010; Kim & Song, 2009). Early role model verification through mentoring, and peer teaching strategies that address differentiated gender needs, would seem to address the self and society needs of boys and, especially girls, with respect to creating a positive educational experience for students at the middle school science level (Glynn et al., 2006; Spindler, 2010).

The differentiated needs of girls outlined by Goebel implicitly correlate with the collaborative social nature of the study research questions. The next sections bridge these correlations more explicitly.

Positive Role Portrayal

The BC Physics 11 curriculum organizer promoting positive social role models is important since adolescents are beginning to formulate self-image prototypes and look for verification of those prototypes in their everyday experiences (Taconis & Kessels, 2009). Boys and girls appear to hold vastly different perceptions towards how to approach science stereotypes and their own prototypes in their peer social settings. Science subculture and student identity can be perceived as incongruent since science may not seem to allow for intellectual freedom or self realization (Taconis & Kessels, 2009). The more socially varied the course presentation, the more acceptable it can become to each child's constructs of social development as they intertwine with the constructs of their course knowledge (Bruner & Haste, 1987). Bruner emphasizes, "there is no unique sequence for all learners, and the optimum in any particular case will depend upon a variety of factors, including past learning, stages of development, nature of the material, and individual differences" (Bruner, 1966, p.49). Also, to make a student's course experience more complete, the encouragement of social interactions with science role models of much higher ability levels as possible mentors outside of the regular classroom is a very positive endeavor (Madill et al., 1997; Taconis & Kessels, 2009).

Field Trips

The use of field trips with middle-school students is an effective way to engage students in the field of science. Christianson (2010) relates that boys and girls generally enjoy experiential education opportunities and that negative memories of past field trips usually relate to physical discomforts and longevity of travel. One-day quick workshop

fieldtrips have shown to be a very effective format for promoting interest in science in girls (Spindler, 2010; Madill et al., 1997). One-day field trips organized around the idea of creating connections with science professionals should be very effective if the comfort needs of the students are taken into account before and during the field trip so that students will not be tired, dehydrated, cold, wet, injured etc. (Christianson, 2010).

Epistemology: Constructs of Knowledge

Peer Teaching

The BC K-10 science assessment idea of peer teaching can be interpreted as a type of peer instruction, a term used to describe collaborative strategies used in lecture environments by Eric Mazur (2011). Peer instruction effectively solves some problems inherent with the traditional ‘teach by telling’ lecture model that many students find ineffective (Bernhard, 1997; Costenson & Lawson, 1986). Mazur’s peer instruction model utilizes what is termed the Force Concept Inventory (FCI) multiple-choice test regarding Newton’s Laws of Motion. The FCI is used as a pre and post-test to decipher whether or not increased physics conceptual understanding has resulted in his undergraduate physics classes that practice peer instruction. The original FCI multiple-choice test was created at the University of Arizona in 1992 (Hestenes & Swackhammer, 1992). Hestenes states that the test was specifically designed to address preconceptions students have towards Newtonian physics. If student pre-conceptions are not found out and eradicated, Hestenes suggests they may lead student towards continued misconceptions in the field of physics. Newtonian physics is the result of Isaac Newton creating his own cognitive constructs through his physics laws to help him go beyond the

misconceptions of past scientists (Hestense, 1992). Therefore, it seems it would be necessary for students to understand the paradigm of Newton's constructs without any misconceptions for them to attempt to approach the real physical world with his scientific model. Data collected by Hestenes shows there are two Newtonian concepts that are the most troublesome for students who have taken his FCI. Hestenes realized most misconceptions in Newtonian physics fall away if the theory of impetus, and dominance principle are first addressed with appropriate instruction (Hestenes et al., 1992).

What is important to take from the vast body of research that accompanies Mazur's peer teaching style and use of the FCI is that conceptual/cognitive conflict must sometimes occur for students to go beyond misconceptions and continue to learn towards higher levels. One study done by Richard R. Hake (1996) took data from 62 introductory physics courses spanning American high schools, colleges and universities that surveyed $N=6542$ students. Included in the study were 14 high schools with $N=1113$ students as part of the survey. The Mechanics Baseline Test (MBI) and FCI were used by Hake to produce his survey results. The MBI is a quantitative test used mainly as a post-test and the FCI is a qualitative pre/post test concerned with physics concepts. The Hake study compares the traditional teach-by-lecture model with Interactive Engagement (IE) teaching styles, which includes peer instruction/collaboration models, and found these IE models to increase student FCI scores by almost two standard deviations above traditional teach-by-lecture methods (Hake, 1996).

Physics by Inquiry

Another IE teaching method of importance is the inquiry-based model developed by the Physics Education Group at the University of Washington, which emphasizes

tutorial material that is research-based. Gregory E. Francis of the Department of Physics at Montana State University (MSU) conducted a study based on his implementation of the University of Washington's inquiry-based Tutorials in Introductory Physics. In his study, Francis delves into whether or not previous students of his, who had had pre/post FCI testing in an introductory undergraduate physics program, retained their knowledge over a significant period of time (Francis, Adams, Noonan, 1998). One hundred and twenty seven students from his fall 1994, 95 and 96 terms were invited back to MSU and were re-administered the FCI test in the fall of 1998. It is important to note that the original pre/post FCI test normalized gain findings of $g=.55$ that the MSU students achieved, while enrolled in their inquiry based physics course, were consistent with the findings of IE method use in Hake's (1996) study. Further to this, the 127 students that came back years later scored in a range consistent with the normalized gain of 55%.

Conceptual/Cognitive Conflict

The current educational theories concerning how adolescents construct knowledge can be traced back to Piaget's theory of social interaction on cognitive and moral development (Piaget 1932, 1959). Piaget asserted that children had to be in a state of disequilibrium as a result of a cognitive conflict to learn (Piaget, 1929). In the early eighties some strategies began to be investigated on how to bring students' thinking in line with scientific thinking through a conceptual change model of learning (Posner, Strike, Hewson, & Gertzog, 1982; Hewson & Hewson, 1983). The process of cognitive conflict can succinctly be described herein, "Piagetian scholars argue that cognitive conflict, a difference in perspective that leads to discussions of each partner's opinion, is necessary for development. In trying to resolve conflicts, partners have to explain to each

other their points of view.” (Tudge & Caruso, 1989, p.1). Studies have shown that this social process of explanation, or peer teaching, in which students discovered whether or not their reasoning was correct, resulted in greater improvements in understanding than if no discussion was held (Tudge, 1987).

Assessment for learning and of learning using conceptual conflict teaching strategies will be discussed next as part of the conceptual framework for the study. FCI data gives a sound body of data to support peer teaching at the high school level. Before moving forward, one important critical snapshot of the FCI usage in high schools should be noted. Any post-test gains are much more obvious in honors level classes compared to regular high school physics classes (Hake, 1996). The FCI is an assessment of learning. Possibly, the Peer Instruction method could be modified to embrace conceptual conflict in a slightly different fashion to enhance assessment for learning in the regular as well as honors high school physics classroom.

Collaborative Group Conceptual Conflict Process

There are a number of cognitive conflict models of varying forms. These models have been shown to be effective in fostering conceptual change (Guzzetti, Snyder, Glass & Gumas, 1993). One model of interest, the Collaborative Group Conceptual Conflict Process (CGCCP), has been shown to be more effective than Mazur’s peer instruction (Kalman, Milner-Bolotin, Antinirova, 2010; Thornton & Sokoloff, 1998). Conceptual conflict can occur when different student groups attempt to explain a phenomenon. The CGCCP is outlined briefly here as follows. Students form groups to work on solving a physics phenomenon. Each group comes up with an explanation. Different groups may come up with different conceptual explanations of the same phenomenon and thus

conceptual conflicts take place between groups, *not individuals*. Groups are then asked to explain their conceptualizations with a question and answer period and then the class votes on the most plausible conceptualization of the phenomenon. The instructor then demonstrates the correct solution. This process is considered non judgmental and meaningful at the same time (Kalman et al., 2010).

The Peer Instruction model is notably different. Students are shown a multiple-choice question on the board and are asked to give their response. Once answered, student responses are separated into two large groups, those with correct answers to the problem and those with wrong answers. The *individuals* with the wrong answers discuss the possible right answers in groups of two to three and then resubmit their answer. This process would not seem to enhance an enthusiasm for public discussion at the high school level. Peer instruction may possibly reduce social interaction and interest in the long term and most likely create a gap between feelings of connectedness between self and society in the high school science classroom. The CGCCP model closely matches the differentiated needs of girls with its ability to promote interpersonal connections, consideration of ideas and non-confrontational positive feedback (Goebel, 2010).

Synopsis

The inquiry based physics, an IE method, has been shown to be very effective at teaching the subject of physics at the undergraduate level (Francis et al., 1998). Concept conflict strategies, like the Peer Instruction and CGCCP IE methods, used at the secondary level have been shown to be very effective with some form of pre-class preparation (Docktor & Heller 2008; Bernhard & Dalarna, 1997). Introducing concepts

utilizing the inquiry based tutorial model before the use of the CGCCP method would seem to follow hand in hand.

Effective peer teaching strategies, such as Inquiry and CGCCP, in the regular classroom only partially address a connectedness with self and society. The strategies may only lead to a feeling of self-efficacy in a subject area. Many boys already embrace the idea of a career in science as a result of societal gender specific role model prototype verification (Kim & Song, 2009; Takonis & Kessels, 2009; Zeyer & Wolf, 2010).

Bridging the gap between subject areas and positive role models may be done by taking students on field trips to meet professional scientists. These bridges have been shown to be effective for girls to appreciate STEM areas as a possible career direction (Spindler, 2010). Field trips should be conducted with consideration to individual student comfort level and time constraints so that the positive experience is not lost (Christianson, 2010; Madill et al., 1997; Spindler, 2010).

With *peer teaching* in the regular classroom utilizing *inquiry* and the *CGCCP*, and experiential field trips to promote *positive role model* mentorships outside of the regular classroom, student confidence in physics should promote a positive sense of *self* as it approaches *society* with respect to the careers that may result from learning the science of physics.

METHODOLOGY

The classroom treatment was conducted over a five-week period from January 30 to March 9, 2012. Two field trips were conducted prior to the classroom treatment and were on November 17 and November 30, 2011. The main focus of the study was to see if collaborative peer problem solving in the Physics 11 classroom and field trips to initiate collaborative connections with scientists in their professional settings motivated students to be more interested in the field of Physics. The study started with a fun field trip to 'Science World' in Vancouver BC as an initial motivational kick-start.

The fun one-day trip was to a facility that provides high school educators across the province extra curricular science opportunities. The next trip was specifically planned as a mentorship/collaborative connection trip to the University of British Columbia (UBC) to promote *self and society* connections. These two intrinsically different types of trips were chosen for compare/contrast type data analyses. Before the first field trip a pre-treatment Science Interest Questionnaire (SIQ) was administered that was also administered after the last field trip as a post field trip treatment questionnaire (Appendix A). The SIQ was comprised of 10 questions that looked at student motivation to learn science and self-efficacy towards learning science. Also administered was the Draw A Scientist Test (DAST) as a pre treatment that would be revisited at the end of the study for post treatment analysis (Appendix B). The DAST was a way to look into how the study experiences affected students' conceptions of themselves as possible scientists. After each field trip students wrote down their thoughts in their Field Trip Journal (FTJ) sheets and submitted them for interpretation (Appendix C). I also wrote my reflections

down in an observation log that was completed during and after each field trip to aid in my data analysis interpretation.

At the start of the classroom treatment period and prior to the first CGCCP session the Force Concept Inventory was administered as a pre-test that would be given again mid-treatment and as a post-treatment (Appendix D). The FCI pre-post data was analyzed with the normalized gain formula (Hake, 1996). The CGCCP Process consisted of five classroom sessions, one at the end of each week following inquiry based physics instruction (Appendix E). Also, before the first CGCCP session, students completed the Learning Style/Interest Questionnaire (LSI) pre-treatment survey (Appendix F). The LSI delved into whether or not students initially thought they would benefit from a group work setting, and was administered at the end of the five CGCCP sessions to see any changes in students' perceptions of their learning styles. As the study progressed through each of the five CGCCP problem solving sessions students in the groups rotated between five roles, which are as follows: 1) Time keeper, 2) Critic, 3) Facilitator, 4) Recorder, 5) Presenter. Changing roles caused each student to be actively engaged in the CGCCP process and also gave students a chance to experience it from different perspectives each time.

For the treatment of the first CGCCP session, students were introduced to the concepts of speed, velocity and acceleration through inquiry classes. After the inquiry classes, but before the CGCCP implementation, students were individually asked to write down the answer to the first CGCCP concept question. After individual students handed in a pre-CGCCP Question Written Responses (QWR) to the concept question, they were put into groups to start the CGCCP session (Appendix G). Students discussed the answer

to the concept question for approximately seven minutes as I circled among the groups to observe. Next, the two class groups were asked to have their presenter explain their answers to the class. After the explanations I facilitated a brief discussion session with the presenters, and the class voted on the most plausible explanation. I gave the right answer after the vote. Students described the CGCCP in their journals, and I described it in my CGCCP log. The next four CGCCP treatments followed the same implementation pattern.

When each of five CGCCP processes were complete students were asked to answer three questions as part of the CGCCP Post Concept Written Survey (PCWS) (Appendix H). The questions related to whether or not the CGCCP activity was enjoyable and aided learning.

The question relating to how much students enjoyed the CGCCP activity directly related to the main purpose of the study regarding social connections, field trips and interest in the fields of science. The initial written answer to the problem questions, and questions as to whether or not the CGCCP sessions helped students understand the problem, related to the first sub question concerned with the effectiveness of the CGCCP process itself. If the CGCCP process was shown to be helpful it would stand to reason that students should like it, which relates to the second sub question concerning enjoyment and motivation to learn science. The enjoyment and motivation aspect was examined with the pre treatment LSI and the CGCCP post treatment surveys.

At the conclusion of the study the Post Study Interview (PSI) was conducted (Appendix I). With this final data source the study's third sub question was looked into fully. The third sub question was concerned with understanding any differences in

opinion girls and boys may hold relating to self-efficacy and interest surrounding the science sub field of physics using collaborative techniques as a study method.

All the data sources described in the methodology are summarized in Table 1 below. The data sources as a grouping provide a way to triangulate information to help organize my focus and sub questions graphically.

Table 1
Triangulation Matrix

Focus Questions	Data Source 1 (Artifact)	Data Source 2 (Observational)	Data Source 3 (Inquiry)
<i>Primary Question:</i> SELF & SOCIETY Does peers & professional collaboration create a sense of connection to scientific fields?	Draw a Scientist Test (DAST) Pre-Post FIELD TRIPS	Teacher Observation Log. Field Trip Journal (FTJ) Post trips FIELD TRIPS	Science Interest Questionnaire (SIQ) Pre-Post Post Study Interview (PSI) FIELD TRIPS
<i>Sub Question 1:</i> PEER TEACHING CRITICAL THINKING Collaborative Group Concept Conflict Process (CGCCP). Does social collaboration build problem solving competency?	Force Concept Inventory Test (FCI) Pre-Mid-Post CGCCP(5) Pre-session Question Written Responses QWR (5) PCWS (5)	CGCCP Teacher Observation Log concerning group activity CGCCP student group recorder notes	Learning Style/Interest Survey (LSI). Pre treatment (4 Physics Inquiry tutorial classes per week with 5 th CGCCP based on inquiry)(McDermott Physics Inquiry Model. CGCCP PTS (each of 5 treatments). Revisit QWR
<i>Sub Question 2:</i> PEER TEACHING INTRINSIC Does collaboration motivates physics Enjoyment?	CGCCP Processes(5) PCWS (5) Teacher Observation Log (CGCCP)	CGCCP Teacher Observation Log CGCCP student recorder notes	LSI pre treatment Survey Pre-Post SIQ PSI Post CGCCP PTS
<i>Sub Question 3:</i> PEER TEACHING EFFICACY Difference between boys and girls?	QWR PCWS DAST Pre-Post	Teacher field notes Teacher Observation Log	SIQ Pre-Post PSI Post LSI Pre-Post CGCCP PTS

DATA AND ANALYSIS

The first phase of my action research data collection involved two one-day field trips to assess the quality of the collaborative nature of science interaction with society for students outside the regular classroom. Acquiring an understanding of students' preconceived stereotypical attitudes towards scientists was essential for later post study analysis to assess students' continuing science prototype formation. The SIQ was administered to $N=8$ students before and after the two field trips for comparative purposes. $N=9$ students completed the DAST before the first field trip and after the end of the study to get an overall look at how negative stereotypes may have changed and positive prototypes may be forming. It became immediately apparent that stereotype threat and feelings of self/society connections were beginning to surface while conducting the data collection techniques and organizing the field trips. One of the students, who had handed in her SIQ and DAST, was the last to turn in her field trip permission forms stating, "I'd rather skip out those days and go snowboarding since they are just field trip days." When I explained the nature of the mentorship aspect of the UBC trip she was still unchanged in her steadfastness to avoid the field trips. When I explained that the UBC trip would be conducted by a woman originally trained in physics in the Ukraine and further educated at the University of Texas and UBC, she said "I'm Ukrainian, awesome, sounds like fun!"

The SIQ gathered data using a five choice Likert Scale consisting of ten questions. With all individual tests scores tallied, five responses for each of 10 questions from nine students totaled together, a sample size of $n=400$ would produce 100% interest

as a group of students. Interest in science on the pre-field trip SIQ as a group was shown to be 67%. Interest from the post-field trip SIQ was again 67% overall. There are, however, significant differences on three of the questions when comparing the pre and post-tests. This 67th percentile would fall between the third and fourth choices on the scale, showing interest in science around the center of the scale leaning slightly towards the more interested side of the scale. One SIQ question that may give more insight into why science interest in students is not much higher seems to have resulted from students being asked to ponder whether: *My friends and I talk about science and technology*. This question, with its underlying STEM social extrinsic implication, resulted in the lowest overall agreement on the entire SIQ at 58% on the pre-test and 55% on the post-test, which just hovers between the *Rarely* and *Sometimes* responses. The next lowest tallied question at 63% on both the pre and post-tests inquired whether: *Science and technology subjects are discussed at home*. Both of these low ranking percentiles show in areas that look at the social nature of science knowledge in general.

One student that came on the fieldtrips but was not in my Physics 11 course yet, because of timetable conflicts, but who later joined the course two weeks into the treatment period, specifically added written information about one question. When asked if *I am good at retaining science concepts when I learn them* he couldn't decide between the mid scale responses of *Sometimes* or *Often* on the SIQ Likert Scale. His statement that it depends "if it interests me" again hints at the intrinsic value students attribute to science knowledge and the overall importance they attach to it in their daily lives. If this student is uninterested he indicates lower on the Likert scale compared to all students, and if he is interested he indicates higher on the Likert scale compared to all students

concerning his conceptual science retention. This student was also enrolled in my mechanics course and was thoroughly enjoying it. Throughout the physics 11 course he continually asked which aspects of physics related to mechanics and engineering, which seemed to be his interests.

The final question on the SIQ, geared towards feelings of intrinsic efficacy, asked if *Understanding science makes me feel smarter than other subjects*. On the pre-test this question tallied 78%, the highest of all questions, which would be right between the *Sometimes* and *Often* responses. A 68% overall score on the post-test on this question hinted at something altogether different. Possibly, the field trips showed students a more complex understanding of the interaction of science and science professionals. Possibly, for the students, science became part of a larger sense of self. Student responses seem to suggest the feeling that they were now smart enough to be scientists, whereas in the past they may have held the stereotype that they had to be smarter to become a scientist.

The most dramatic change in percentiles was from question five, which inquired into whether students were more interested in learning science knowledge or getting a good science grade. The pre-test showed a 50/50 split on these opposing possibilities, whereas the post-test showed that students leaned towards a 65% interest in learning science knowledge over their grade. This is a healthy change in perspective that would seem to greatly promote learning science knowledge and retaining that knowledge.

The last question on the SIQ that showed a significant change was number six, which asked whether science facts would help students in their daily lives. There was an eight percent increase towards this sentiment from 70-78%, which again may denote a

growing appreciation for the value of science knowledge in general, and promote long-term science knowledge retention. SIQ group data percentiles are shown in Figure 1.

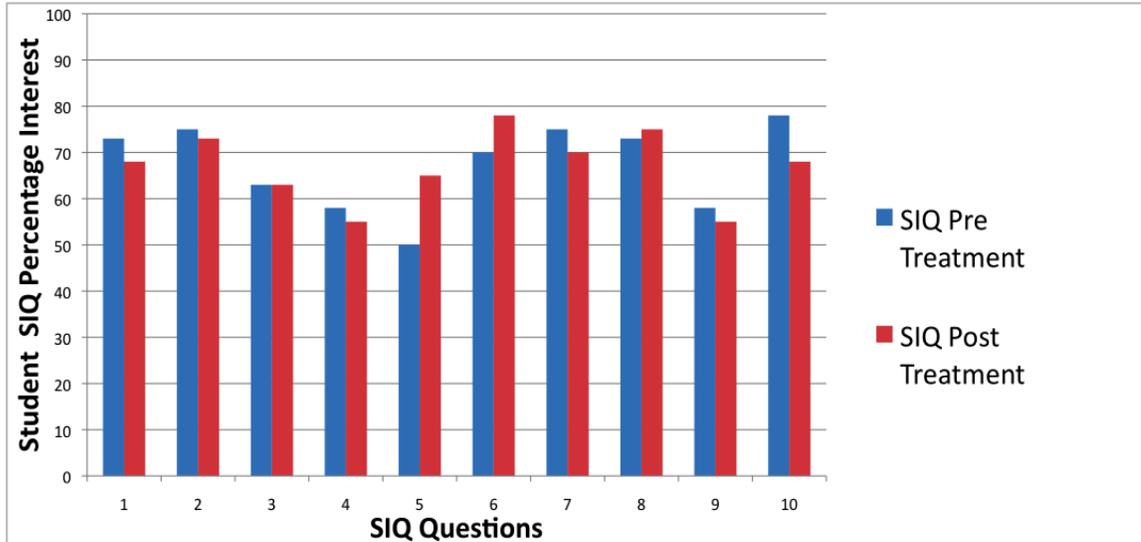


Figure 1. SIQ group data ($N=8$) students with ($n=400$) possible responses as a group.

The DAST drawing, with $N=9$ students, gave a nonlinguistic look at student stereotype and prototype formation. In the DAST pre-treatment drawings students showed 8/9 scientists as male, whereas the post-treatment DAST showed a trend towards personification in girls with now only 7/9 drawings being male. Lab-coats showed up on 6/9 of pre-treatment drawings as a statement of how a scientist looks, but significantly changed post-treatment with only 3/9 scientists drawn wearing lab coats. As a profession a chemist showed up in 6/9 pre-treatment drawings. The other three professions that showed up were one biologist, one astronomer and one technologist. The post-treatment drawings were markedly different with a drop to 3/9 students showing chemists, an increase to 3/9 showing physicists, 2/9 showing biologists, and one student drawing herself simply thinking (second picture in Figure 2). The student who is highlighted in

the pictures of Figure 2 offered that scientists would “have chats with other scientists”. Her pre-treatment DAST was the most stereotypical with the male scientist and the female assistant. Her post-test DAST moved from an extreme stereotype to what could be considered the other extreme as a very healthy prototype, showing herself simply as a girl thinking about concepts. She later described a scientist as “passionate, curious, intelligent... thinking deep thoughts”.

With nine students and six areas to give written statements describing scientists on the DAST, 40 descriptive words resulted. Themes showed up as modes of equal weight. Thirteen words emerged relating to *Intellect/Intelligence* that a scientist should exhibit, as well as thirteen words relating to aspects of *Experimentation*. Other themes were categorized as, *Profession, Research, Persona, and Social Collaboration*.



Male lab-coat wearing chemist-stereotype



Girl learning science-personification

Figure 2. Pre and post-treatment DAST from female student.

One student of interest described a scientist as “eating” and “sleeping”. This student was the only one to draw himself as a scientist and, in particular, a field biologist in Figure 3. This student’s father teaches science courses at a local university, which sheds light on his particular prototype formation. He could be considered an outlier within this group of students for his unique and pre existing in-depth understanding of the

nature of science and scientists in general from his home life. This may have given him the ability to personify himself as a scientist at a young age. However, his post treatment DAST showed the possible influence of my Physics 11 course in that his second drawing moved more towards a serious representation of an adolescent science prototype than a tongue in cheek junior science superhero. The second picture denotes a description of, “any normal person with an interest in science” holding a science degree. He further describes his post treatment prototype as “talking to friends, maybe relative to science”.



Student biologist-personification



Adolescent as scientist-personification

Figure 3. Pre and post-treatment DAST from male student.

Another descriptor that showed up with 13 word responses was in the thematic area of *Experimentation*. Students described scientists as “data collectors”, “experimenters”, “field researchers”, and “report writers”. Of particular interest was the theme termed *Social Collaboration*. This theme drew the least results on the pre-treatment DAST with only two student statements. Both students who hinted at *Social Collaboration* were girls. The statements they made described scientists as “chatting with other scientists” and “interacting with scientists”. This apparent lack of understanding of the social nature of science by most students gets to the heart of the study and the DAST data inquiry.

Triangulating the artistic representation of a scientist with linguistic statements shows a mild discrepancy between how students sketch and scribe ideas. The thematic area of *Profession* showed that half of student written response statements concerning scientific fields thought of scientists as chemists, compared to the 6/9 students who drew chemists. One student stated that scientists are involved with electricity in Figure 4. This student was the one who drew a scientist observing the stars above. He was not in the first two weeks of the classroom treatment because of timetable issues but joined at the start of the third week. I thought it would broaden his horizons to see physicists in the university setting on the mentorship field trip, which is why he came along. His post-treatment DAST reflects the second portion of our UBC field trip experience. After spending time with Dr. Marina Milner-Bolotin in the education building we went across campus to meet her husband, Dr. Valerie Bolotin, at the Physics building on campus. Dr. Bolotin is in charge of an experimental lab utilizing laser technology. The field trip experience showed in the students' post-test DAST as a specific constructive statement of real world science prototype formation.



Pre-treatment. Student as astronomer



Post-treatment. Student as laser technician

Figure 4. Pre and post treatment DAST student as physicist.

Of significance is the fact that the post treatment DAST showed 3/9 students now envisioning themselves as physicists, compared with *none* on the pre-treatment. Students were swayed from a 6/9 to 3/9 as a chemist towards physics.

Post-treatment DAST statements concerning social collaboration that now numbered five responses compared to the two pre-treatment responses. The notion of a scientist exhibiting *Intellect/Intelligence* cropped up in 20 statements, an increase over the 13 of the pre-treatment. This change may be a statement that students seem to have been lead away from the idea of scientists as solitary experimenters. The 13 statements relating to experimenting were reduced to five on the post-treatment DAST. Another possibility could have been the heavy emphasis on the conceptual thinking relating to the use of the FCI as an assessment tool. The FCI usage could have contributed to a change in perspective between rational and empirical science knowledge acquisition from the pedagogic structure of my Physics 11 course through the continuation of the course into the CGCCP process. Looking at the increased statements towards *Social Collaboration* with a more rational outlook towards conceptual thinking and a more social way to interact empirically through inquiry with informal conceptual student discussions seems to show up in the written portion of the post-treatment DAST.

The LSI looked at how students perceived their learning patterns before the physics 11 course, and then after the treatment period. The first and third questions on the LSI asked students what the most effective teaching style was for them to learn science. Students chose from, *Lecturing, Group Projects, Reading Textbooks, Discussions* and *Labs*. Some students chose two responses on question one and three, which caused me to separate them into a half answer for data collection purposes, so I chose to report the data

as percentiles for the LSI $N=9$ student data. By far the highest response was *Discussions* with 56% in the pre-data and 72% in the post-data. Students backed up their fondness for discussions with statements like “discussion is the only way for me to learn because otherwise I am not engaged”, “I enjoy working with my buds”, “I like asking questions - chat time” and “when you have multiple minds cycling through different theories and concepts, it helps me understand and remember”.

Question number three asked how students described themselves as learning, from *Reading, Listening, or Discussing*, science. Data again showed *Discussing* as the resounding popular choice with a pre-treatment of 72% and post-treatment of 83%. Not only did students seem to already intuitively know that discussing science concepts socially was effective, but both questions solidified this notion with fairly significant increases in the sentiment after the treatment period. One student summed it up nicely with a post-treatment statement when she said, “discussing science problems get concepts resolved in a back and forth discussion”.

The LSI also looked into the particular science fields that each student gravitated towards. Again, some students chose two responses here, which resulted in half answers that I chose to report as percentiles with the $N=9$ student data. An inquiry as to what field of science they understood the easiest yielded biology and earth science with equal interest ratings at 33%, with physics trailing at 22%. The post-treatment data showed physics tying with biology at 37.5% and earth science at 25%. A question that asked, *What field of science could you most likely see yourself pursuing*, showed pre-treatment data with a resounding response towards the field of biology with 61%, and only 11% physics. Post treatment data was altered with 44% choosing biology and 33% choosing

physics as the next highest choice. The last question on the LSI asked *which type of science interested them the most*. Biology and earth science tied with 33% as the highest response and physics at 22% from pre treatment data. Post treatment showed a change to 38% biology, 18% earth science and 33% physics. All three of these questions concerning fields of science showed gains that favored an increase in physics understanding, appreciation/interest.

Now, a look at the core of the study: whether or not IE methods of instruction such as Physics by Inquiry (Francis et al. 1998) and the CGCCP (Kalman et al. 2010) were effective at promoting interest and conceptual physics knowledge acquisition in students at the senior high school level.

Specimen #2, as one of my students fondly referred to herself, explained “I feel that the inquiry gives me a better understanding of the material because of the hands-on part of the experiment. I can see the experiment happening and can work with other classmates to get a better understanding”, and when referring to her best friend, specimen #1 she added, “We will continue to monitor general morale and progress”.

Data was collected from $N=8$ students and is reported in percentile format based on the 30 questions on the FCI test. When the FCI was given to $N=8$ students as a pre-test before the IE methods the class as a whole achieved 22.5% correct answers. The FCI was administered again as a mid-treatment test and students as a whole achieved 32.5%. On the final post-treatment administration of the FCI students achieved 57% as a group. The normalized gain formula $g = \frac{\text{posttest} - \text{pretest}}{100 - \text{pretest}}$ was used to compare FCI pre and post-test individual and group percentiles (Hake, 1996). FCI test scores with my Physics

11 students over the treatment period showed a Group Normalized Gain on the FCI of 45%.

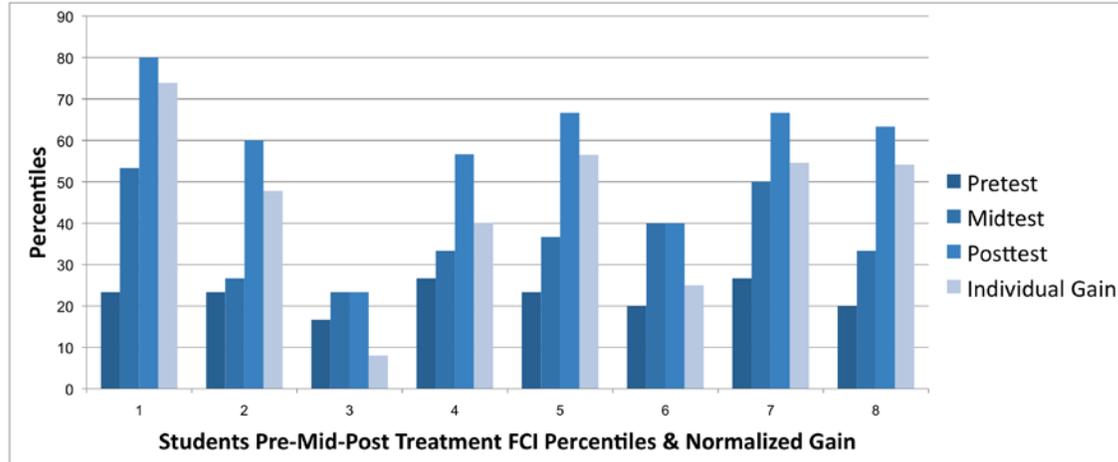


Figure 5. Individual Normalized Gain for Pender Harbour Secondary students, ($N=8$).

A 45% Normalized Gain in a regular high school senior physics course falls slightly above the highest regular classroom gain shown on the Hake plot, Figure 6. This gain is very acceptable since it has been shown in high school use of the FCI that most significant gains are realized in honors physics classes. Pender Harbour Secondary is a small rural school in which students often take senior academic courses since there are no other courses offered to fill their timetable with graduation credits. The third student on the individual gain graph is an example of this. She really isn't interested in the course but has to stay in it to graduate since she already dropped her Math 12 course because it was too difficult. She only realized an 8% gain over the treatment period and, if considered an outlier, the 45% group normalized gain would be even higher. One should also note that all of the high schools shown in the $N=1113$ student plot were in classes of 20 students or more, whereas my data is in a small group of $N=8$.

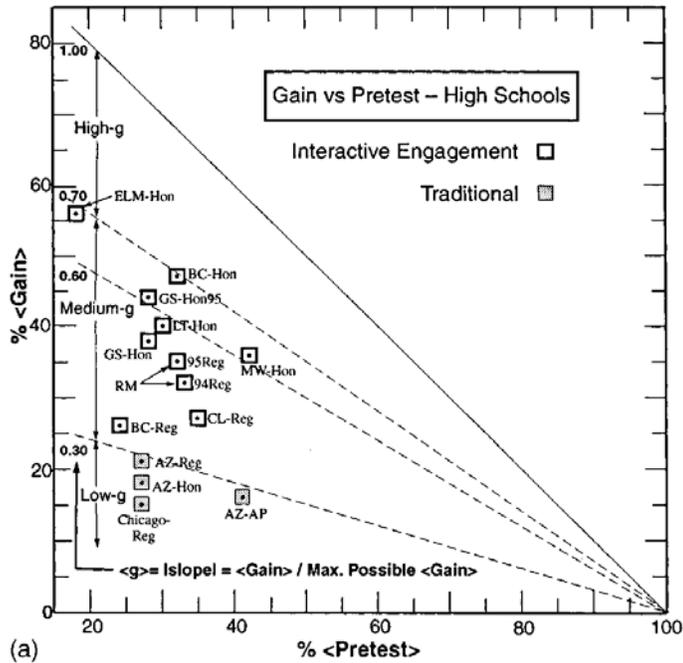


Figure 6. Normalized gain plot $N=1113$ high school students (Adapted from Hake 1996).

The CGCCP, which was administered on five consecutive Fridays to $N=9$ students, yielded 45 responses over the treatment period. The PCWS showed that students felt the concept activity helped them to understand physics concept problems more fully 87% of the time and that this made learning physics more enjoyable 92% of the time. The third and final question on the PCWS asked students whether or not their initial written response to the concept questions each week were right or not, and students reported that they were correct 77% of the time. All concept questions used in the CGCCP sessions were taken from chapter 11 of *Peer Instruction: A User's Manual* by Eric Mazur (1997). One girl, who got the answer to one of the concept questions right, initially offered after the group discussion activity that "I found out other ways to find the answer", and on another occasion praised the CGCCP by saying "because not everyone got it, it's nice for them to not just be 'wrong', but learn from it in a positive way".

Another student added after a group discussion, “I was initially wrong but I see why it was wrong and how to get it right in the future”. One boy exclaimed, “when looking at it by myself I couldn’t understand, but the group work allowed me to understand” and “This thing *does* promote learning”! One final statement would seem to sum it up nicely. One of the girls explained that “we were right but it still helped me to figure out WHY”. This is a telling statement since it became obvious as a teacher that when students conducted step #4 of the CGCCP process that getting the group to explain their answer and reasoning to the rest of the class showed that often students got the right answer but had the wrong reasoning. Possibly, they had just guessed correctly at times. Giving students the correct reasoning with the answer at the end of the CGCCP process was obviously an essential step.

The final source of data collected in the treatment period was qualitative in nature. The PSI gave a look into all aspects of the study. When asked whether they thought the CGCCP process helped wrap up the inquiry learning process, all but one student thought so. One student added “Yes, it brought the material we learned together into one question”. When asked if those CGCCP concept questions helped them overcome misconceptions on the PSI, 100% of students agreed.

The one boy that didn’t think the CGCCP wrapped up the inquiry but did agree that the CGCCP helped overcome misconceptions, seemed to exhibit a more hands-on empirical learning style. On the PCWS he stated each Friday on question number three that he got the answer to the concept question wrong on his QWR before group discussion. He indicated, however, that every group CGCCP process except one resulted in him understanding the right answer to the concept. At the end of the study his post-

treatment FCI score was by far the highest in the class at 80%, which showed a personal normalized gain for him of 73.9%. He is definitely a social learner and stated that he “would still like to do the inquiry experiments” because we had stopped doing them until we reached the light and optics portion of the course, which was after the treatment period.

Analyzing data concerning the difference between boys and girls in this study was looked at from a qualitative perspective ($N=9$ students). When asked on the PCWS if discussing problems in a collaborative way with peers made learning physics enjoyable, 92% of the 45 responses after all five CGCCP sessions were positive. There was no differentiation here between boys and girls. Other sources of data did not show significant differentiation either. This relates directly to the fact that my research led me to implement the treatment period in a way that suited girls’ needs (Christianson, 2010; Gobel, 2010; Madill et al., 1997; Spindler, 2010) and that boys would also benefit from this teaching style (Taconis & Kessels, 2009; Zeyer & Wolf, 2010).

I added one question to the PSI after discussions during the PSI interviews ($N=9$ students). One student made a statement that seemed to sum the treatment period up in a way that made perfect sense. She said that “Leaving the math for last makes it easier to understand in the end”. I phrased the additional PSI question in order to look into the pedagogic progression I had organized, which utilized the inquiry method, lectures and discussions, and finally the math as it related to their learning. Every student agreed that this was an effective approach. One student added, “we all learn differently and these steps made us all learn”.

INTERPRETATION AND CONCLUSION

This study provided evidence that a collaborative approach to implementing physics curriculum could result in student gains intrinsically and conceptually. The broader qualitative approach of adding field trips that connect students to a fuller appreciation of the fields of science beyond the classroom curriculum were shown to be effective. The interaction decision of one student to come on the UBC field trip after skipping out on the Science World trip because of an intrinsic connection of being Ukrainian, seemed to confirm my ‘Self, Society and STEM’, ‘Positive Role Portrayal’ and ‘Field Trip’ research towards stereotypes and subsequent prototype enhancement (Glynn et al., 2006; Goebel, 2010; Jones, 2010; Madill, et al, 1997; Spindler, 2010; Taconis & Kessels, 2009; Zeyer & Wolf, 2010). As a result of the UBC trip students became aware of possible career directions relating to physics that they had not been aware of before my Physics 11 class, as was shown in the field trip interviews.

The DAST was a good non-linguistic look into students changing belief systems towards stereotypes and their growing science personifications. The student in Figure 3 moved beyond his initial representation of a biologist, which is the field his father holds a degree in, towards his decision to get an electronics degree in his post treatment LSI statement, which is a statement of healthy science personification.

Another student made the statement that “scientists are involved with electricity”. This student, as seen in Figure 4, was the one who drew a scientist in a laser laboratory, and seems to have a real-world grasp of the subject areas of physics. He was not in the first two weeks of the classroom treatment because of timetable issues but joined at the start of the third week. He took an automotive course in the second semester, which is

another statement of his understanding of the real-world application of physics. He seems to have an innate grasp of the technological applications of physics and I thought it would broaden his horizons to see physicists in the university setting on the mentorship field trip, which is why he came along.

Without this student in the study there would have been a marked lack of understanding of the aspects of physics in the pre treatment DAST data. It should be noted at this point that *no* students registered at the start of my Physics 11 course actually envisioned themselves in any way as a physicist in the pre-treatment DAST. Part of the change in students towards drawing physics related subject area seems to come directly from a change from drawing chemists in the pre-treatment DAST. The two additional students who drew a physicist could be correlated with the three-student decline in chemist artwork. This could be viewed as a concrete statement of a real world constructivist prototype formation. Many of the students in my Physics 11 class had previously taken chemistry courses so it was easy for them to envision scientists as chemists from their past experience constructs. After the Physics 11 treatment period students now can envision scientists as physicists from constructed, triangulated experience. Hence the self and society nature of my study unfolds as classroom curricular experience with societal physics connections.

It was obvious from the beginning of the study from the FCI results that students needed instruction that related to conceptual understanding. The Physics by Inquiry IE method promoted an understanding of the vocabulary used in physics, and the lab apparatus and experimentation styles that enhanced a further understanding of physics concepts in a hands-on way with informal student discussion. Although quantitative data

was not collected that could be specifically attributed to the inquiry method in isolation, it was a necessary part of my students' learning process since it brought in physics vocabulary and physics lab processes. For most students this was their first experience with physics labs, concepts, formulas and vocabulary. To qualify the implicit positive effect of the inquiry process I need only refer to the fact that when implementing the FCI as a pre-test, student hands went up asking about the meaning of physics vocabulary words on the FCI test itself. The subsequent inquiry process and lecture with question periods that brought in an understanding of Newton's three laws helped iron out student misunderstanding along with the CGCCP process. I tailored these methods to specifically target Newtonian physics concept acquisition. The CGCCP became a more formal student discussion format, which helped iron out lingering conceptual misunderstanding. The inquiry and CGCCP IE methods also merged in a positive way, which addressed the more implicit social collaborative nature of the study.

The FCI was used as a formative and summative test with positive results. The pre-treatment FCI gave an indication of the lack of student understanding of physics vocabulary and concepts that they, as well as I, used to progress their learning. The student who received the highest normalized gain results is an individual I have taught for six years in social studies, science, and technology courses throughout high school, and he is definitely not usually an overachiever or a motivated learner. The inquiry, coupled with the CGCCP process, seemed to have greatly benefited this student conceptually, and motivated him greatly. He was determined to ace the FCI and continually asked me if we were going to write it again. This is a concrete example of a student using a standardized test as a formative tool to assess *for* learning, and *of* learning.

Using the FCI as a mid-treatment formative assessment was not as motivational for students as I had expected since not all concepts had been taught. As a result I asked students to tell me their thoughts after the mid term FCI had been administered, since a few students were feeling somewhat demoralized by their mid-test mark. I explained that they had been introduced to about only half of the concepts questioned in the test and that the majority of data collected on this test was from $N=6542$ university students. To help alleviate the disappointment for some of the students I changed the tone in the classroom by explaining that doing this test was a great way to connect them with higher physics education. This is a significant point since Mazur suggests that setting a motivated tone in the classroom is of utmost importance when peer instruction is undertaken, and attributes an entire chapter of his *Peer Instruction* book to motivating students (Mazur, 1997).

By happenstance two of the girls sat in on a 100 level psychology course at a local university on an orientation day shortly after their FCI mid-test. The next day back in my physics class the two girls could hardly contain their exuberance exclaiming, “the psychology professor was talking about common misconceptions people can have and used an example about physics...we were the only two students in her university class that got the question right because we learned the concept in your physics class”. One of the students drew the physics concept on her post-treatment DAST, Figure 7. The tone had been set once again. Students no longer questioned the use of the FCI as a formative assessment tool. The sentiment now changed to wanting to ace the test when the post-

treatment FCI would be administered.



Figure 7. Post-treatment DAST female student thinking about circular motion.

The FCI as a post treatment summative assessment tool gave concrete evidence that the IE methods used in the study yielded a normalized gain in the regular Physics 11 classroom that bettered comprehensive existing data. The 45% gain in my regular Physics 11 classroom was achieved in only 25 treatment period instructional hours compared to the usual 48 hours of a full course that I compared my data to (Hake, 1996).

Ultimately students did collaborate with professionals as well as peers in their burgeoning understanding of the field of physics. Combined were the effects of the field trips, group IE methods, FCI gain, and general positive feelings that resulted in students. The quantitative summative data of the FCI bolstered students' feelings of ability in the physics subject area. The study also seemed to achieve its qualitative purpose in promoting positive feelings within students relating to their science prototype formation.

The students seemed to feel a sense of connection between themselves and our culture of science and can now envision themselves possibly becoming a scientist in their career pursuits.

VALUE

In retrospect I gained more from this action research project than I could have imagined. This was my first attempt at teaching a senior academic science course, let alone the Physics 11 course. The students and I were learning at the same time. I was learning how to implement physics pedagogy and my students were learning physics curriculum. As a result of the study I have now seen the value in solid pre-existing data that supports the right direction in educational pedagogy relating to physics through IE methods. I also saw the value of using a summative test such as the FCI as a formative tool through its use as a mid-term test.

From the positive data collected in my study I have witnessed the value of the literature review I was asked to conduct in the MSSE program. Building on this, my study has led me to make conjectures as to how I could enhance my Physics 11 course implementation in subsequent years. My experiences have led me to think about how to enhance field trip experiences, positive role model formation, and classroom curricular implementation.

The unexpected richness of the field trip experience to see Dr. Marina Milner-Bolotin at UBC not only gave my students a professional/career connection, but also gave me a chance to see a professor in charge of physics pedagogy expertly conduct an IE session with my soon-to-be students. Although my students and I enjoyed a standardized field trip to a science centre, it just didn't connect students in a comprehensive way with science curriculum and professionals. The field trip to UBC became part of a curricular experience, a self and society experience.

It was quite obvious at the onset of the study that my research relating to science stereotypes/prototypes was confirmed through the use of the initial DAST, SIQ and LSI data collection instruments. Most students wondered what physics was or couldn't see themselves as physicists. The post study DAST and LSI information showed me that using the field trips along with a peer teaching/collaborative classroom model made physics more social in a way that made students feel like they were immersed in the field of physics, which could help them envision themselves as possible scientists in a career setting.

As a teacher the most important part was to see the collaborative aspects of the inquiry and CGCCP IE methods and the resultant quantitative data to support it using the FCI as a summative tool. I could see the conceptual awareness unfold in students as I listened to their informal questions during the inquiry process and their formal discussions during the CGCCP process. As a teacher I could tell that their gains would increase on the FCI since I could hear student discussions leading to ongoing formation of Newtonian concepts in the regular classroom setting.

As the course unfolded I pondered how one might move a predominantly conceptual physics course towards a more traditional algebra/calculus-based course in a cohesive merger of math ability supported by conceptual understanding. During the PSI interviews when asked whether or not the CGCCP process helped wrap up the science inquiry learning a student offered, "yes, I think it's cool to step back and do the comprehension stuff, it's nice to not just focus on the math". During a PSI interview with another student the math/concept discrepancy seemed to all come together for me as a teacher. She commented after the inquiry process "Holy, I liked physics after that. If you

see it you can understand it and it actually proves it. I can go back to it and say I really did the experiment!". This student had much more to add and an informal discussion evolved from which we decided on what really worked during the treatment period. We came to the realization that there was an underlying structure to my pedagogy that followed each chapter/section of the course in a very effective three-step pattern. First, let the students learn through inquiry until the point that an instructional session is necessary, which would give me an idea of which concept to present each Friday with the CGCCP process, second, give a 15 minute or so lecture with a question and answer period. Third, and most importantly, only when concepts were solidly planted for students, would I bring in the math formulas and word problems. This student found this three-step process very effective and as a result the math made sense in a pragmatic way to her.

There was more value than I expected in the correlative discussions that I had with students after the study. The idea of looking at designing physics courses with concept *vs* math, and girl differentiation *vs* boy differentiation began to form for me in a pedagogically conceptual way. There seemed to be a pattern emerging that I did not investigate in my conceptual framework for the study.

The CGCCP, Inquiry, PCWS and resultant FCI Normalized Gain scores gave me unexpected insight into the differentiated ways that boys and girls might be helped to acquire physics knowledge at their senior high school ability level. I realized from the one boy who answered none of the CGCCP question correctly on his QWR sheets, but who got the highest Normalized Gain on the FCI, that perhaps differentiated instruction should be looked at through a finer lens. This boy was conceptually very strong, but his math skills were quite average (Table 2).

Table 2
Boy/Girl Normalized Gain Scores

Normalized Gain. PHSS Students Physics 11 Regular	Pre Test Percentile	Mid Test Percentile	Post Test Percentile	NG Pre to Mid Percentile	NG Pre to Post Percentile
*Boy-Best Conceptual	23.334	53.334	80	39.130 %	73.914 %
Girl	23.334	26.667	60	4.348 %	47.826 %
Girl	16.667	23.334	23.334	8 %	8 %
Girl	26.667	33.334	56.667	9.092 %	40.091 %
Boy	23.667	36.667	66.667	17.391 %	56.522 %
Girl	20	40	40	25 %	25 %
Boy	26.667	50	66.667	31.818 %	54.546 %
*Girl-Best Math	20	33.334	63.667	20 %	54.167 %
Group NG				19.347 % NG	45.008 % NG

By contrast the girl in the class with the strongest math skills on tests, so good in fact that when I talked to her math 12 instructor I was told that she was also the strongest in her class at math, was only the 5th of 8 Normalized gain scores at 54.17%. I then looked at the other scores and realized that the top three FCI Normalized Gain Scores were boys, but they were all average at math. The top three math students in my class, however, were obviously girls. I did not, however, collect formal math data for my study.

To reflect and conclude, the 92% of responses on the PCWS, and 100% of responses on the PSI from students that the CGCCP was enjoyable and effective, confirmed to me that teaching to the social needs of girls would by design also support the boys' classroom environmental needs (Gobel 2010; Taconis & Kessels, 2009; Zeyer & Wolf, 2010). A further Action Research study could look into the differentiated needs

of boys from a mathematic perspective towards physics, from which I could possibly create a teaching style for the differentiated needs of boys that could, by design, also work for girls. Hence, a collaborative approach that focuses on the math curricular needs of boys alongside differentiated social conceptual strategies for girls could be informative. I could possibly conduct a study in the future titled, *Physics: Concept/Math Gender Differentiation*.

To summarize, my literature review guided me to posit the notion of *Physics through Collaboration*, which informed my pupils as learners and me as a teacher. This experience lead us to collaborate and brainstorm a three-step concept-math based pedagogic structure for my future physics implementation. Extrinsically, my socially collaborative action research has lead me to ponder a new direction in pedagogic study that would take a more specific look into the differentiated needs of boys and girls in the Physics 11 classroom. Intrinsically, my action research brought me full circle, from one perspective of the notion of *self and society* as an educator, to another, realizing my students as a creative *society* of learners who could also give construct to *myself* as a teacher.

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APPENDICES

APPENDIX A

SCIENCE INTEREST QUESTIONNAIRE

Name:_____ **Subject:**_____ **Date:**_____

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

To give your teacher a better idea of how you view your past science education and what interest you have in science topics, please answer the following questions thoughtfully.

1. I am interested in science ideas if I see them on TV
Always Often Sometimes Rarely Never
2. I take science courses because I like to, not because I need to
Always Often Sometimes Rarely Never
3. Science and technology subjects are discussed at home
Always Often Sometimes Rarely Never
4. My friends and I talk about science and technology
Always Often Sometimes Rarely Never
5. I am more interested in learning science than my science grade
Always Often Sometimes Rarely Never
6. I think that knowing science facts will help me in my everyday life
Always Often Sometimes Rarely Never
7. I imagine myself working in a lab or doing science field research
Always Often Sometimes Rarely Never
8. I am good at retaining science concepts when I learn them
Always Often Sometimes Rarely Never
9. I read books about facts, not fiction
Always Often Sometimes Rarely Never
10. Understanding science makes me feel smarter than other subjects
Always Often Sometimes Rarely Never

APPENDIX B

DRAW A SCIENTIST TEST

Name:_____ **Subject:**_____ **Date:**_____

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.



Imagine a scientist at work. In the space above, draw a scientist at work (use colored pencils).

A. Describe what the scientist in your picture is doing. Write at least 2 sentences.

B. List 3 words that come to mind when you think of a scientist.

1. _____ 2. _____ 3. _____

C. What kinds of things you do you think a scientist does on a typical day? List 3 things below.

1. _____

2. _____

3. _____

APPENDIX C

FIELD TRIP JOURNAL

Student: _____

Trip Location: _____

Was there any particular science field presented on the trip that you recall?

_____.

Did you meet any scientists on the trip in this field of science?

____ Yes ____ No

Did you learn any science knowledge on the trip?

____ Yes ____ No

Did you make any connections with scientists on the trip?

____ Yes ____ No

Did the displays/discussions teach you any science concepts?

____ Yes ____ No

If yes,

Explain _____

_____.

Please describe the field trip experience in your own words:

_____.

APPENDIX D

FORCE CONCEPT INVENTORY

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

The Force Concept Inventory is in 'Peer Instruction' by Eric Mazur

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ISBN-13: 9780135654415

or go to <http://modeling.asu.edu/R&E/Research.html> and scroll down to 'Evaluation Instruments' which explains the following:

Using your school e-mail, please request the password from David Koch FCIMBT@verizon.net, including your school name and location. Your signature in your request will be your promise to keep the test and password secure, as described in the document you will receive. David is a retired physics teacher who kindly volunteered in August 2009 for this service. (David asks that you include an alternate e-mail address if you think your school is very restrictive of outside e-mail. If you do not receive a reply within two days, ask for it again, from a different e-mail address.)

APPENDIX E

CGCCP PROCESS

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

The process takes approximately 20 Minutes

STEP 1

A problem is presented on a single PowerPoint slide. At the same time handouts with the problem are distributed to the students (one handout per group)

STEP 2

Groups of 3-5 students work together for about 7 minutes to figure out a solution to the problem. Students have taken on different roles: timekeeper, critic, facilitator, recorder, or presenter. Students' solution is recorded on the collaborative group (CG) worksheet.

STEP 3 (During step 2)

The instructor circulates among the groups observing students' work, As a result she/he selects two or three groups with different views on the solution and possibly different answers.

STEP 4

The presenters of the selected groups show their solutions (on the board) to the entire class. This is followed by a brief discussion between the presenters (3-4 minutes).

STEP 5

The instructor facilitates a question and answer period between the presenter and the entire class (3 minutes).

STEP 6

The class votes on the correct solution to the problem (2 minutes).

STEP 7

Using experimental evidence the instructor demonstrates the correct solution to the problem: video demonstration, real life demonstration using available equipment, etc. (2 minutes).

APPENDIX F

LEARNING STYLE INTEREST QUESTIONNAIRE

Name: _____ **Subject:** _____ **Date:** _____

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

- 1) What is the most effective teaching style for you to understand science concepts? Do you have an idea of why?
 - a) Lecturing (teacher talking)
 - b) Group projects
 - c) Reading textbooks
 - d) Discussion/question periods
 - e) Labs

- 2) What field of science do you understand the easiest? Why do you think this would be for you?
 - a) Biology
 - b) Chemistry
 - c) Physics
 - d) Earth science

- 3) Would you describe yourself as learning best from reading, listening to or discussing science?

- 4) Does studying for tests and test writing help you to remember science concepts?

- 5) What field of science could you most likely see yourself pursuing as you get older?

- 6) Which type of science has interested you most over the years?

APPENDIX G

CGCCP QUESTION WRITTEN RESPONSES

APPENDIX H

CGCCP POST CONCEPT WRITTEN SURVEY

Name: _____ Subject: _____ Date: _____

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

Indicate a 'yes' or 'no' answer and add a written response if you wish in the space provided.

Did the CGCCP process help you to more fully understand the answer to the problem?

YES
 NO

Does discussing physics problems with your peers in a collaborative way make learning physics more enjoyable?

YES
 NO

Was your initial question written response (QWR) to the problem question right? If not, do you think the CGCCP session promoted learning? Explain.

YES
 NO

APPENDIX I

POST STUDY INTERVIEW

Name:_____ **Subject:**_____ **Date:**_____

Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

Did the CGCCP process help wrap up the science inquiry learning you did throughout the week? Explain.

Which of the roles did you like the best in the CGCCP process?

Even though you worked in groups during the CGCCP process, did you still feel dignified in having your individual thoughts accepted by the group?

Think back to other courses where you have done group work with other students. Were you satisfied with the teachers evaluation of you contribution and your mark?

How would you compare your CGCCP group experience with group work you have done in the past?

Do you think the CGCCP process helped you understand science concepts and overcome any misconceptions you may have held about the subject of physics?
