THE IMPACT OF PROCESS ORIENTED GUIDED INQUIRY LEARNING ON STUDENT UNDERSTANDING IN NINTH GRADE PHYSICAL SCIENCE

by

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A professional paper submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

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DEDICATION

This paper is dedicated to my students past present and future who constantly entertain and inspire me to become the best teacher I can be.

ACKNOWLEDGEMENTS

I would like to thank all of the professors in the MSSE program for their thoughtful contributions to helping me become a better teacher. I would most especially like to acknowledge Diana Paterson without whom this project would certainly never have been completed.

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ABSTRACT

In this study the role of Process Oriented Guided Inquiry Learning (POGIL) on student understanding of chemistry topics was explored. In addition, the role of engagement and active participation in those activities was monitored. Student understanding was evaluated through pre and post unit quizzes for both control and intervention topics of study and through responses to a post unit survey and student interviews. It was found that POGIL activities contribute to a greater proportion of students achieving high growth in understanding. Students who described themselves as active participants in POGIL activities were significantly more likely to show high levels of understanding and confidence in their ability to answer questions related to the topic covered in the POGIL activity.

INTRODUCTION AND BACKGROUND

School and Community Demographics

I teach Physical Science 9 at Proctor High School in Proctor, Minnesota. Our school is a public high school fed by a rural area just outside of Duluth, Minnesota. Many of our students bus in from around 40 miles away from school. Proctor High School serves around 600 students in grades 9-12. The district is not particularly diverse, about 93% of the student body is white. About half of our students reside in the small town of Proctor while the remaining live in small outlying communities or in the countryside.

Proctor is a town of around 3000 residents that acts as a bedroom community to neighboring Duluth, MN. Despite being part of a metro area of around 150,000 people, Proctor has the character of a small town, with many students the third or fourth generation of their family to attend Proctor Schools. The town enthusiastically supports the school and recently passed a tax referendum to build new athletic facilities for the school district.

Classroom Environment

During this study, I taught five sections of a required ninth grade physical science course that spends one semester on basic chemistry and a second semester on basic physics. All ninth-grade students are expected to complete the course. Most classes have between 25 and 30 students. Students typically complete group activities with an assigned table group chosen by me. About 50% of the work we do in class is completed in groups of three or four.

One of my primary areas of interest in teaching is the role of collaboration within the science classroom. In general, science is a collaborative area of study and I hope to foster collaborative skills for my students in a science setting. I try to encourage collaboration with varied amounts of formality in my classroom. I use more structured collaboration by assigning roles in Process Oriented Guided Inquiry Learning (POGIL) activities. In addition to the structured collaboration provided by POGIL activities, I also encourage informal collaboration on lab experiments and homework assignments. I generally allow and encourage students to work together to solve problems and complete lab work. One concern I have had is on how this impacts individual learning, and if it allows some students to get through classwork without developing their own understanding of the material. Additionally, I have observed anecdotally that students who do poorly on assessments tend to be those who are less engaged with the POGIL activities and merely record answers on their assignment as the group works through the activity without being an active participant.

Problem Statement and Research Questions

The roles of collaboration and inquiry in science are massive. Process Oriented Guided Inquiry Learning provides a framework for involving students in important scientific practices like collaboration and inquiry through structured group activities. The primary question addressed by this research project was: does the implementation of guided inquiry activities based on the POGIL model improve individual student understanding of chemistry topics? This research also investigated the following sub-questions: 1) Does student engagement during POGIL activities correlate to understanding? and 2) Do POGIL activities improve student confidence levels about solving problems related to the content covered in the activities? The goal of this research project was to investigate the role that POGIL based guided inquiry activities have on student understanding, and how student engagement in those activities influences achievement.

CONCEPTUAL FRAMEWORK

This paper will investigate the effects of structured collaborative learning in the form of Process Oriented Guided Inquiry Learning (POGIL) format activities compared to the effect of unstructured collaboration in the form of partner work on daily assignments in an introductory high school chemistry course. Science used to be a more competitive endeavor, but in general, many fields have begun to recognize the benefit in collaborations. Thus, it makes sense to teach science in a cooperative rather than a competitive way. There is a large amount of research supporting the effectiveness of POGIL activities and cooperative learning in chemistry classrooms. Literature examining the effects of both practices will be reviewed.

Collaboration in some form is a standard feature of most classrooms in the country. The simple act of working together to complete daily assignments is an example of student collaboration. Most science classrooms employ more formal collaboration in the laboratory setting. While these arrangements are often out of convenience or to preserve materials, there is educational theory that supports the use of collaborative learning as a core instructional practice. In addition to collaboration’s role in the classroom, the ability to work collaboratively will be essential in meeting the challenges of the 21st century.

Johnson and Johnson (2014) argue, “In all of these challenges, cooperative learning… will play a central role in teaching children, adolescents, and young adults the competencies and values they need to cope with these and other challenges and lead productive and fulfilling lives during the 21st century” (p. 850).

. In recent years, a group of science education pedagogies that Eberlein et al. identify as the “PXnL pedagogies” (Eberlein et al., 2008, p. 262) have become common at both the high school and undergraduate levels. This group of pedagogies includes problem-based learning (PBL), peer led team learning (PLTL), and process oriented guided inquiry learning (POGIL). All three of these pedagogies are rooted in some type of constructivist theory, which emphasizes student construction of knowledge from experience rather than teacher imparted knowledge, and seek to “intentionally create learning environments that stimulate students to construct a robust understanding of concepts” (p. 263).

Within this wider set of pedagogies, POGIL has its own particular theoretical underpinning. In addition to constructivism, the learning cycle plays a fundamental role in how POGIL activities are developed. The original developers of POGIL used a version of the learning cycle containing three phases; exploration, concept invention, and application (Spencer, 1999). The POGIL developers suggest that while the learning cycle is most obvious in the laboratory, it can also be used in more traditional classroom settings. Collaboration is not only important for preparing students to work in science careers, but that it also has inherent educational value.

With a firmly established theoretical framework in handbv the basic tenets of implementation can be explored. POGIL was first implemented as a base curriculum for general chemistry undergraduates (Farrell, Moog, & Spencer, 1999). The basic structure of the original POGIL implementation was as follows:

- No lectures are given.
- Students have assigned roles within groups (usually of four).
- Groups use guided inquiry activities that follow the learning cycle paradigm to develop and learn concepts.
- A five-minute quiz is given at the beginning of each class on the previous day's material.
- There is a textbook for the course, and students are expected to reinforce learning by reading the appropriate sections after introduction of concepts in class.
- Students are graded individually on hour exams and a final exam

The authors acknowledge that this structure does not necessarily transfer perfectly to other settings, but can be easily adapted to fit an instructor's needs. The portion of the original POGIL concept that has gone on to be more widely used is group guided inquiry activities that often take the place of lectures. These activities contain three key components; model/data, critical thinking questions, and applications.

The majority of the literature regarding the effectiveness of POGIL activities in science relates to undergraduate level coursework. Within that setting, POGIL has been found to be effective across a range of scientific disciplines (Brown, 2010; Hein, 2012;

Roller & Zori, 2017; Soltis, Verlinden, Kruger, Carroll, & Trumbo, 2015; Vanags, Pammer, & Brinker, 2013). The authors of the original POGIL saw a decrease in the rate of students receiving D, F, or W grades in their introductory undergraduate chemistry course from 21.9% to 9.6% after implementing POGIL (Farrell et al., 1999). Hein (2012) showed that POGIL improved percentile scores on the ACS organic chemistry exam amongst undergraduate organic chemistry students. In addition, they found that the overall share of students scoring below the 25th percentile on the exam significantly decreased after implementing POGIL. Finally, Vanags et al. (2103) found that POGIL remains effective even when adapted or used by inexperienced implementers. In a study of POGIL in a first-year undergraduate psychology class, they found that improved retention of material in the following variations of implementation: inexperienced facilitator using a reporting out component, experienced facilitator with reporting out, and experienced facilitator without reporting out. The implication of these findings is that the structure of the written POGIL activities themselves is the most important factor in determining the effectiveness of POGIL as a whole.

Process Oriented Guided Inquiry learning is more generally underpinned by the principles of cooperative learning. Johnson and Johnson define cooperative learning as, “the instructional use of small groups so that students work together to maximize their own and each other’s learning” (Johnson & Johnson, 2014, p. 841). Cooperative learning, in their understanding, is built on the concept of social interdependence. Social interdependence is built on the idea that an individual’s outcome in a given situation depends on both their own actions and those of their collaborators. Effective collaborative learning promotes positive social interdependence and engages students to work together to achieve both their own and the group's goals.

According to Robert Slavin, cooperative learning can be understood through four lenses: motivational, social cohesion, developmental, and cognitive elaboration (Slavin, 1996). The motivational perspective views effective cooperative instruction as a scenario in which an individual can only attain their personal goals by also helping their group to achieve its goals. Slavin explains that theorists of the social cohesion perspective believe that students work well in groups because they care about the success of the other members of the group. The first of two cognitive perspectives defined by Slavin is the developmental perspective rooted in Vygotsky's zone of proximal development. Slavin describes the perspective, "the fundamental assumption of the developmental perspective on cooperative learning is that interaction among children around appropriate tasks increases their mastery of critical concepts" (p. 48). The final perspective described by Slavin is that of cognitive elaboration. He explains that elaboration is the restructuring of material to allow it to be retained in the memory, which can be effectively achieved by explaining concepts to others. The varied perspectives described by Slavin all have supporting evidence and can inform different types of collaborative and cooperative learning activities. By understanding how the theory behind an activity works, teachers can more effectively implement different types of collaborative learning.

Armed with a deeper understanding of the different theoretical perspectives on cooperative learning, the effects of it in the classroom can be explored. There are numerous studies supporting the positive effects of collaborative and cooperative learning. A recent meta-analysis of 25 studies on cooperative learning in high school and undergraduate chemistry courses found that there was a positive correlation between student achievement and the use of cooperative learning activities (Warfa, 2016). Even simple collaboration such as partner work on problem sets has been shown to improve student achievement on critical thinking questions in a study of undergraduate electronics students (Gokhale, 1995). In a study of transitioning undergraduate chemistry recitation sessions from large group problem sessions to small group collaborative problem solving sessions, Mahalingam, Schaefer and Morlino found that, "implementation of the group work was a decrease in the percentage of students receiving less than a 60% average on exams, from 27.5% to about 19%" (Mahalingam, Schaefer, & Morlino, 2008, p. 1579).

There is extensive evidence in the literature supporting the effectiveness of POGIL specifically and of cooperative learning in general. The majority of this research has occurred in post-secondary environments, with a limited number of studies in high school classrooms. POGIL has its foundation in cooperative learning theory, including Johnson and Johnson's ideas about social interdependence and the broader philosophy of constructivism. The effectiveness of POGIL seems to be rooted in the way the activities are structured to promote the assembly of knowledge and the input of multiple viewpoints.

METHODOLOGY

This research investigated the effect of POGIL activities on student understanding in the high school physical science classroom. It also addressed the sub-questions of how student engagement in those activities correlates with understanding and how POGIL affects student confidence about solving related problems. In order to evaluate these questions, POGIL activities were used to introduce new concepts to about 50 high school freshmen enrolled in a general physical science course. The effectiveness of these interventions was compared to more traditional instruction based on reading and lecture. The research methodology for this project received an exemption by Montana State University's Institutional Review Board (Appendix A).

This research was conducted on two sections of general physical science taught to freshmen at Proctor High School in Proctor, MN. Each section had 20-30 students. A total of 43 students participated in this research. Physical science is a required course at our school and the same course is taken by high achieving students and those who struggle with school. Overall, the student body of our school represents a wide range of abilities, with just under 50% of the students meeting proficiency benchmarks on state tests in reading and math.

Intervention and control treatments were created by varying the method of instruction. The intervention used in this research was the use of Process Oriented Guided Inquiry Learning (POGIL) as an introductory activity for teaching chemistry concepts. In this research, covalent chemical nomenclature was introduced to all students using a POGIL activity published by Flinn Scientific (Appendix B). In the control treatment binary ionic chemical nomenclature was introduced to all students using a more traditional approach of reading and lecture.

Table 1

Summary of treatments

Treatment	Control	Intervention
Topic	Binary ionic chemical nomenclature	Binary covalent chemical nomenclature
Instructional Method	Lecture	POGIL

Student understanding was measured using pre and post quizzes for both the control and intervention treatments. The Chemical Nomenclature Pre-Quiz was administered prior to any instruction in naming binary chemical compounds and consisted of ten questions asking students to name covalent compounds when given a formula and ten questions asking them to do the same for ionic compounds (Appendix C). The Chemical Nomenclature Post-Quiz was administered after students had received instruction in the intervention group and control group settings and used the same format as the Pre-Quiz (Appendix D). Students did not receive partial credit for answers. Student scores from the pre and post quizzes were analyzed by calculating normalized gain scores for each type of nomenclature.

Following the completion of the intervention, students completed the five question POGIL Post Survey (Appendix E). This survey consisted of five Likert item questions on student engagement, confidence and understanding. Each question asked students to rate their agreement with a statement on a scale from strongly disagree to strongly agree with no neutral option.

POGIL Post Survey data were analyzed for distribution of answers and correlation between engagement and confidence and engagement and understanding. The correlations were evaluated for significance using Fisher’s exact test. Student responses to interview questions were used to corroborate data from the pre and post quizzes and survey (Appendix F).

The data collection tools used to evaluate the various research questions posed in this study are summarized in Table 2.

Table 2
Data Triangulation Matrix

Data Source	Questions		
	Focus Question: What are the effects of Process Oriented Guided Inquiry Learning on student understanding of chemistry concepts?	*Secondary Question:* How does student engagement and participation in Process Oriented Guided Inquiry Learning affect student understanding of chemistry concepts	*Secondary Question:* How does Process Oriented Guided Inquiry Learning affect student confidence about their ability to solve chemical nomenclature problems
Chemical Nomenclature Pre-Quiz	X	X	
Chemical Nomenclature Post Quiz	X	X	
POGIL Post Survey	X	X	X
Student Interview Responses	X	X	X

DATA ANALYSIS

Student understanding was evaluated by calculating normalized gains for student scores from the Chemical Nomenclature Pre-Quiz to the Chemical Nomenclature Post-Quiz in both the intervention and control groups. Student gain scores were separated into three categories; no growth (<0), low growth (0-0.5) and high growth (0.5-

1). These categories were then plotted in a histogram for each group and evaluated qualitatively as shown in Figures 1 and 2.

Based on the data, 88% of students in the intervention group who completed a POGIL activity on covalent chemical nomenclature showed growth (*N*=43). Additionally, 79% of students in this growth showed high growth, 12% of students showed no growth or regression.

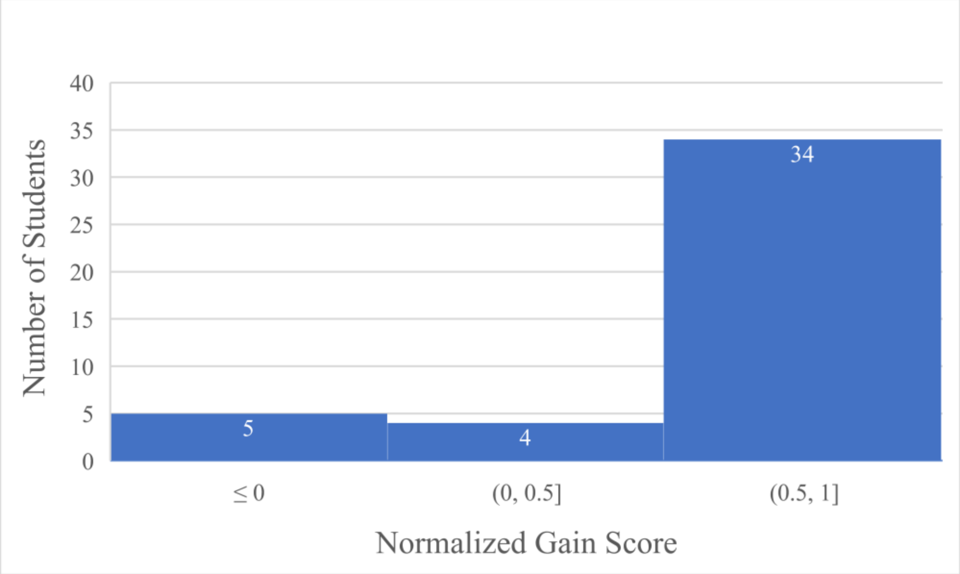

Figure 1: Normalized gain scores for students completing POGIL activity on covalent chemical nomenclature, (*N*=43).

For students in the control group, who received traditional lecture-based instruction in binary ionic nomenclature, 86% showed growth (*N*=43). Additionally, 60% of students in the control group showed high growth, 14% of students showed no growth or regression.

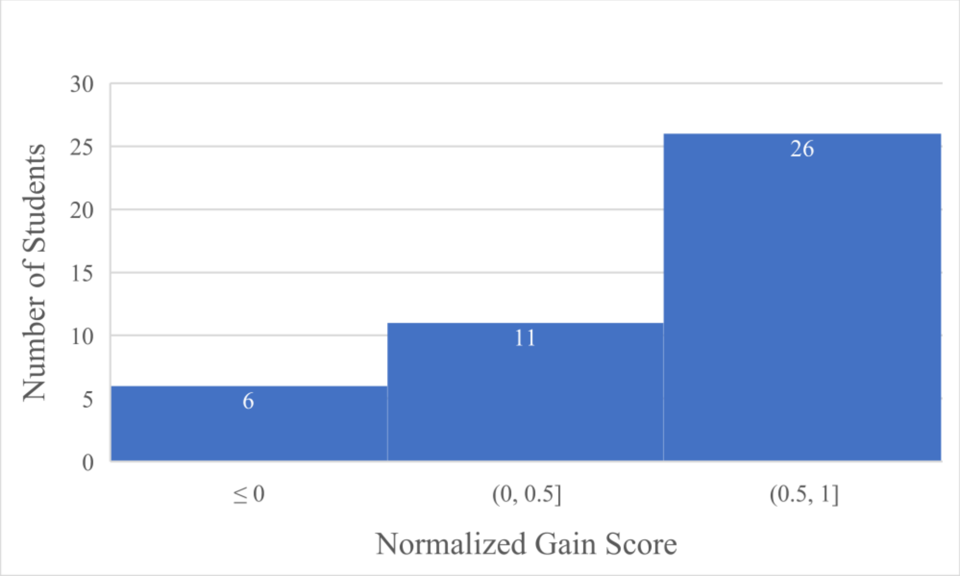

Figure 2: Normalized gain scores for students completing traditional lecture-based instruction on binary ionic nomenclature, (*N*=43).

Both the treatment and control groups showed an approximately equal proportion of students exhibiting some growth. The students in the treatment group showed a greater proportion demonstrating high growth. The average normalized gain score for students in the treatment group was 0.73 and for the control group 0.55.

In addition to quizzes students were asked to report their understanding on the POGIL Post Survey. Of students completing the survey, 37.5% strongly agreed with the statement, “Today's POGIL increased my understanding of naming covalent compounds,” *(N=32)*. An additional 47% agreed with the statement as shown in Figure 3. Student perceptions of their understanding supported the normalized gain scores, showing that the vast majority of students improved their understanding of covalent nomenclature through the use of POGIL activities.

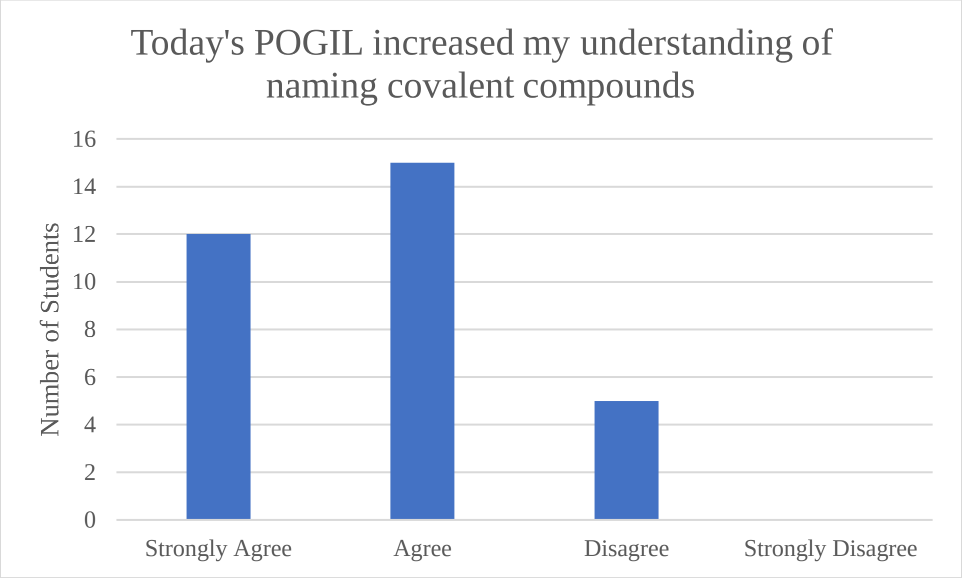

Figure 3: Student understanding of content following completion of POGIL activity (*N*=32).

Student interview responses also indicated that participation in POGIL activities lead to increased understanding of the materials. One student noted, “If you don’t know something and your group does, they can teach you.” Other students felt that they learned more and faster using POGIL activities. All students interviewed indicated that they would like to do more activities of that type in the future.

Students completing the POGIL Post Survey also reported on their levels of engagement, participation and confidence in their ability to name covalent compounds shown in Figure 4. Only 9% of students reported being disengaged with the material during the POGIL activity, and 16% reported not being active participants in their groups. Sixty-six percent of students reported feeling confident in their ability to name covalent compounds.

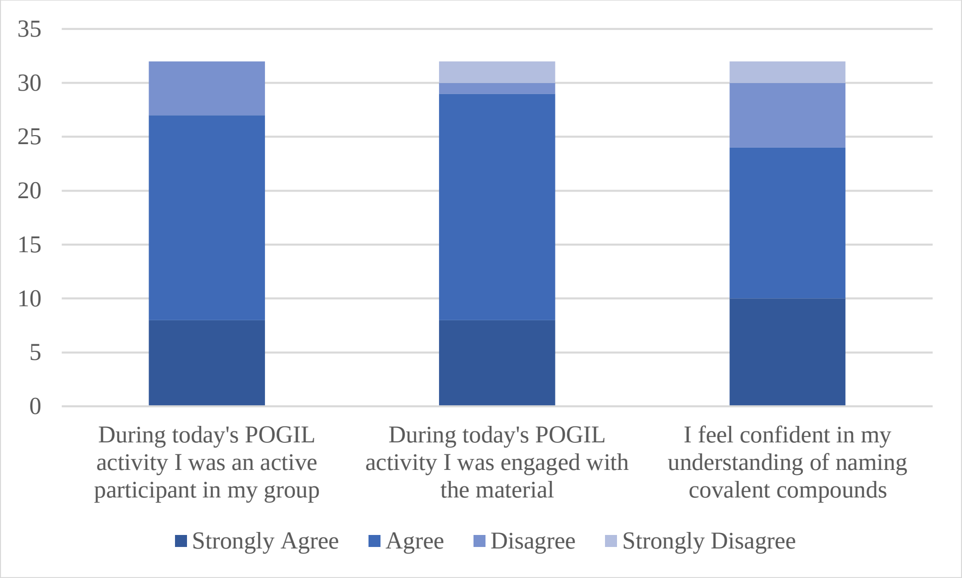

Figure 4: Students levels of engagement, participation, and confidence as reported in the POGIL Post Survey, (*N*=32).

Data from the POGIL Post Survey shown in Table 3 was also analyzed using Fisher's exact test to analyze the relationship between student reports of participation and both their confidence in their ability and understanding of covalent nomenclature. There was a significant relationship between students' active participation and their confidence in their understanding of naming covalent compounds. Students who reported being active participants in their group were more likely to feel confident in their ability to name covalent compounds (p=0.0003). The same was true for the relationship between active participation and increases in understanding (p=0.0007).

Table 3

Contingency table of student participation and confidence and understanding of naming covalent compounds

	Active participant in group during POGIL activity	Not active participant in POGIL activity
Confident in understanding of naming covalent compounds	24	0
Not confident in understanding of naming covalent compounds	3	5
Increased understanding of naming covalent compounds	26	1
No increase in understanding of naming covalent compounds	1	4

Student interviews also pointed to the importance of active participation in POGIL activities to improved understanding and confidence. All students interviewed touched on the importance of having everyone in the group participate in helping their own understanding improve. The students also reported that they liked working together and that they felt getting input from other group members helped them learn. One student reported that she felt, “it was easier to figure things out with a group and it helped me stay focused.”

INTERPRETATION AND CONCLUSIONS

The results of this study suggest that Process Oriented Guided Inquiry Learning (POGIL) is an effective pedagogy for improving understanding of chemical concepts in 9th grade science classrooms. The POGIL pedagogy has been shown to be effective in college and high school classrooms by others, but has had limited research in use with younger students. The results of this study show that POGIL is not only an effective pedagogy but can be a more effective instructional approach than a traditional lecture and practice to teach new chemistry concepts. Most students showed more growth with the POGIL activity and also reported that the POGIL increased their understanding of the material.

While the majority of students in both the control group and the POGIL group showed growth, more students in the POGIL group showed high levels of growth. This finding suggests that the POGIL activity may promote a deeper level of understanding than a lecture-based approach. The construction of knowledge and the benefits of having multiple viewpoints were two important ideas that informed the design of POGIL by the original practitioners. Several students reported in interviews that they felt the POGIL activities helped them to learn better because they got to figure things out themselves and learn from their classmates. This suggests that students were thinking more critically about the material and were able to spend more time understanding the material instead of copying down lists.

A key element that emerged from this study was the importance of active participation of group members in the effectiveness of POGIL as an instructional strategy. Perhaps unsurprisingly, students who were not active participants in the activities reported lower levels of confidence and understanding of the concepts covered by the POGIL activity. More surprising was the fact that nearly all students who reported being active participants also reported high levels of confidence and understanding. I expected most students who participated in the activity to improve their understanding, but it was quite unexpected to have it be so universal. This seems to indicate that POGIL activities do an exceptional job of promoting positive social interdependence, encouraging students to work together to further their own learning, but also that of their group members.

The importance of social interdependence also emerged during student interviews in an area I had not considered as closely: the role of fellow group members participation in a student's learning. Many students reported learning a lot from the POGIL activity and enjoying it but feeling like they could have learned more if all the members of their group had worked together better. The students also reported that having students in the group who did not participate held them back from getting as much done so they felt they couldn't finish the activity and get all the information. Students also reported having great experiences with groups where everyone participated and felt that the format of the POGIL encouraged everyone in the group to participate more.

VALUE

This study served as an important confirmation that POGIL activities can be effective with younger students. I have used POGIL activities with older students and felt successful with the results but I felt like it might be a difficult pedagogy for younger students to use. This study showed me that younger students are capable of using POGIL successfully and encouraged me to continue using POGIL activities with my ninth-grade students.

The thing that will be most impactful on my future teaching is how much of a difference active participation made in outcome for all of the students. While I always encourage active participation and students completing work, it was eye-opening to see how closely participation was linked to increases in understanding. All of the students in the study turned in completed POGIL activities, but those who did not actively participate in the construction of meaning in those activities had much poorer outcomes than those that did. Additionally, their lack of participation caused other members of their groups to feel like they learned less.

These two outcomes together lead me to believe that I need to work on constructing systems that better encourage the active participation of all group members. One of the things I would be interested in doing further investigating of is various methods for doing that. One thing I have considered doing is increasing the amount of choice students have in their groupings. Students frequently suggest that they would work better if they knew the people in their groups better. For various reasons, I have always assigned groups for collaborative activities, but it would be interesting to see if allowing students to have more choice in their groups would encourage more active participation.

Another thing that has been mentioned in some of the research on POGIL is the presence or absence of a reporting out component in which students are required to communicate their learning with other groups in some way. I did not include a reporting out component in this study, but I am curious if it would further encourage participation.

One of the benefits of doing this research was taking the opportunity to think more deeply about why a particular activity may or may not be effective. It encouraged me to evaluate other activities I use in my classroom with a more critical eye to determine if they fit in well with the values of collaboration and problem solving I want to develop in my classroom. Additionally, the feedback I got from students has led me to more carefully consider how I structure collaboration in my classroom. I think moving forward I will try to be more intentional about setting up systems that promote active participation and hold students accountable for their individual contributions to the group's work.

Ultimately, I am happy to see that POGIL was an effective strategy with my ninth graders, and I will continue to use it with them going forward in my teaching. In the future, I would like to find or develop POGIL activities for the physics portion of my curriculum so that it can be used in both semesters of my course. I will also research ways to encourage more active participation in POGIL activities, and to refine grouping strategies that lead to more positive outcomes for my students.

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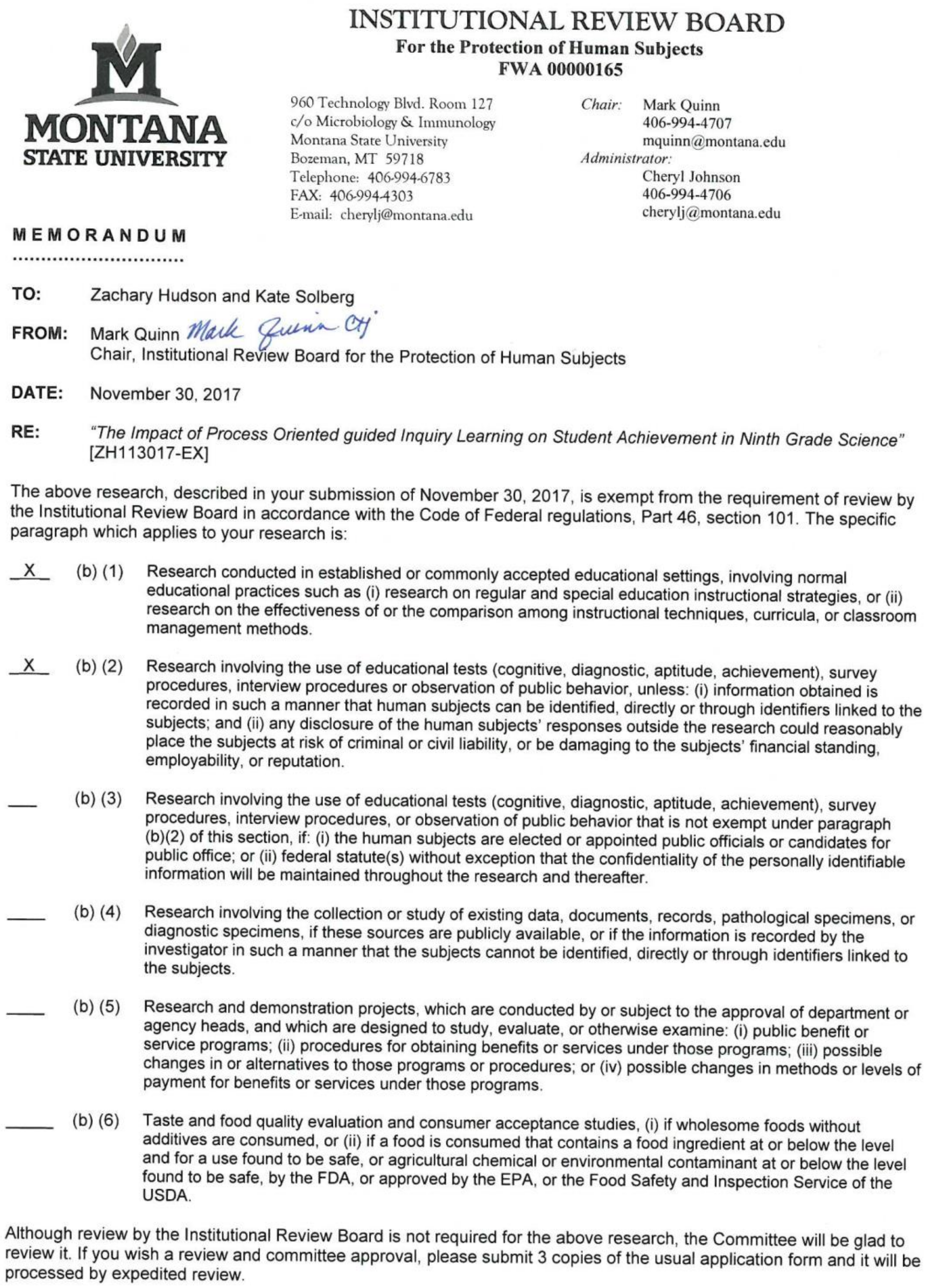
APPENDICES

APPENDIX A

IRB Exemption Letter



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MEMORANDUM

TO: Zachary Hudson and Kate Solberg

FROM: Mark Quinn Mark Quinn cj
Chair, Institutional Review Board for the Protection of Human Subjects

DATE: November 30, 2017

RE: *"The Impact of Process Oriented guided Inquiry Learning on Student Achievement in Ninth Grade Science"* [ZH113017-EX]

The above research, described in your submission of November 30, 2017, is exempt from the requirement of review by the Institutional Review Board in accordance with the Code of Federal regulations, Part 46, section 101. The specific paragraph which applies to your research is:

_X_ (b) (1) Research conducted in established or commonly accepted educational settings, involving normal educational practices such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.

_X_ (b) (2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.

___ (b) (3) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph (b)(2) of this section, if: (i) the human subjects are elected or appointed public officials or candidates for public office; or (ii) federal statute(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.

___ (b) (4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available, or if the information is recorded by the investigator in such a manner that the subjects cannot be identified, directly or through identifiers linked to the subjects.

___ (b) (5) Research and demonstration projects, which are conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine: (i) public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs.

___ (b) (6) Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed, or (ii) if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the FDA, or approved by the EPA, or the Food Safety and Inspection Service of the USDA.

Although review by the Institutional Review Board is not required for the above research, the Committee will be glad to review it. If you wish a review and committee approval, please submit 3 copies of the usual application form and it will be processed by expedited review.

APPENDIX B

Flinn Scientific POGIL Activity

Naming Molecular Compounds

How are the chemical formula and name of a molecular compound related?

Why?

When you began chemistry class this year, you probably already knew that the chemical formula for carbon dioxide was CO_2. Today you will find out why CO_2 is named that way. Naming chemical compounds correctly is of paramount importance. The slight difference between the names carbon monoxide (CO, a poisonous, deadly gas) and carbon dioxide (CO_2, a greenhouse gas that we exhale when we breathe out) can be the difference between life and death! In this activity you will learn the naming system for molecular compounds.

Model 1 – Molecular Compounds

Molecular Formula	Number of Atoms of First Element	Number of Atoms of Second Element	Name of Compound
ClF			Chlorine monofluoride
ClF_5	1	5	Chlorine pentafluoride
CO			Carbon monoxide
CO_2			Carbon dioxide
Cl_2O			Dichlorine monoxide
PCl_5			Phosphorus pentachlroride
N_2O_5			Dinitrogen pentoxide

1. Fill in the table to indicate the number of atoms of each type in the molecular formula.
2. Examine the molecular formulas given in Model 1 for various molecular compounds.
   a. How many different *elements* are present in each compound shown?

   b. Do the compounds combine metals with metals, metals with nonmetals, or nonmetals with nonmetals?

   c. Based on your answer to *b*, what type of bonding must be involved in molecular compounds?
3. Find all of the compounds in Model 1 that have chlorine and fluorine in them. Explain why the name "chlorine fluoride" is not sufficient to identify a specific compound.
4. Assuming that the name of the compound gives a clue to its molecular formula, predict how many atoms each of these prefixes indicates, and provide two examples.

   mono-

   di-

   penta-

16. For each of the following compounds, indicate whether or not your naming rules from Question 15 will apply. If not, explain why the naming rules do not apply.

FeI_3 ICl_5 $HBrO_4$

17. Using the rules your group developed in Question 15, name each of the following molecular compounds.

Molecular Formula	**Molecule Name**
PBr_3	
SCl_4	
N_2F_2	
SO_3	
BrF	

18. Write molecular formulas for the following compounds.

Molecular Formula	**Molecule Name**
	Disulfur decafluoride
	Carbon tetrachloride
	Oxygen difluoride
	Dinitrogen trioxide
	Tetraphosphorus heptasulfide

10. Find two compounds in Model 2 that contain the prefix “mono-” in their names.

    a. List the formulas and names for the two compounds.

    b. What is different about the spelling of the prefix meaning “one” in these two names?

11. Identify any remaining names of compounds in Model 2 where the prefixes that do not exactly match the spelling shown in the prefix table.

12. Use your answers to Questions 9–11 to write a guideline for how and when to modify a prefix name for a molecular compound. Come to a consensus within your group.

13. Would the guideline you wrote for Question 12 give you the correct name for NI_3 as it is given in Model 2? If not, modify your guideline to include this example.

14. All of the compounds listed in Model 2 are binary molecular compounds. Compounds such as CH_3OH or PF_2Cl_3 are not binary, and compounds such as NaCl or $CaCl_2$ are not molecular. Propose a definition for “binary molecular compounds.”

15. Collaborate with your group members to write a list of rules for recognizing and naming binary molecular compounds from their chemical formulas.

STOP

Model 2 – Prefixes and Suffixes

Prefix	Numerical Value
mono-	
di-	
tri-	
tetra-	
penta-	
hexa-	
hepta-	
octa-	
nona-	
deca-	

Molecular Formula	Name of Compound
BCl_3	Boron trichloride
SF_6	Sulfur hexafluoride
IF_7	Iodine heptafluoride
NI_3	Nitrogen triiodide
N_2O_4	Dinitrogen tetroxide
Cl_2O	Dichlorine monoxide
P_4O_{10}	Tetraphosphorus decoxide
B_5H_9	Pentaboron nonahydride
Br_3O_8	Tribromine octoxide
ClF	Chlorine monofluoride

5. Examine the prefixes in Model 2. Fill in the numerical value that corresponds to each prefix.
6. What suffix (ending) do all the compound names in Model 2 have in common?
7. Carefully examine the names of the compounds in Model 2. When is a prefix NOT used in front of the name of an element?
8. Consider the compound NO.
   a. Which element, nitrogen or oxygen, would require a prefix in the molecule name? Explain your answer.

   b. Name the molecule NO.

9. Find two compounds in Model 2 that contain a subscript of "4" in their molecular formula.
   a. List the formulas and names for the two compounds.

   b. What is different about the spelling of the prefix meaning "four" in these two names?

21. In the table below, first identify the type of bonding present in each compounds. Then fill in the missing name or formula for each compound using the appropriate set of rules.

Chemical Formula	**Type of Compound/Bonding**	**Compound Name**
CS_2		
PbI_2		
$BaCl_2$		
Se_2S_6		
		Xenon tetrafluoride
		Sodium phosphide
		Dinitrogen pentoxide
		Cobalt(III) bromide

Extension Questions

19. This activity focused on molecular (covalent) compounds, while an earlier activity addressed ionic compounds. Notice that the formulas for both types of compounds can look very similar, even though their names are quite different:

Chemical Formula	**Type of Compound/Bonding**	**Compound Name**
MgF_2	Ionic	Magnesium fluoride
CuF_2	Ionic	Copper(II) fluoride
SF_2	Molecular (covalent)	Sulfur difluoride
NaBr	Ionic	Sodium bromide
AuBr	Ionic	Gold(I) bromide
IBr	Molecular (covalent)	Iodine monobromide

Identify two differences between the names or formulas for ionic compounds versus those for binary molecular compounds. Also identify two similarities.

	Names and Formulas of Ionic Compounds	**Names and Formula of Molecular (Covalent) Compounds**
Differences		
Similarities		

20. Use complete sentences to explain why $AlCl_3$ is called “aluminum chloride” (no prefix required), but BCl_3 is called “boron trichloride.”

APPENDIX C

NOMENCLATURE PRE-TEST

Name each of the following compounds

Formula	Name
KI	
NaCl	
Al_2O_3	
MgF_2	
NaBr	
MgO	
CaC_2	
LiCl	
Fe_2O_3	
BaCl	
CO	
N_2O	
SiO_2	
SF_6	
CCl_4	
NO	
SO_2	
CS_2	
Si_3Cl_5	
CF	

APPENDIX D

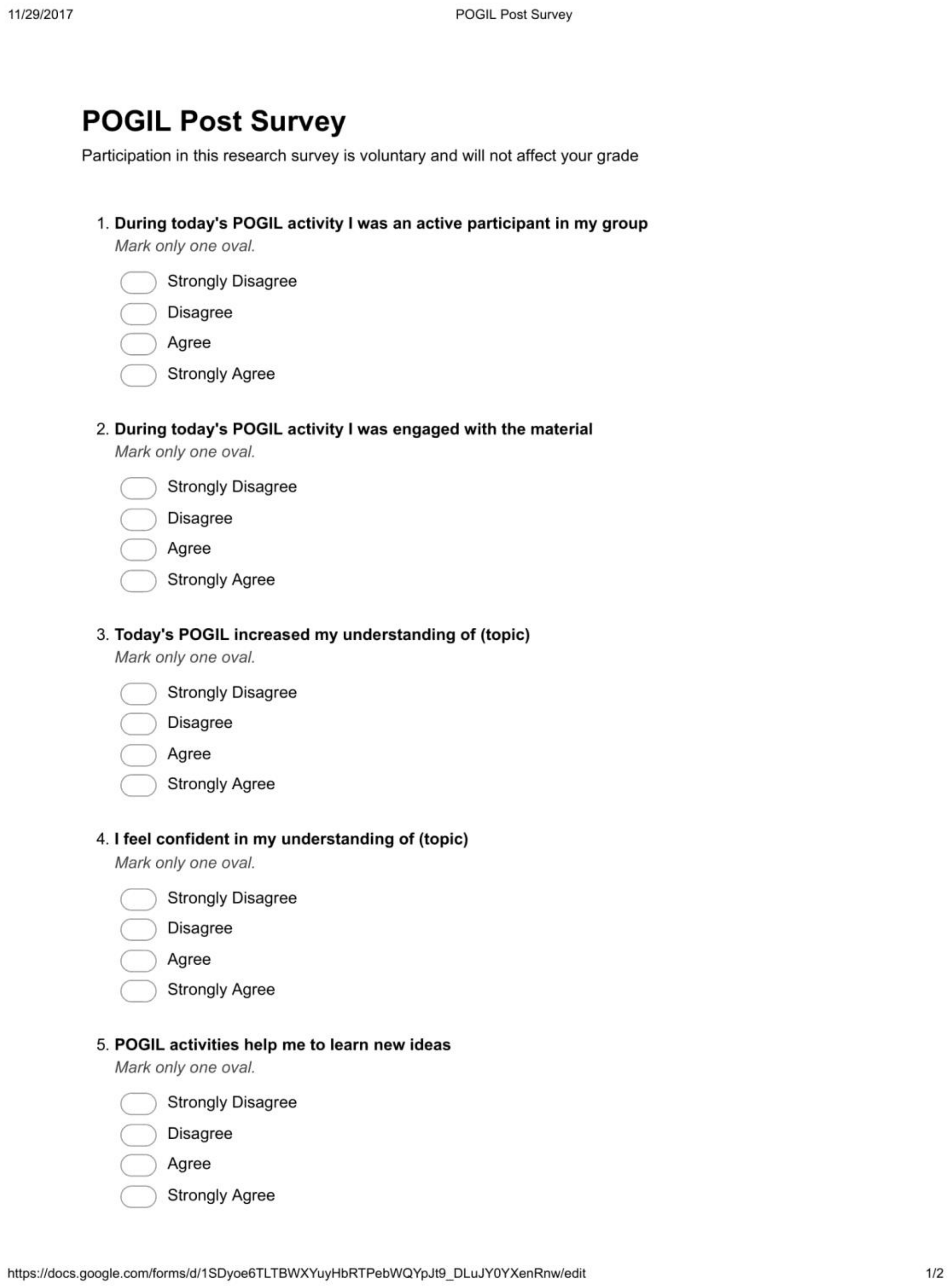
NOMENCLATURE POST-TEST

Name each of the following compounds

Formula	Name
NaI	
KCl	
Cr_2O_3	
BaF_2	
KBr	
MgS	
CaC_2	
LiBr	
Bi_2O_3	
RbBr	
SiO	
H_2O	
CO_2	
XeF_6	
CF_4	
NO_3	
SO_2	
$S1S_2$	
C_3Cl_5	
CS	

APPENDIX E

POGIL Post Survey



11/29/2017 POGIL Post Survey

POGIL Post Survey

Participation in this research survey is voluntary and will not affect your grade

1. **During today's POGIL activity I was an active participant in my group**
Mark only one oval.

○ Strongly Disagree
○ Disagree
○ Agree
○ Strongly Agree

2. **During today's POGIL activity I was engaged with the material**
Mark only one oval.

○ Strongly Disagree
○ Disagree
○ Agree
○ Strongly Agree

3. **Today's POGIL increased my understanding of (topic)**
Mark only one oval.

○ Strongly Disagree
○ Disagree
○ Agree
○ Strongly Agree

4. **I feel confident in my understanding of (topic)**
Mark only one oval.

○ Strongly Disagree
○ Disagree
○ Agree
○ Strongly Agree

5. **POGIL activities help me to learn new ideas**
Mark only one oval.

○ Strongly Disagree
○ Disagree
○ Agree
○ Strongly Agree

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APPENDIX F

Student Interview Questions

Interview Questions

1. Compared to a more traditional class activity do you think the POGIL (group) activity helped you learn more or less? Why?
2. What did you like about the POGIL (group) activity?
3. Would you want to do more POGIL activities in the future?