From Discovery to Implementation of Organic Chemistry Learning Models in Secondary and Post-Secondary Classrooms

Joy Ballard
FROM DISCOVERY TO IMPLEMENTATION OF ORGANIC CHEMISTRY LEARNING MODELS IN SECONDARY AND POST-SECONDARY CLASSROOMS

By

JOY BALLARD

Under the Direction of Suazette Mooring, PhD

ABSTRACT

Three projects will be discussed that shape my future as a science educator. Discovery of chemical probes as anti-cancer agents provided a deep chemistry knowledge base. Analysis of engagement protocols gave insights into how to structure and train a group for successful group work. The design and implementation of a learning module provided practice developing and assessing learning activities for the secondary classroom.

INDEX WORDS: Small-Molecule Inhibitors, Green Chemistry, Engagement, Chemistry Attitudes, Learning Module, Flipped Classrooms, Community of Inquiry
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by

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Office of Graduate Studies
College of Arts and Sciences
Georgia State University
December 2019
DEDICATION

I dedicate this body of work to my family and friends. Without your encouraging words, and strengthening talks I would not have made it thus far. Undoubtedly, there were times when I felt like giving up was my only option. It was your kindness and support I needed to keep going on my journey. Thank you!

To my amazing husband Amir Ballard, your support and love guided me through to the very end of this journey. You did not let me give up, and I appreciate you for that. God blessed me when he placed you in my life, and for that, I am forever grateful! Thank you Jibriel, you are the most beautiful, curious little boy and all of this work is for you my son. I also thank my mom, Julia Yancey for giving me life and setting a strong educational foundation for me. Mom, you have always been my number one supporter and encourager, and I know this accomplishment is one you have been anticipating for a while. Thank you so much for caring for my precious baby boy in my absence. To my boys, Amir Jr. and Da’Wud, thank you guys for keeping me on my toes! Your curious and kind conversations gave me the motivation to complete my work and make you both proud! Dad, thank you for always being one call away when or if I needed anything. You have always shown how proud you were of me and I appreciate the love and encouragement. To my siblings, Jasmine Yancey, Miles Wilson, Mea Wilson, Genesis Wilson, Sarea Wilson, Jameson Wilson thank you guys for love!

To my friends Giselle, Jasmine, Nya, and Yanique, you guys spent countless hours listening to me obsess over my studies. Each time when I felt like giving up you reverted me to the end goal. I am so happy to be able to make you guys proud. Thank you!
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<tr>
<td>Chemistry Attitudes and Experiences Questionnaire</td>
<td>(CAEQ)</td>
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<tr>
<td>Environmental Protection Agency</td>
<td>(EPA)</td>
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1 INTRODUCTION

Education is an essential part of the matriculation through life. Without a solid educational foundation anyone could easily become lost with all the things the world has to offer. This body of work characterizes three studies done with the primary goal being to become an extraordinary educator. Chapter 2 encompasses the study of a real-world problem through the design and synthesis of anti-cancer therapeutics which gave context to a serious issue that our future generations of scientist will have to face. Chapter 3 is an analysis of the discourse and interactions of students during an organic chemistry group quiz. The results of this analysis will uncover what interaction types are vital for successful discourse in a blended learning environment. Lastly, Chapter 4 details the design, implementation and assessment of a green chemistry learning module which informs us of what strategies can be used to engage students in the science curriculum. Together these three studies shape the background and expertise of the researcher. Throughout these chapters you will discover the valuable skills gained during my studies at Georgia State University.
2 DISCOVERY OF SMALL MOLECULE INHIBITORS OF THE HYPOXIA INDUCIBLE FACTOR 1 (HIF-1) PATHWAY

2.1 Abstract

The goal of every educator is to motivate their students to learn. Motivation has been found to be a key process for enhancing student learning outcomes in STEM classrooms (Michaelis, 2017). We are tasked with developing curricula that includes activities and labs that engage students. Cancer research is at the forefront of chemistry research, and it has the potential to engage students with its real-world application. We seek to highlight a study to develop novel small-molecule inhibitors, and to foster research skills and deep chemistry content knowledge that can be used to better educate our scholars.

In 2019, there will be an estimated 1,735,350 new cancer cases diagnosed and 609,640 cancer deaths in the US (National Cancer Institute, 2016). In solid tumors, a condition known as hypoxia is most often present. Hypoxia is when tumors contain areas of low oxygen pressure. Under hypoxia, the Hypoxia Inducible Factor (HIF) pathway activates several genes that allow the tumor to survive and thrive. This condition makes them resistant to radiation and more likely to metastasize. The HIF pathway is an excellent place to start to treat various tumors. Herein, we describe the design and synthesis of chemical probes that would reduce tumor growth by inhibiting the HIF-1 signaling pathway.

2.2 Introduction

Cancer is one of the leading causes of death in the United States of America (Weir et al., 2016). The death toll alone has made it of high importance to scientists and the public to find suitable treatment methods and preventative therapies. The subsequent research was done to develop small-molecule inhibitors that target solid tumors and to foster related research skills. This project
highlights the needs that our future chemist will have to meet. By researching a real-world problem such as cancer and anti-cancer therapeutics, a scientist can gain skills otherwise unknown to an instructor that exclusively reads literature. The added benefit of an experienced scientist teaching science is the enhancement of the teaching and learning process. A scientist will have more knowledge, finer skills, and advanced ideas about the natural world. Educators trained in this way will help students bridge the gaps between chemistry and themselves since they often fail to make the connection (Hagay & Baram Tsabari, 2015). The skills gained while conducting this research will be valuable tools used to teach students and to help them to make connections between chemistry and their lives. With this dual purpose, research has been done to develop small-molecule inhibitors that target solid tumors via the hypoxia-inducible factor-1 (HIF-1) pathway.

Often in solid tumors, the cells are hypoxic, meaning the cellular environment has a low presence of oxygen (Harris, 2002). The low oxygen pressure can be attributed to minimized vasculature (Harris, 2002). Cancer cells thrive in hypoxic conditions. When the cells are hypoxic, HIF activates many genes that would allow the cells to continue to grow and divide. These genes promote cell growth, glycolysis and angiogenesis. The transcription factor HIF-1 is heterodimeric and has a basic loop-helix-loop motif. HIF-1 is also a complex that is comprised of two subunits: HIF-1α and HIF-1β. In the presence of oxygen, HIF-1α is oxidized by the enzyme prolyl hydroxylase (PH) (Figure 1). The dihydroxylated form of HIF-1α is able to bind to von Hippel-Lindau tumor suppressor protein (VHL), which then undergoes a series of ubiquitination reactions (E. Cockman et al., 2000). Ubiquitination targets cells for proteasomal degradation. This proteasomal degradation prevents the activation of additional pathways that would lead to survival of the hypoxic cells (Lee, Bae, Jeong, Kim, & Kim, 2004).
Under hypoxic conditions, HIF-1α does not get hydroxylated by prolyl hydroxylase and VHL does not bind to begin the ubiquitination reactions. Alternatively, HIF-1α is stabilized and proceeds into the nucleus of the cell, where it dimerizes with HIF-1β (Figure 2). This complex gets activated by p300, and results in the subsequent transcription of several genes, such as human erythropoietin gene (EPO), nitric oxide synthase (NOS), and vascular endothelial growth factor (VEGF) (Forsythe et al., 1996). Expression of human erythropoietin gene leads to increased erythropoiesis and enhanced oxygen-carrying capacity of blood (Wenger & Hoogewijs, 2010). The expression of VEGF leads to angiogenesis, or vascular development inside the tumor cells (Williams, Kenyon, & Adamson, 2010). NOS assists in the vascularization of the cells (Knowles & Moncada, 1994).
The result of these tumor-specific changes in a microenvironment shows implications in reduced effectiveness of clinical treatments of cancer such as radiation therapy (Cairns, Papandreou, Sutphin, & Denko, 2007). Hypoxia is an almost universal feature of solid tumors, this fact makes bioregulation of the HIF-1 pathway an appealing approach to anti-cancer therapeutics (Cairns et al., 2007).

Our collaborators, the Erwin van Meir laboratory at Emory University, developed an HRE-alkaline phosphatase assay to screen a library of 10,000 compounds from a 2,2-dimethylbenzopyran combinatorial library (Nicolaou et al., 2000). The HRE-alkaline assay uses LN229 glioblastoma cells that were transfected with the alkaline phosphatase reporter and 6 copies of the HRE (hypoxia response element) for the VEGF gene (Tan et al., 2005). The analogs would either bind to HIF-1 complex substrates or the complex itself. Several properties effect binding. Properties such as van der Waal interactions and hydrogen bonding can determine where the drug
binds to the complex. Binding of the analog to the substrate could inhibit the complex either by blocking the active site or by deactivating the substrate. The initial screening identified a few hits, with the lead compound being KCN-1 \textbf{1} having an IC$_{50}$ of 0.4 $\mu$M (Figure 3) (Tan et al., 2011). Using KCN-1 as the lead, our laboratory began to synthesize a library of analogs. This library of analogs was screened against human glioblastoma cell line LN229-HRE-AP, with a luciferase reporter gene. This study yielded, N-cyclobutyl-N-((2,2-dimethyl-wH-pyranol[3,2-b]pyridine-6-yl)methyl)-3,4-dimethoxybenzenesulfonamide \textbf{2} with an IC$_{50}$ value of $\sim$0.3 $\mu$M (Figure 4) (Suazette Reid Mooring et al., 2011). Despite the inhibitory effects shown by the sulfonamide compounds, they possess poor water solubility (Wang et al., 2012). In efforts to increase solubility, we proposed using a benzhydrol moiety. Our efforts yielded tert-butyl 4-((4-(3,4-dimethoxyphenyl)(hydroxyl)methyl)phenoxy)methyl) piperidine-1-carboxylate \textbf{3} with an IC$_{50}$ value of 0.33 $\mu$M. This study aims to design and synthesize a library of benzhydrol compounds that could be used as anti-cancer therapeutics. Our analogs include a symmetrical design with methoxy substituents, along with the benzhydrol moiety (Figure 5).

\textit{Figure 3 Compound 1. IC$_{50}$ = 0.4 $\mu$M}

\textit{Figure 4 Compound 2. IC$_{50}$ = $\sim$0.3 $\mu$M}
2.3 Materials and Methods

Design

Dividing the molecule into four regions as shown in Figure 5 is the approach we chose for the modification of compound 3. Collectively three classes of compounds were designed and synthesized (Figure 6). Region I was modified with alkyl substituents. Region II employed benzene, naphthalene, and quinoline derivatives. Region III maintained an alcohol group and region IV contained a 3,4-methoxy or 3, 4, 5-trimethoxy moiety. All compounds were synthesized using known synthetic procedures.

*Figure 5 Four Regions of Modification of 3. IC₅₀ = 0.33 µM*

*Figure 6 Analogs Designed and Synthesized.*

Class I: Benzene analogs

Class II: Naphthalene analogs

Class III: Quinoline analogs
**Chemistry.**

Class I analogs were designed to probe the importance of different ether derivatives on the benzene moiety. Class II analogs were designed to probe the use of fused ring systems with similar ether groups as class I. Lastly class III analogs were synthesized to observe the importance of adding heteroatoms to the fused ring system.

*Class I*: Synthesis of class I compounds (Figure 6) was afforded in 2 steps from 3-bromophenol. To afford these analogs, the ether derivative of region I-II was synthesized followed by a halogen lithium exchange reaction and the addition of aldehyde (region IV) that lead to the benzhydrol product.

The synthesis of the class I derivatives began with 3-bromophenol undergoing a nucleophilic substitution reaction to form the subsequent ether intermediate. The bromo group on the ether intermediate was subjected to a halogen lithium exchange reaction and upon addition of the aldehyde the benzhydrol was formed.

*Scheme 1 Synthesis of the Benzene Analogs*

\[ \text{HOBr} \quad + \quad R_1\text{-Br} \quad \xrightarrow{a} \quad R_1\text{-OBr} \]

\[ \text{R}_1\text{-OBr} \quad + \quad \text{OMe}_{\text{Me}}\text{OMe}_{\text{Me}} \quad \xrightarrow{b} \quad \text{R}_1\text{-OMe}_{\text{Me}}\text{OMe}_{\text{Me}}\]

*Note.* $R_1 = $ propane (2a). Reagents and conditions; (a) 1-bromopropane, K$_2$CO$_3$, acetonitrile, reflux, 86%; (b) buLi, THF, -78°C, 1 hr., addition of 3,4,5-trimethoxybenzaldehyde, 58%.
**Class II:** Next, instead of using the phenyl moiety in region II, a naphthyl analog was used as the starting material in a nucleophilic substitution reaction to form derivatives that contain various alkyl groups in region I. We reacted the ether product with n-butyllithium followed by the addition of an aldehyde to form the benzhydrol product.

*Scheme 2 Synthesis of Naphthalene Analogs*

\[
\begin{align*}
&\text{HO} \quad \text{Br} \quad + \quad R_1-\text{Br} \quad \xrightarrow{a} \quad R_1\text{O} \quad \text{Br} \\
&\text{R}_1\text{O} \quad \text{Br} \quad + \quad \text{OHC} \quad \text{R}_2 \quad \xrightarrow{b} \quad R_1\text{O} \quad \text{R}_2
\end{align*}
\]

*Note.* \(R_1 = 3\)-methylbutyl \(R_2 = 3,4,5\)-trimethoxyphenyl (3a); \(R_1 = 3\)-methylbutyl \(R_2 = 3,4\)-dimethoxyphenyl (3b); \(R_1 = \text{but-3-enyl} \ R_2 = 3,4\)-dimethoxyphenyl (3c); \(R_1 = \text{but-3-enyl} \ R_2 = 3,4,5\)-trimethoxyphenyl (3d); \(R_1 = \text{ethyl} \ R_2 = 3,4\)-dimethoxyphenyl (3e); \(R_1 = \text{ethyl} \ R_2 = 3,4,5\)-trimethoxyphenyl (3f); \(R_1 = \text{isopropyl} \ R_2 = 3,4\)-dimethoxyphenyl (3g); \(R_1 = \text{isopropyl} \ R_2 = 3,4,5\)-trimethoxyphenyl (3h); Reagents and conditions; (a) \(\text{K}_2\text{CO}_3\), acetonitrile, reflux, 80-90%; (b) (1) under \(\text{N}_2\), THF, -78°C, n-butyllithium; (2) addition of 3,4,5-trimethoxybenzaldehyde, 40-60%.

**Class III:** After the use of a fused ring system, the next modification was the addition of a heteroatom to the naphthyl ring. A quinolyl analog was used as the starting material in a nucleophilic substitution reaction to form derivatives that contain various alkyl groups in region I. We reacted the ether product with n-butyllithium followed by the addition of an aldehyde to form
the benzhydrol product. The introduction of a nitrogen group into the ring has the potential to increase the solubility of the analog as well as decrease the toxicity.

*Scheme 3 Synthesis of Quinoline Analogs*

Note. \( R_1 = 3,4\)-methoxyphenyl (4a); \( R_2 = 3,4,5\)-trimethoxyphenyl (4b); Reagents and conditions; (a) \( \text{buLi, THF, } -78^\circ\text{C, 1 hr., addition of 3,4,5-trimethoxybenzaldehyde, 50-60\%} \).

**Biology**

The synthesized analogs will be evaluated for their potential to inhibit HIF-1-mediated transcription under 1% \( \text{O}_2 \) (hypoxia) using human glioma cell line LN229-HRE-Lux, which expresses a hypoxia-responsive luciferase reporter gene.

**Table 1 Data Collected from Synthesized Products**

<table>
<thead>
<tr>
<th>Name</th>
<th>Structure</th>
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<tbody>
<tr>
<td>2a</td>
<td><img src="image" alt="Structure 2a" /></td>
<td>1.3 ( \mu\text{M} )</td>
</tr>
<tr>
<td>3a</td>
<td><img src="image" alt="Structure 3a" /></td>
<td>1.3 ( \mu\text{M} )</td>
</tr>
<tr>
<td>3c</td>
<td><img src="image" alt="Structure 3c" /></td>
<td>1.3 ( \mu\text{M} )</td>
</tr>
<tr>
<td>3e</td>
<td><img src="image" alt="Structure 3e" /></td>
<td>2.4 ( \mu\text{M} )</td>
</tr>
</tbody>
</table>
2.4 Discussion

The analogs synthesized with the fused ring system (IC$_{50}$ 1.3-3.5 µM) in region II showed more inhibitory effects than the analogs with fused systems and heteroatoms (IC$_{50}$ >10 µM). The analog with the benzene moiety also showed inhibitory effects (IC$_{50}$ 1.3 µM). In region I, the analogs with longer length chains showed more inhibitory effects than the simple chain structures.

2.5 Conclusion

Several analogs of the lead compound 3 were synthesized. IC$_{50}$ data (Table 1) showed that some of the analogs synthesized may have inhibitory activity for the HIF-1 pathway. Concurrently, valuable skills were developed by the researcher. The utilization of column chromatography and nuclear magnetic resonance boosted skills used every day in chemical research (Gaucher, 1969; Roberts, 1961). Communication skills were enhanced by weekly group meetings and collaboration.
with another university. Predominately, chemical knowledge and background was increased. These skills will be translated into secondary and post-secondary classroom curricula to enhance the learning process. Investigating a real-world problem helped to broaden the scope of chemistry lessons. Instead of shallowly teaching chemistry, the background allows for the integration of advanced research skills into the secondary and post-secondary curricula that will be discussed in Parts II and III of this dissertation.

2.6 Experimental

Chemistry. All commercial chemicals and solvents were reagent grade and were used without further purification. $^1$H NMR and $^{13}$C NMR were recorded at 400 and 100 MHz, respectively, on a Bruker 400 NMR spectrometer with deuterated solvent or TMS as the internal standard. Coupling constants are in Hz. Mass spec analysis was performed by the Mass Spectrometry Facilities at Georgia State University.

General Procedure for Synthesis of 2a and 3a-h starting materials. To a solution of the hydroxyl starting material (1 equiv) in acetonitrile was added a bromo compound containing the respective R group (1.2 equiv) and K$_2$CO$_3$ (2 equiv). The mixture was allowed to reflux overnight. The solvent was removed by rotary evaporation. The organic layer was extracted by ethyl acetate, washed with H$_2$O (x3), washed with brine, dried with Na$_2$SO$_4$, and concentrated in vacuo. The crude product was purified by flash column chromatography (silica gel).

2-Bromo-6-(isopentyloxy) naphthalene 3a and 3b starting material. Yield 92%. $^1$H NMR (CDCl$_3$): δ 7.90 (s, 1H), 7.65-7.62 (d, J= 8.8Hz, 1H), 7.60-7.57 (d, J=8.8Hz, 1H), 7.49-7.47 (d, J = 8.8Hz, 1H), 7.17-7.16 (dd, J=9.2Hz, 8.8Hz, 1H), 7.09-7.08 (d, J=1.6Hz, 1H), 4.11-4.07 (t, J=6.6Hz, 2H), 1.90-1.85 (dd, J=13.2Hz, 13.6Hz, 1H), 1.77-1.72 (dd, J=13.6Hz, 13.6Hz, 2H), 0.93 (s, 6H).

2-Bromo-6-(but-3-en-1-yloxy) naphthalene 3c and 3d starting material. Yield 95%. $^1$H NMR (CDCl$_3$): δ 7.91-7.91 (d, J=1.6Hz, 1H), 7.65-7.63 1e (d, J=8.8Hz, 1H), 7.60-7.57 (d, J=8.8Hz, 1H), 7.50-7.48 (dd, J= 8.8Hz, 6.8Hz, 1H), 7.18-7.15 (dd, J=8.8Hz, 8.8Hz, 1H), 7.10-7.09 (d, J=2.4Hz, 1H).

2-Bromo-6-ethoxynaphalene 3e and 3f starting material. Yield 91%. $^1$H NMR (CDCl$_3$): δ 7.91-7.91 (d, J=1.6Hz, 1H), 7.65-7.63 (d, J=8.8Hz, 1H), 7.59-7.57 (d, J=8.8Hz, 1H), 7.50-7.47
(dd, J= 8.8Hz, 8.8Hz, 1H), 7.19-7.16 (dd, J=8.8Hz, 8.8Hz, 1H), 7.08-7.08 (d, J= 5.6Hz, 1H), 3.84-3.82 (d, J=6.4Hz, 2H), 2.19-2.12 (m, 1H), 1.10 (s, 6H).

General Procedure for 2a, 3a-3h, and 4a-b. Respective starting materials (1 equiv.) were allowed to dry before 2ml dry THF were added under N2 and cooled to -78°C, n-butyllithium (1 equiv.) was added and the mixture was allowed to stir 1 hour before the aldehyde (1.2 equiv.) was added and temperature was allowed to slowly increase. The reaction was quenched with NH4Cl, washed with H2O, extracted with EtOAc, washed with brine, and dried with Na2SO4. Crude product was concentrated in vacuo and purified via flash column chromatography (silica gel).

(3-ropoxyphenyl) (3,4,5-trimethoxyphenyl) methanol (2a). Yield: 43%. 1H NMR (CDCl3): δ 7.26-7.22 (dd, 1H), 6.94-6.92 (d, 2H), 6.82-6.79 (dd, 1H), 6.60 (s, 1H), 5.70 (s, 1H), 3.94-3.87 (q, 2H), 3.86 (s, 9H), 2.45 (s, 1H), 1.82-1.75 (m, 2H), 1.04-1.00ppm (t, 3H). 13C(CDCl3): δ 159.3, 153.2, 145.3, 139.4, 129.5, 118.7, 113.5, 112.8, 76.2, 69.5, 60.8, 22.6, 10.5ppm. HRMS (ESI) m/z calcd for C19H24O5 [(M + H)⁺] 333.1697; found 333.1683.

(6-(isopentyloxy) naphthalen-2-yl) (3,4,5-trimethoxyphenyl) methanol (3a). Yield 52%. 1H NMR (CDCl3): δ 7.71 (s, 1H), 7.67-7.65 (d, J=8.8Hz, 1H), 7.63-7.61 (d, J=8.8Hz 1H), 7.33-7.31 (dd, J=8.4Hz, 8.4Hz, 1H), 7.19 (s, 1H), 7.10-7.09 (d, J=2.4Hz, 1H), 7.07-7.05 (dd, J=8.4Hz, J=8.4, 2H), 6.58 (s, 1H), 4.05-4.01 (t, J=6.8, 2H), 3.76 (s, 9H), 2.21-2.20 (d, J=2.6Hz,1H), 1.83-1.78 (m, 1H), 1.70-1.65 (dd, J=13.2Hz, 13.6Hz, 2H), 1.48 (s, 1H), 0.93-0.91 (s, 6H). 13C(CDCl3): δ 157.3, 153.2, 139.8, 138.9, 137.1, 134.1, 129.5, 128.6, 127.1, 125.3, 125.1, 119.3, 106.6, 103.7, 76.2, 66.5, 60.8, 56.0, 38.0, 25.2, 22.7ppm. C25H30O5.

(6-(but-3-en-1-yloxy) naphthalen-2-yl) (3,4-dimethoxyphenyl) methanol (3c). Yield 32%. 1H NMR (CDCl3): δ 7.79 (s, 1H), 7.74-7.72 (d, J=8.8Hz 1H), 7.69-7.67 (d, J=8.8Hz 1H), 7.40-7.37 (dd, J=8.8Hz, 8.4Hz, 1H), 7.17-7.16 (d, J=2.8Hz 1H), 7.15-7.14 (d, J=2.4Hz 1H), 7.12-7.11 (d, J=2.4Hz 1H), 6.97-6.96 (d, J=2Hz, 1H), 6.94-6.92 (d, J=8.4Hz, 1H), 6.84-6.82 (d, J=8Hz, 1H). 13C(CDCl3): δ 157.2, 149.2, 148.7, 139.1, 136.7, 134.6, 134.2, 129.7, 128.8, 127.3, 125.4, 125.0, 119.4, 119.2, 117.2, 111.1, 110.0, 106.8, 76.3, 67.4, 56.1, 56.0, 33.8ppm. HRMS (ESI) m/z calcd for C23H24O4 [(M + H)⁺] 364.1675; found 365.1752.
(6-ethoxynaphthalen-2-yl)(3,4-dimethoxyphenyl)methanol 3e. Yield 30%. $^1$H NMR (CDCl$_3$): δ 7.78 (s, 1H), 7.73-7.71 (d, J=9.2Hz, 1H), 7.68-7.66 (d, J=8.4Hz, 1H), 7.39-7.39 (d, J=1.2Hz, 1H), 7.39-7.36 (dd, J=8.4Hz, 8.8Hz, 1H), 7.16-7.13 (dd, J=8.8Hz, 8.8Hz, 1H), 7.11-7.10 (d, J=2Hz, 1H), 6.96-6.95 (d, J=2Hz, 1H), 6.93-6.92 (d, J=2Hz, 1H), 6.91-6.90 (d, J=1.6, 1H), 6.84-6.81 (d, J=8.4Hz, 1H), 5.92 (s, 1H), 4.17-4.11 (dd, J=14Hz, 14Hz, 2H), 3.86-3.83 (d, J=11.2, 6H), 2.32 (s, 1H), 1.49-1.46 (t, J=6.8Hz, 7.2Hz, 3H).

$^{13}$C (CDCl$_3$): δ 157.3, 149.2, 148.6, 139.0, 136.7, 134.2, 129.6, 128.7, 127.3, 125.4, 125.0, 119.4, 119.2, 111.1, 110.0, 106.7, 76.2, 63.6, 56.1, 56.0, 14.9ppm. C$_{21}$H$_{22}$O$_4$

(6-ethoxynaphthalen-2-yl)(3,4,5-trimethoxyphenyl) methanol 3f. Yield 30%. $^1$H NMR (CDCl$_3$): δ 7.76 (s, 1H), 7.73-7.70 (d, J=8.8Hz, 1H), 7.68-7.66 (d, J=8.4Hz, 1H), 7.40-7.37 (dd, J=8.8Hz, 8.8Hz, 1H), 7.16-7.13 (dd, J=9.2Hz, 8.8Hz, 1H), 7.10-7.09 (d, J=2.4, 1H), 4.16-4.11 (dd, J=14Hz, 14Hz, 2H), 3.82 (d, 9H), 2.15 (s, 1H), 1.49-1.45 (t, J=1.2Hz, 7.2Hz, 3H). $^{13}$C (CDCl$_3$): δ 157.3, 153.4, 139.6, 138.8, 137.3, 134.2, 129.6, 128.7, 127.3, 125.3, 125.2, 119.4, 106.6, 103.7, 76.5, 63.6, 60.9, 56.2, 14.9ppm. C$_{22}$H$_{24}$O$_5$

quinolin-3-yl (3,4-dimethoxyphenyl) methanol 4a. Yield 32%. $^1$H NMR (CDCl$_3$): δ 8.66-8.65 (d, J=1.2Hz, 1H), 8.08 (s, 1H), 7.94-7.92 (d, J=8.4Hz, 1H), 7.69-7.67 (d, J=8.4Hz, 1H), 7.58-7.55 (t, J=7.2Hz, 1H), 7.46-7.42 (t, J=7.6Hz, 1H), 6.89-6.88 (d, J=1.2Hz, 1H), 6.80-6.78 (dd, J=8.4Hz, 8Hz, 1H) 6.72-6.70 (d, J=8Hz, 1H), 5.87 (s, 1H), 3.78-3.71 (d, J=6Hz, 1H), 1.98 (s, 1H). $^{13}$C (CDCl$_3$): δ 149.8, 149.1, 148.5, 146.7, 137.3, 136.0, 133.0, 129.3, 128.5, 127.9, 127.7, 126.8, 119.2, 111.0, 109.8, 73.6, 60.4, 55.8, 55.8, 21.0, 14.1ppm. HRMS (ESI) m/z calcd for C$_{18}$H$_{17}$NO$_3$ [(M + H)$^+$] 296.1286; found 296.1281.

quinolin-3-yl (3,4,5-trimethoxyphenyl) methanol 4b. Yield 47%. $^1$H NMR (CDCl$_3$): δ 8.76 (s, 1H), 8.12 (d, 1H), 7.99-7.98 (d, J=8Hz, 1H), 7.76-7.74 (d, J=8Hz, 1H), 7.64-7.61 (t,
$J = 7.4\text{Hz}, 1\text{H})$, 7.51-7.48 (t, $J = 7\text{Hz}, 1\text{H}$), 6.59 (s, 2H), 5.90 (s, 1H), 3.79-3.75 (d, 9H), 2.01 (s, 1H), 1.25-1.23 (d, $J = 9.6\text{Hz}, 1\text{H}$). C$_{19}$H$_{19}$NO$_4$ HRMS (ESI) m/z calcd for C$_{19}$H$_{19}$NO$_4$ [(M + H)$^+$] 326.1392; found 326.1388.

3-bromoquinoline sigma Aldrich reagent CAS # 5332-24-1

(6-isopropoxynaphthal-2-yl) (3,4,5-trimethoxyphenyl) methanol 3h. Yield 42%. $^1$H NMR (CDCl$_3$): $\delta$ 7.78 (s, 1H), 7.73-7.71 (d, $J = 8.8\text{Hz}, 1\text{H}$), 7.68-7.66 (d, $J = 8\text{Hz}, 1\text{H}$), 7.39-7.36 (d, $J = 8.4\text{Hz}, 1\text{H}$), 7.17-7.15 (d, $J = 8.8\text{Hz}, 1\text{H}$), 7.10 (s, 1H), 6.96-6.92 (t, $J = 8.8, 1\text{H}$), 6.84-6.82 (d, $J = 8\text{Hz}, 1\text{H}$), 5.93 (s, 1H), 3.86-3.84 (d, 9H), 2.30 (s, 1H), 2.17-2.13 (t, $J = 6.4\text{Hz}, 1\text{H}$), 1.08-1.06 (d, $J = 6.4\text{Hz}, 6\text{H}$). C$_{23}$H$_{26}$O$_5$
3 ANALYSIS OF STUDENT ENGAGEMENT TYPES

3.1 Abstract

Flipped classrooms have been shown to improve motivation and persistence in STEM among minorities and women. Limited research has been performed to analyze the drivers behind the success of these collaborative learning environments. This exploratory research seeks to describe the engagement types needed for successful discourse during a group quiz. We analyzed four groups of African American women during an in-class organic chemistry I group quiz and we uncovered engagement types that lead to correctly answering organic chemistry I problems.

3.2 Introduction

Institutions of Higher Education in the United States continue to have challenges with diversity and inclusion (Luster-Eduard & Martin, 2018). Moreover, research often characterizes the scantiness of African-American students in Science, Technology, Engineering, and Mathematics, STEM, fields. This narrative may affect students’ willingness to study and advance in such areas. We must create opportunities for minorities to build upon and showcase their scientific skills. Creating a positive image of minorities in science will make the career field more appealing by displaying that success is attainable. We must foster this attitude and develop skills by implementing culturally relevant curricula that result in the active engagement of students of color. Our strategy is the implementation of a community-based, blended learning environment (P. Rovai & Jordan, 2004). In this environment, students are encouraged to interact with learning material online at their own pace and to use their class time to interact with their peers while doing activities to sharpen scientific skills. One of the commonly known blended learning environments is the flipped classroom. Flipped classrooms present the course material online, while having the hand-on problems solving in-class. Flipped classrooms have been shown to increase the success
of students in science classrooms. Studies describe increased passing rates and reduction in DWF rates (Suazette R. Mooring, Mitchell, & Burrows, 2016). Moreover, there are some studies that observe a more pronounced positive effect of flipped classrooms on women and underrepresented minorities (Sullivan-Green, 2018). Despite the observed successes limited studies have been implemented to characterize the underlying mechanisms that lead to the success of flipped courses. It is also vital that we explore environments that lead to the success of women and underrepresented minorities (URMs) in order to better design course material and activities. One aspect of active learning employed in many flipped classrooms is group activities.

This qualitative, exploratory investigation examines URM women involved in flipped and blended courses during group quizzes. We seek to qualitatively describe their interaction, discourse, and group engagement. During the group quizzes, the students were asked to interact with one another to form an answer to organic chemistry problems. In our observation of group interactions, we looked for instances when the students are contributing to the group work or a lack thereof. After careful review of the videos, we created codes using the constant comparative coding method (Strauss & Corbin, 1990). We uncovered codes that speak to group interactions and discourse that affected the quality of answers to organic chemistry I problems. These levels of engagement allude to the mechanisms required to have successful group discourse. In addition, we will explore how the students group engagement levels affect the quality of their answers on group quiz problems. We used the Community of Inquiry framework (described in section 3.4) to characterize the results from our study (Karen, Garrison, & Jennifer, 2009).

**Statement of Problems**

Among employed adults with a bachelor’s degree or higher, African-Americans make up only 7% of the STEM workforce (Funk & Parker, 2018). Concurrently, the participation of women
in STEM fields are not commensurate with that of men (Baker, 2002). Positive images of URMs and women success in STEM, are needed to retain and attract students to such disciplines. Instead of only displaying minority disparity in these areas, we must change the dialogue to a positive one. URMs have shown increased success in science courses when flipped classrooms were implemented. It is important we explore the driver of success within blended learning environments implemented for minority and women students. This knowledge will support the development of innovative, inclusive, and engaging course materials. Such materials will aid in retaining the pipeline of URM students throughout their scientific education and increase URM and women participation in STEM fields.

**Purpose of Study**

Curricula has been piloted that results in the active engagement of women and URMs. In this study, we use qualitative analysis to explore students’ interactions during group quizzes to uncover what methods minority students, specifically African American women use to succeed in STEM-related learning environments. The purpose of this study is to explore the discourse between students during a group quiz and to uncover which measures lead to high quality quiz answers. Uniquely, this work focuses on a student groups composed entirely of African American women and could therefore uncover the strategies that lead to success in this group.

**Research Questions**

- What are the engagement profiles for groups composed of African American women in organic chemistry I during a group quiz?
- How does group engagement affect the quality of answers on the group quiz problems?
Significance of Study

This research was done at a historically black, all women institution in the southeast United States. The students were enrolled in a first-semester Organic Chemistry course. Research has shown women often fail to engage in science learning, thus conducting research at an all women institution will give unique insights on individuals at this institution and institutions across the United States (Thompson & Windschitl, 2005). We will give a deep description of the student engagement of the students who are enrolled in blended courses. We will also show which types of engagement leads to high quality quiz answers and how quiz questions can affect engagement and collaboration levels. This research will help create meaningful course materials and activities that will increase minority participation in STEM fields.

3.3 Literature Review

Minorities absence in STEM careers

In 2015 only four percent of African-Americans were employed as physical or related scientist (National Science Foundation, 2017). Of the total number of scientist and engineers employed in their respective fields in 2015, only two percent were found to be African-American women (National Science Foundation, 2017). Experts recognize the need for more diversity in STEM. Therefore, research has been done to understand the reasons behind and intervene in the decline of minorities in STEM.

However, past research has often focused on the academic deficits and lower socioeconomic status of women and minorities to explain their absence from the STEM fields (Elliott, Strenta, Adair, Matier, & Scott, 1996). Women and minority student interests were found to be limited because of the lack of experiences with the true nature of science. Contrary to these beliefs, Beasley & Fisher found that some women initially intend to major in STEM fields;
therefore, aptitude, socialization, and interest alone can not explain the lack of women and minorities in such fields (2012). Women and underrepresented minorities have been found to leave STEM majors at significantly higher rates than non-underrepresented minorities (Toven-Lindsey, Levis-Fitzgerald, Barber, & Hasson, 2015). Based on these documented disparities, it is vital for education professionals to find creative ways to engage students of color and motivate them to pursue careers in related STEM fields. Minority students’ experiences in the classroom have a significant impact on their pathways into STEM fields (Hayden, Ouyang, Scinski, Olszewski, & Bielefeldt, 2011). Therefore, national efforts are focused on shifting the trend from the decline of minorities and women in STEM to the growth of minorities and women in STEM. In November 2009, President Obama launched *Educate to Innovate* with the primary goal of encouraging student interest and participation in STEM-related activities and careers (Obama, 2009). More efforts must be asserted to change the dialogue and promote the inclusion of women and minorities in STEM. For over a half of century, the United States has maintained its report as a dominant player in terms of intellect and economics based on the strength of our research efforts in science and technology. For that reason, it is especially important to remain competitive in world research efforts. To maintain our competitive edge, we must include diverse thinking to solve our global problems. Collaborative efforts from individuals with different backgrounds and experiences will lead to the most innovative approaches to solving problems. Bolaños-Guzmán & Zarate Jr (2016) emphasized, “…diversity of thought, of background, and of experience leads to a wider pool of innovative hypotheses for scientists to draw from.” The diversity of thought strengthens scientific enterprise by enriching it with more ideas. Job growth predictions made by the U.S. Bureau of Labor Statistics makes it especially important to equip our students with the skills and
reinforcements to keep them in the STEM pipeline. It is necessary that we encourage more women and minorities to participate in STEM to meet the needs of our growing country (McLaren, 2009).

**Interventions**

In response to the alarming underrepresentation of minorities in STEM, scientists conducted studies on methods that would effectively increase minority participation in STEM. Many strategies have been implemented with similar intentions. Educators have been advised to incorporate group activities into their classrooms (National Research Council, 1999; National Science Foundation, 1996), to allow the students to explore the nature of science and engage in collaborative talks like the talk used in research and development. Peer-led team learning (PLTL) has been shown to improve student performance in organic chemistry, and the students also valued the collaborative nature of PLTL (Snyder, Sloane, Dunk, & Wiles, 2016). Emphasis has also been placed on undergraduate research experiences as a driving force to gain student interest in STEM fields (Hurtado, Cabrera, Lin, Arellano, & Espinosa, 2009). Research experience reduces the dropout rate of students from science programs (Linn, Palmer, Baranger, Gerard, & Stone, 2015).

Additionally, project-based science curricula have been employed and shown to positively impact students interests and plans on pursuing science careers (Kanter & Konstantopoulos, 2010). These interventions rely strongly on the underlying premise that the use of collaborative/group work will boost students’ interests in science, technology, engineering, and mathematics fields. Another notable intervention is the blended/flipped classroom. Blended learning environments encourage student collaboration and individual study efforts. This study seeks to characterize the drivers of success during a group activity with students who have been taught in a blended learning environment.
**Blended Learning Environment/ Flipped Classroom**

In blended learning environments, lectures are often replaced by short videos and/or readings, and class time is used for problem-solving and other collaborative group activities (Lage, Platt, & Treglia, 2000). Blended environments give students the opportunity to learn the course material at their own pace and practice the skills needed to solve problems during class. Research in flipped organic chemistry courses has shown that students achieve at higher rates in this environment (Flynn, 2015; Teo, Tan, Yan, Teo, & Yeo, 2014; Weaver & Sturtevant, 2015). Mooring, Mitchell, and Burrows found that overall course scores increased and DFW rates decreased for students who were taught using the flipped classroom method compared to students in a traditional course (2016). The students in the flipped course had a better attitude towards chemistry. That is, they were more emotionally satisfied and felt that the course material was more intellectually accessible than students in the traditional course (Suazette R. Mooring et al., 2016). This organization of course materials and exposure to guided problem solving has often had a significant impact on minorities and women, with even more pronounced effects on their scores and attitudes. Despite this knowledge, very little research has been done on what factors drive the success of students and particularly students from underrepresented groups in flipped courses.

**Group Engagement and Persistence in STEM**

This study seeks to use an analysis of an in-class group quiz to understand the drivers behind minority women’s success in a blended learning environment. Sahin, Ayar, & Adiguzel found that collaboration contributes to students learning from each other to their understanding of the different aspects of specific tasks at hand, and the successful accomplishment of the tasks assigned to them (2014). Learning communities or study groups described by Wilson et al., are critical to graduate school success (2014). Studies also suggest that when students participate in
professional or departmental organizations, they have an increased likelihood to maintain persistence in science (Nocera & Harrison, 1996). Such experiences and organizations may provide students with a forum to use science talk and collaborate with individuals with similar interest. Group activities have often lead to positive attitudes about the topics at hand. This group engagement analysis will be used to thoughtfully prepare engaging learning materials/activities that can be used to boost student interest in chemistry and retain those URM students on the chemistry pipeline.

3.4 Theoretical Framework

*Figure 7 Community of Inquiry Model*

Community of Inquiry, CoI, was chosen as the underlying framework for this study because it addresses the critical elements needed for effective communication and group work.
The CoI framework has been used in the past to characterize student engagement in an online setting (D. R. Garrison, Anderson, & Archer, 1999). However, the framework captures the ideals and definitions that are appropriate to characterize group engagement in a blended learning, collaborative, and active learning Organic Chemistry course.

CoI is a student-center framework focused on facilitating a rich educational experience (D. Garrison & Akyol, 2013). Student-centered learning strategies have been shown to enhance learning as compared to traditional lecture techniques (Kober, 2015). The CoI model shows that the interrelationships between teaching, cognitive, and social interactions influence the student learning experience (Figure 1) (D. R. Garrison et al., 1999). This CoI model is based on a constructivist approach to learning (Swan, Garrison, & Richardson, 2009). Constructivists believe that learning occurs when the learner is actively involved in the process of creating meaning and constructing knowledge (Swan et al., 2009). The CoI construct states that three elements are critical for successful, meaningful learning: Cognitive Presence, Social Presence, and Teaching Presence (Figure 1). The overlap of these critical elements provides the students the ability to learn course content, discuss and apply information, and interconnect with their peers and instructor. In the upcoming sections, we will discuss each element and how they relate to the study of group engagement.

<table>
<thead>
<tr>
<th>Elements</th>
<th>Categories</th>
<th>Indicators (examples)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive Presence</td>
<td>Triggering Event</td>
<td>Sense of puzzlement</td>
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<tr>
<td></td>
<td>Exploration</td>
<td>Information exchange</td>
</tr>
<tr>
<td></td>
<td>Integration</td>
<td>Connecting ideas</td>
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<tr>
<td></td>
<td>Resolution</td>
<td>Apply new ideas</td>
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<tr>
<td>Social Presence</td>
<td>Emotional Expression</td>
<td>Emoticons</td>
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<td>-----------------</td>
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<tr>
<td>Teaching Presence</td>
<td>Instructional Management</td>
<td>Defining &amp; initiating discussion topics</td>
</tr>
</tbody>
</table>

*Note. Adapted from Garrison, Anderson, & Archer (1999)*

**Table 3 CoI Codes Alignment with Observed Codes**

<table>
<thead>
<tr>
<th>Categories</th>
<th>Indicators (examples)</th>
<th>Observed Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triggering Event</td>
<td>Sense of puzzlement</td>
<td>IDK</td>
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<tr>
<td>Exploration</td>
<td>Information exchange</td>
<td>Affirmation</td>
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<td>Closed</td>
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<td></td>
<td>questioning</td>
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<td></td>
<td></td>
<td>Idea swapping</td>
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<td></td>
<td></td>
<td>Open questioning</td>
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<td></td>
<td></td>
<td>Verification of</td>
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<tr>
<td></td>
<td></td>
<td>answer</td>
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<tr>
<td>Integration</td>
<td>Connecting ideas</td>
<td>Argumentation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Restating</td>
</tr>
<tr>
<td>Resolution</td>
<td>Apply new ideas</td>
<td></td>
</tr>
<tr>
<td>Emotional</td>
<td>Emoticons</td>
<td></td>
</tr>
<tr>
<td>Expression</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open Communication</td>
<td>Risk-free expression</td>
<td>Off-task</td>
</tr>
<tr>
<td>Group Cohesion</td>
<td>Encouraging collaboration</td>
<td>Peer encouragement</td>
</tr>
</tbody>
</table>
Cognitive Presence

Cognitive presence is the essential element used in higher education. Cognitive presence is the scope to which students in a community of inquiry can construct meaning through sustained communication (D. R. Garrison et al., 1999). Cognitive presence includes the categories: triggering event, exploration, integration, and resolution. These categories aid in understanding what is taking place in a text-based environment. Students in both online and blended learning environments were able to reach high levels of cognitive presence and learning outcomes while using the community of inquiry construct to monitor their studies (Akyol & Garrison, 2011). In our study of group engagement, the questions on the organic chemistry group quiz acts as the triggering event. Throughout the group quiz, the questions triggered the students to express their confusion, or lack of knowledge on a subject, noted by the code IDK. Primarily, the students participated in exploration denoted by the codes: affirmation, closed questioning, idea swapping, open questioning, and verification of answer. Exploration is often found as the dominating phase in face-to-face and online interactions (Vaughan & Garrison, 2005). Group members often exchange ideas back-and-forth using the techniques listed above before constructing the final answer. The integration of group thoughts can be found with the code restating used when a group member restates the answer that was developed by the group. Argumentation also integrates the group
thoughts being that a student states a claim and provides backing for their claim using facts from the group discussion. Rich integration examples can be found during online interactions because students have time to reflect and accurately synthesize a meaningful answer using knowledge and literature. To reach the level of resolution during an activity also requires a deep level of thought and meaningful collaboration efforts to use constructed knowledge to answer new questions. Minimal resolution is captured in our group observations being that very little *newly constructed* information is developed during these conversations. Research shows that it is rare for students to move beyond the exploration phase while collaborating in a group setting (McKlin, Harmon, Evans, & Jones, 2001; Meyer, 2004; Vaughan & Garrison, 2005).

**Social Presence**

Social presence is the ability of the learner to exhibit their personality into the community of learners. Social presence has been shown to impact student motivation and participation, actual and perceived learning, course and instructor satisfaction and retention in online courses. The participants must find the interaction in the group enjoyable so that they will remain an active contributor to activities taking place in groups (D. R. Garrison et al., 1999). There is a positive relationship between social presence and students’ satisfaction with e-learning. Social presence may be displayed as the use of emoticons, risk-free expression, and encouraging collaboration. The use of emoticons is not observed in the face-to-face setting of the group quiz. However, the risk-free expression is mostly observed during off-task conversations the students participated in while waiting on the scribe to enter the answer on the iPad. For example, the students were overheard discussing their favorite thanksgiving meat choice and current stories of interest in the news – this type of conversation displays risk-free expression. The students were projecting their personality into the community. Encouraging collaboration was also observed when the students
encouraged one another while answering questions during the group quiz. Studies have found a relationship between social presence and retention in science (Akyol, Garrison, & Ozden, 2009; Arbaugh & Benbunan-Finch, 2006; Richardson & Swan, 2003).

**Teaching Presence**

Teaching presence includes instructional management, building understanding, and direct instruction. In our study, the teaching presence included the selection, organization, presentation of course content, and the development of learning activities. Therefore, the instructor was responsible for teaching the content, designing the group quiz and giving students instructions regarding their interactions during the group quiz. The design of the group quiz sets the tone and flow for the students. Questions that provoke deep thought or the connection of many ideas lead to rich conversations and interactions (Chi & Wylie, 2014). During the group quiz, the students had to rely on their knowledge and the knowledge of their classmates to answer questions. They were not allowed to use text or the internet to answer questions. Seldomly, a group would reach a roadblock on an answer and require hints from the instructor. The instructor assisted without giving any major details or techniques to solve the problems. These minor events were not coded since they do not align with our research questions.

3.5 **Methodology**

**Purpose of Study**

This work was undertaken as part of a larger project to showcase narratives of success for minority students in STEM learning environments. Curricula has been piloted in organic chemistry courses that result in the active engagement of students of color. With our results we wish to create a narrative that minority students, specifically African American women can meet and exceed
STEM standards. This portion of the work seeks to characterize the nature of effective learning with student engagement in a community-based, blended learning environment.

**Research Questions**

RQ1: Which types of engagement lead to the successful completion of an in-class group quiz?

RQ2: Which discourse types lead to the successful completion of an in-class group quiz?

3.5.1 **Research Design**

**Setting of Study**

This research was performed at an all women, historically black institution in the Southeast of the United States. In a community-based, blended learning environment, the students were exposed to the course content through reading and online lectures, and they were able to engage in collaborative learning with small group activities and whole class discussions while in class. Each group contained three to four students from perspective Organic Chemistry classes. During selected class times they participated in group quizzes. The quizzes presented questions from material covered in class. Students were encouraged to discuss the questions with each other. The online, out of class material was posted on Moodle (a learning management system).

**Participants**

This study included seven all African-American women groups of Organic Chemistry students. Each group contained 3-4 students. We chose to evaluate the group dynamics and individual roles played by students while participating in a group quiz. Approximately, two class periods before an exam, the instructor would give students a quiz. The quizzes were either individual or group. During the group quiz the students could not use supplemental information to answer the questions, they had to rely on each other. They were encouraged to discuss the questions
out loud. Prior to class, students were expected to review (using the textbook, slides, reading
guides) on the topic to be covered in class. A general outline of topics covered were included in
the syllabus. Additionally, the instructor would open a new topic section on Moodle weekly.

**In the Classroom**

In class, the instructor would spend the first 5-10 minutes answering student questions
focused on material covered in the previous class period. The instructor would then pass out an in-
class problem set (available on Moodle prior to the class) and use the problem-set as well as
PowerPoint slides (when necessary) to cover new material (15-20 min). For the remainder of the
class period (20 – 30 min) students would work on the in-class problem sets. Students would often
be asked to present their answer(s) to classmates for feedback. Problems not finished in class, were
finished as homework/ used to start the next class discussion. Occasionally (at random), the
instructor would collect the worksheets for a grade (5-10 points max).

After class, students were responsible for finishing the worksheet(s) and, if the topic was
finished being covered in class, completing the Moodle quiz for the topic.

The students used a learning management system called Moodle to view lectures, practice
problems, and to complete assessments. Students were provided with a slide deck for each chapter
as well as instructor developed reading guides (short problem sets) and in class problem set
worksheets. Additionally, a Moodle quiz (via Respondus) existed for each topic area (10-15
multiple choice questions of various difficulty). After a topic area was covered in class (2-3 class
periods) students were responsible for finishing the Moodle Quiz (counted as an assignment
grade). The quizzes were due prior to the start of the next topic.
### 3.5.2 Data Collection

Qualitative data was collected that will give insight on what the students are doing during the group activity. IRB approval was obtained from both universities (Appendix F and G). Each group was recorded using overhead video cameras, as well as iPad’s for audio and screen recording to monitor the responses to the quiz questions. The students entered their responses in the app “Explain Everything.” There were two sets of recordings; group quiz 2 and group quiz 3, respectively. The quizzes covered Conformations, and Alcohol Substitution. Each topic followed the schedule of exams.

### 3.5.3 Data Analysis

The videos used for analysis were chosen based on the quality of the recording. The recordings in which all group members were visual, and the audio was clear were chosen for further observation. To analyze the engagement during group activities, we watched the videos and discovered initial codes for the actions present. After several rounds of coding, concrete codes were put in place.

**Emergent Coding Categories**

Our data was analyzed using the constant comparative method. In the initial stage of development, we took an unstructured look at the group quiz videos to note actions, and dialogue types exhibited by the students. During this process, the incipient set of coding categories were identified. The codes were grouped based on similar messages. Two types of codes emerged, student engagement, and group dynamics. Student engagement codes outlined the level at which students completed group work. This category can be separated into three types of engagement: active engagement, passive engagement, and disengaged. Group dynamics were coded to describe the management of the group by the students. Some students took on more of an instructor role in
the group setting by leading the group, organizing the actions of the group, dominating, or encouraging. Others maintained a student role by collaborating, and/or acting as the group scribe. Our codes alluded to specific dialogue that can be seen in the group quiz videos. After the codes were identified, and the broader categories were outlined through the constant comparative method, we summarized our findings in a code book that gives examples of each code, and shows how the codes should be used while analyzing data. The codes that were found closely resembled the CoI framework with respect to the cognitive and social presences. For example, the code “IDK” closely resembles “Sense of Puzzlement”, and the code “Collaborator” mirrors “Information Exchange” and “Connecting Ideas.” There are also instances of social presences seen as “Risk-free expression” and “Encouraging collaboration.” After several rounds of coding inter rater reliability was performed by two individuals. The first coder was a doctoral candidate in science education, and was a part of the research team. To measure the reliability of the coding project, one additional coder was used. The additional coder holds a Ph.D. in Organic Chemistry, and training in Chemical Education. The coder was trained to use the codes to represent actions, and dialogue during the group quizzes. If disagreements arose based on the use or meaning of a code they were discussed, and the codes were adjusted, or redefined accordingly. Coding continued until reliability was obtained. The Cohen’s Kappa was calculated for inter-rater reliability. Cohen’s Kappa is a qualitative measure for inter-rater reliability. The codes were aligned with and analyzed by using the Community of Inquiry framework later discussed in the theoretical framework.

Marzano Level & Dialogue Type

Along with the observation data, each quiz question was assigned a Marzano level (Marzano, 2013). The Marzano taxonomy can be used to define the level of each question as one of four levels – retrieval, comprehension, analysis or knowledge utilization. Different question types
require different levels of cognitive presence. Each question’s Marzano level are presented in the results with discussion.

The type of dialogue the group used to develop their answers was also analyzed. The group dialogue was characterized as either high level or low level. High-level dialogue includes explaining ideas, asking questions, and clarifying any discrepancies. Low level dialogue includes only giving answers with no details, and/or not questioning group member comments.

3.6 Results & Discussion

This result and discussion section will describe the engagement – including dialogue of female African-American students as they attempted to answer organic chemistry I questions during a group quiz session. Three groups of students will be characterized, and their dialogue will be presented. The COI model will be used to discuss the interactions present in these group settings. The students will be identified using pseudonyms to preserve their anonymity. Each group quiz will be described along with the ideal answers, as analyzed by the researcher. Each group quiz was analyzed for two groups of students. Group B participated in both group quiz 2 and group quiz 3. For the two quizzes, we will describe the overall social and teaching presences of each group. Following each set of results, the quality of group engagement, and the interaction of the social and cognitive presence within and between groups will be discussed.
Table 4 Group Member Pseudonyms

<table>
<thead>
<tr>
<th></th>
<th>Group Quiz 2</th>
<th>Group Quiz 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group A</strong></td>
<td>Ashley</td>
<td>Candice</td>
</tr>
<tr>
<td></td>
<td>Britanny</td>
<td>Dawn</td>
</tr>
<tr>
<td><strong>Group B</strong></td>
<td>Tiffany</td>
<td>Farrah</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lisa</td>
</tr>
<tr>
<td><strong>Group C</strong></td>
<td>Jasmine</td>
<td>Michelle</td>
</tr>
</tbody>
</table>

3.6.1 Group Quiz 2

Group quiz 2 presented questions about “Newman projections” (Table 2). The students were asked to draw anti, and eclipsed conformations. They were also asked to explain the stability of the anti-conformations of two molecules. Lastly, they were probed to develop an analogy to describe the stability of two interacting large substituents. The questions and ideal answers for quiz 2 are listed below (Table 2). The Marzano level for each question in the quiz is also shown in Table 2. The complete quiz can be found in Appendix H.
<table>
<thead>
<tr>
<th>Marzano Level</th>
<th>Questions</th>
<th>Ideal Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1-Retrieval</td>
<td>1. Define anti-conformation.</td>
<td>Highest energy group furthest apart</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dihedral 180°</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The most stable conformation</td>
</tr>
<tr>
<td>Level 2- Comprehension</td>
<td>2. Draw a template to illustrate the anti-conformation of an alkane</td>
<td>Correct groups and conformation drawn on Newman projection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Structure of alkane</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reasoning behind drawing Newman projection</td>
</tr>
<tr>
<td>Level 2- Comprehension</td>
<td>3. Draw the most stable anti conformation of heptane for the rotation around the C3 C4 axis</td>
<td>Correct groups and conformation drawn on Newman projection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Structure of alkane</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reasoning behind drawing Newman projection</td>
</tr>
<tr>
<td>Level 3- Analysis</td>
<td>4. Compare the most stable anti and the least stable eclipsed conformations of heptane for the rotation around the C3 C4 axis</td>
<td>In the most stable conformation, the two high energy groups are 180 apart.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In the least stable eclipsed conformation, the two high energy groups overlap.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Correct groups and conformation drawn on Newman projection</td>
</tr>
<tr>
<td>Level 3- Analysis</td>
<td>5. Explain the stability of the least stable eclipsed conformations of butane defined for the rotation around the C2-C3 axis in comparison to that of octane defined for the rotation around the C4-C5 axis.</td>
<td>Butane would be more stable because the atoms that overlap are smaller than that of octane.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Correct groups and conformation drawn on Newman projection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Structure of alkane</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reasoning behind drawing Newman projection</td>
</tr>
<tr>
<td>Level 3- Analysis</td>
<td>6. Develop an analogy that explains why the stability of a molecule will Analogy of high energy groups coming together causing increased energy cost, and decreasing stability</td>
<td>Analogy of high energy groups coming together causing increased energy cost, and decreasing stability</td>
</tr>
</tbody>
</table>
Figure 8 Observation Data of Group A for the Newman Projection Quiz

- Idea Swapping: 27%
- Writing: 20%
- Observing: 27%
- Scribe: 18%
- Restating: 4%
- Off-Task: 12%
- Withdrawal: 1%
- Closed Questioning: 1%
- IDK: 3%

Figure 9 Observation Data of Group B for the Newman Projection Quiz

- Writing: 39%
- OBSERVATION DATA GROUP B
- Newman Projection Quiz
- Idea Swapping: 16%
- Observing: 15%
- Working Independently: 4%
- Scribe: 13%
- Verification: 1%
- Restating: 3%
- Off-Task: 7%
- Open Questioning: 1%
- Withdrawal: 1%
Table 6 Group Quiz 2 Students Pseudonyms

<table>
<thead>
<tr>
<th>Group Quiz 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group A</strong></td>
<td><strong>Group B</strong></td>
</tr>
<tr>
<td>Ashley</td>
<td>Brittany</td>
</tr>
<tr>
<td>Candice</td>
<td>Dawn</td>
</tr>
<tr>
<td>Tiffany</td>
<td>Farrah</td>
</tr>
<tr>
<td></td>
<td>Jasmine</td>
</tr>
</tbody>
</table>

Figures 8 and 9 show the actions present while Group A and Group B (Table 3) attempted to answer questions about Newman projections. This observation data shows that the students in these groups participated in open/closed questioning, idea swapping, verification/restating or answers, working independently, writing, and observing to answer quiz questions. These figures also show that during the quiz there were moments of disengagement including the codes off-task and withdrawal. The following sections will describe in detail how these actions helped or hindered the group members to solve their quiz problems.

**Teaching Presence**

For group quiz 2 and 3, the instructor was responsible for the overall design and facilitation of the educational experience. The instructor was responsible for design and the development of the Newman projection group quiz. The instructor was also responsible for the selection, organization, and presentation of course content. The students were instructed to get into groups and were told to talk to each other and discuss their answers as they work on the quiz. They could not use any outside help such as notes or other materials. However, the instructor was available for questioning if the group reached an impasse on a question and needed help.
Social Presence

Group A showed two forms of social presence during the quiz. They displayed peer encouragement, and risk-free expression. Around the midpoint of the quiz, Ashley expressed how the quiz made her feel: “This threw me for a loop - this quiz.” Candice displayed risk-free expression while discussing the quiz, “I don’t like how we can’t go back to the questions that’s very annoying.” Tiffany complimented Ashley on her ability to draw a cyclohexane chair “See look you’re good at drawing them.”

Group B displayed risk-free expression in the form of joking, showing emotion and sharing of personality during their on-task and off-task conversations. Farrah joked about the line-bond model of heptane and compared it to mountains, “See it’s three mountains, there’s three mountains, I am a whole child.” Brittany discussed an incident with her group members that happened to her outside of class. The group also discussed recent news and its social justice implications for African-Americans while waiting for the scribe to record the answer.

Cognitive Presence

In this section we will evaluate each question and the dialogue that follows to understand how the engagement type and level of discourse affected the quality of the group’s answers.

Question 1: Define anti-conformation.

Marzano Level: Level I Retrieval

Group A

Group A primarily used information exchange in the form of idea swapping, affirmation, closed questioning, and verification of answer. Affirmation, closed questioning, and verification of answers usually happen when a student asks a question that only requires a yes or no response.
In this group, the answers were developed by one or two students participating in idea swapping and integrating the information towards an answer.

1 Tiffany: Define anti conformation. (Reading the question aloud)
2 Ashley: That’s when the chair flips (uses hand motion), and that’s when it’s like, when it flips its equatorial
3 Tiffany looks to Candice
4 Candice: (Mumbles) I don’t know, I don’t know
5 Candice: I was thinking about the Newman projections
6 Tiffany: It says anti conformation
7 Candice: It says define?
8 Tiffany: Um huh
9 Candice: I guess we can like draw it and then, I guess
10 Ashley: It’s the flipped conformation, I mean it’s the, I don’t know how to explain it, it’s the chair flip
11 Candice: So like kinda like a flipped opposite that’s what you’re trying to say? I’m trying to understand what you are trying to say.
12 Ashley: It’s literally when you flip the chair (hand motions)
13 Candice: Oh!
14 Tiffany: The chair it flips, and the
15 Ashley: What is it called, what is it called the anti you know what I’m saying, they flip the, the, I done forgot the name of it
16 Candice: So you’re saying the equatorial
17 Ashley: It changes at first it’s something else, it changes to equatorial
18 Tiffany: Axial
19 Ashley: Yea axial changes to equatorial
20 Candice: So when chairs flip….I’ll just put an axial to equatorial
21 Tiffany: Ima say axial turns to equatorial
22 Ashley: Yea

When asked to define anti conformation, Ashley spoke of the different conformations of the cyclohexane chair (line 2) – an incorrect response. Candice mentioned the use of Newman projections to display anti conformation, and no one responded (line 5). Then as a group they discussed the cyclohexane chair conformations (line 9-19). This dialogue consisted mostly of idea swapping until they reached an answer.
**Group B**

The four students in Group B worked independently at first (writing, observing, working-independently) and then discussed their answers aloud. Cognitive presence in the form of information exchange was seen throughout the group quiz in the form of idea swapping, affirmation, open/closed questioning, and verification of answer. The answers were developed primarily by two of the four students.

1. Brittany: Wait what in the **** is anti-conformation, what in the ****?
2. Jasmine: I don’t know what that is
3. Brittany: She’s looking it up (pointing to Dawn)
4. Farrah: Anti conformation? Remember it’s like when the methyl groups are opposite, didn’t we say that it’s the most stable conformation
5. Brittany: Oh that’s what that is
6. Dawn: When the groups are far from each other and across from each other
7. Farrah: Just say the most stable conformation, but it doesn’t have to be methyl groups that just what we used... I don’t know what to call them, they’re not substituents, just say the most stable conformation of a molecule.
8. Brittany: And it’s when the substituents are opposite of each other?
9. Farrah: So it’s like, but they don’t have to be substituents, just the groups with the highest energy are the furthest away from each other
10. Dawn: Wouldn’t they be 180 degrees apart?
11. Farrah: Um huh
12. Brittany: Oh yea you’re right
13. Brittany: (Looking at iPad) is that the first one?
14. Brittany: So it’s the most stable conformation of a molecule,
15. Jasmine: I cannot write on this (iPad), so the most stable…. (Reading what she is putting down as the answer)
16. Dawn: Would that angle be called a dihedral angle?
17. (Student A mouths I don’t know)
18. Jasmine: The most stable conformation is what?
19. Brittany: The most stable conformation of a molecule, um, the highest energy groups are furthest apart

Upon reading the question, two group members expressed that they did not recall the definition of anti-conformation (lines 1-2). Farrah remembered anti-conformation and told her group members (line 4). Adding on to Farrah’s answer, the group swapped ideas until they came to a satisfactory answer.
Discussion

Question 1 presented a Marzano level 1 retrieval question. This question type requires students to recall information from their memory. Both Group A and Group B used idea swapping to solve this problem. Group B arrived at a satisfactory answer and Group A did not. Group A’s idea exchange for this question were considered to be a lower-level dialogue since integration and elaboration of ideas did not occur. Also, there was not a unified chain of reasoning from one person’s contribution to another in order to lead to integration of ideas. Some group members contributed ideas but there was not a logical flow towards achieving a satisfactory answer. A logical flow would include asking probing questions, contributing relevant facts to solve the problem, and summarizing (integration) the answer.

In Group B, one group member (Farrah) recalled the correct information regarding Newman projections. Farrah provided a detailed description when discussing her answer. This knowledge acted as a triggering event that the other group members needed to recall important details. Dawn, and Brittany were able to contribute details that helped generate more detail to the question. Group B was able to form a logical chain of reasoning that included ideas from Farrah, Dawn, and Brittany to reach a satisfactory answer.

According to the COI framework, cognitive presence and social presence work together to support discourse. In both groups there was a reasonable level of social presence through freedom of expression that indicated that the students felt comfortable with each other. However, their level of cognitive presence differed. In Group A, Candice mentioned Newman projections but did not speak up or elaborate. Ashley’s assertiveness could have also shut down Candice’s correct thought. In Group B, Farrah lead the group by providing a detailed description of her thoughts, this information provided the group with a basis to start a discussion. Social presence is important
during group activities because it encourages group cohesion and open communication. These actions that allow student to project themselves into the community of inquiry support cognition by providing a safe collaborative environment giving the students a sense of identity within the group and makes them more comfortable to share their thoughts.

**Question 2**

**Draw a template to illustrate the anti-conformation of an alkane.**

*Marzano Level: Level 2 Comprehension*

**Group A**

1 Tiffany: Sooo…Draw a template to illustrate the anti-conformation of an alkane. (An adjacent group acquired help from the instructor about anti-conformation and each member of Group A observed)
2 Tiffany: Draw a template to illustrate the anti-conformation of….. (Re-reading the question)
3 Candice: It’s the Newman projection right?
4 Tiffany: Yea
5 Candice: So draw an alkane, count CH₂, CH₃, and hydrogens on the…
6 Ashley: I thought we were supposed to draw like the chair
7 Candice: Oh I’m so stuck on Newman projections
8 Ashley: I don’t know, that’s what I was thinking
9 (Tiffany looks around for help)
10 Tiffany: Oh okay so if it’s the chair (begins to draw the chair)
11 Ashley: Is that it flipped? That’s not it flipping.
12 Tiffany: That’s regular, flipped would be…. (Drawing)
13 Ashley: You drew it good
14 Tiffany: So that’s it?
15 Candice: Are we allowed to come back to it? Or you can’t go back once you go to the next question
16 Tiffany: I hope not, let me see….
17 Tiffany: Wait hold up, hold up, hold up, Nope can’t change it….
Figure 10 Group A’s Answer for Question 2

Like question 1, the students in Group A continued idea swapping until they reached an answer. They continued to discuss cyclohexane chair conformations as anti-conformations. Once again, Candice mentioned Newman projections to solve this problem and Ashley reverted the conversation back to chair flipping (lines 3-7). The students then incorrectly drew cyclohexane chairs to illustrate the anti-conformation (Figure 10).

Group B

1 Jasmine: (Reads question partially) oooohhhhh
2 Farrah: I think we just need an example of an alkane, we can just do butane
3 Brittany: Yea that’s the easiest one.
4 Jasmine looks at Farrah’s paper to write the answer on the iPad
5 (Off task conversation about Vegas shooting)

Figure 11 Group B’s Answer for Question 2

Farrah presented a Newman projection of butane for the group to use as its answer. Brittany agreed and Jasmine copied the answer onto the iPad (Figure 11).
Discussion

Question 2 presented a Marzano level 2 comprehension question. This question type requires students to identify important information and integrate or symbolize the information. The students were asked to model the anti-conformation of an alkane. Both groups carried the knowledge used to answer the first question to solve the second problem. When the students were asked to draw the anti-conformation of an alkane, Group A drew a cyclohexane chair in equatorial and axial conformations (Figure 10). They participated in idea swapping to answer this question. While trying to answer the question a low-level dialogue was used. Candice once more brought up Newman projections and no one inquired about Newman projections or what they illustrate. These question types may have triggered the students to remember the idea of Conformations and that a chair diagram has different conformations but a Newman projection also shows a conformation. Group B did not use any dialogue to answer this question. Farrah showed the group the anti-conformation of a butane to record on the iPad. This exchange was also on a lower level, the students in Group B did not question Farrah to understand how she arrived at her answer they just agreed. Both groups used limited discussion or evidence to answer this question.

Question 3

Draw the most stable anti conformation of heptane for the rotation around the C3 C4 axis.

Marzano Level: Level 2 Comprehension

Group A

1 Tiffany reads question out loud
2 Ashley: I don’t know, we need 7
3 Candice: Okay, we need 7 of something
4 Candice: I don’t know how to illustrate because you are the scribe
Tiffany draws, and looks around

(Instructor assists adjacent group, tells them about Newman projection)

Candice: She’s (adjacent group member) drawing a Newman projection

Ashley: Is that when it was mostly spaced out?

-listens to adjacent group and instructor-

Candice: Yea, I can do that Newman projection

Ashley: Can we just draw the ends?

Candice: Its seven, so you gotta draw seven carbons

Ashley: No I’m saying like does it matter if we put like CH3, and all that, does it matter where we put them?

Candice: I know when you draw like this it matters where they go, like they’re always on the ends, and these (drawing on paper) are your CH2’s, so I don’t know if that answered, that

Candice: Now we’re kinda stuck, but we can come back and add

Tiffany: You can only move one of the back carbons at a time, so if you wanna move it here?

(Tiffany writes the answer on iPad)

Figure 12 Group A’s Answer for Question 3 (left), Correct Answer as Proposed by the Researcher (right)

Group A remained confused coming into the third question (lines 2-5). The question asked for the most stable anti conformation of heptane. The students knew they needed seven of something (lines 2-3), but they were not sure what that seven was. An adjacent group asked the instructor for help and she guided them into using Newman projections. Candice who had been mentioning Newman projections since the start of the quiz, probed her group once more to use Newman projections (line 6). The group used idea swapping and closed questioning while trying to figure out the answer (lines 7-15). The students drew a Newman projection to answer the
problem. They drew the Newman projection in the correct anti conformation but they did not properly label the end groups (Figure 12). Ashley (the scribe) was not sure how to label the groups, Candice attempted to explain (line 13). However, the group was still unsure of their answer.

**Group B**

1. (Brittany reads question out loud)
2. Jasmine: It’s three mountains, yes
3. Brittany: Whatever floats your boat
4. Brittany: So by C-3, C-4 do they mean carbons 3 and 4? Which way we counting from though?
5. Farrah: It doesn’t matter, either way it should be the same, same amount of distance
6. Brittany: You’re right
7. Jasmine: See its three mountains
8. Brittany: Yes, Shelby three mountains
9. Jasmine: I’m a whole child
10. Brittany: At least you don’t have a whole child
11. (Jasmine continues to write the answer on iPad while joking with Brittany)
12. Farrah: What did you guys get?
13. Brittany: For which one?
14. Farrah: This is what I got, I got CH$_2$’s instead of CH$_3$’s
15. Brittany: Really?
16. Farrah: Yea, it’s like when I draw out the whole thing here, they’re talking about this one [Pointing to the groups on the end of the line bond model] and this one these two aren’t connected to ethyl groups, ethyl groups are at the end. So for butane that made sense since they were directly connected to one and four, because they’re asking for three and four their connected to CH$_2$ here, so looking at it from this way. I did this one would be up, the one attached to the three the one of the four would be down and then you just attached the H’s and the H’s will be attached to three and four
17. Brittany: Yea I see what you mean. So I should erase this?
18. Farrah: Yes
19. Brittany: And put this?
20. Farrah: No, I mean yea you can write this but the conformation will look like this
21. Brittany: Oh, okay. But this has got to go
22. Farrah: But it might help her understand how we got what we got, so maybe you should write two just in case she does stuff for points. That’s what I think I don’t know guys for sure, that’s what made sense to me.
Farrah continued to lead the group during question three. She provided a detailed description of her answer (line 15). Her description included ethyl groups (CH₂CH₃), but she did not know how to properly label them on a Newman projection, so instead she put CH₂ groups (Figure 13). Brittany asked a few closed ended questions to gain clarity. Brittany and Farrah were the only participants in the dialogue used to answer question three.

**Discussion**

Question 3 presented a Marzano level 2 comprehension question. This question type requires students to identify important information and integrate or symbolize the information. Group A overheard the instructor mention Newman projections to answer a quiz question, so they were able to move away from cyclohexane chair conformations to a more correct answer using a Newman projection. Group B relied heavily on the thoughts of Farrah, she dominated the dialogue and seemed to understand the concept but was not
sure how to label the larger groups on the Newman projection. Both groups were missing information in their answers, although they had the overall concept correct. Both exchanges can be considered low-level, these dialogue types led to a very shallow understanding of the subject.

**Question 4**

**Compare the most stable anti and the least stable eclipsed conformations of heptane for the rotation around the C3-C4 axis.**

**Marzano Level: Level 3 Analysis**

**Group A**

1. Candice reads question aloud.
2. Tiffany: So the most stable would be
3. Candice: Looks like they just asked us the reverse of number three, but now that its asking for
4. Tiffany: So is this (pointing to paper) least stable?
5. Candice: Yea, now it’s asking for the most and the least
6. Tiffany: Yea so we can just draw….
7. Tiffany: Not sure if I drew that right
8. Ashley: Oh so you did more than just a 60°, you did like a.. ion know
9. Tiffany: What you mean?
10. Ashley: Cause you know if this was like 60° this (pointing at the paper) would probably just move like right here
11. Tiffany: Its cause I know this produces, 11 kilojoules of electrical...(mumbles).. cause you have the gauche and the eclipsed, the gauche is like
12. Ashley: But I don’t think these probably move, I think one would have to be.. (pointing).. well that’s just what I think, I’m not sure
13. Tiffany: What do you mean?
14. Ashley: Like I thought it always have to be like, back carbon, front carbon, back carbon, like this (pointing at paper), not like, you have two back carbons
15. Tiffany: Oh this is on the um, this is on the front carbon (pointing to iPad), then it goes like that, then I drew, I just moved the back carbon
16. Ashley: Yea but shouldn’t this one be right here
17. Tiffany begins to edit answer
18. Tiffany: You want me to move…
19. Ashley: No that’s fine just move that one, that’s what I think
20. Tiffany: Are we all comfortable with this answer?
21 Candice: Can I see it please?
22 (Tiffany holds up iPad)
23 Candice: Ok

**Figure 14 Group A’s Answer for Question 4**

Group A used idea swapping, and open questioning to answer question 4. Tiffany’s open questioning (line 13) provides the trigger for further explanation of the topic, as opposed to closed questioning, which only allows room for one-worded answers. Tiffany provided some details about the energy requirement of two large groups when they are gauche or eclipsed conformations. Although Candice had been mentioning Newman projections during the first two problems, she did not offer much assistance on question four. The students agreed on an image to represent their comparison. The images represent the conformation they were trying to compare but they did not specify any comparisons. They could have compared the energy cost, and/or the distance between the groups. Tiffany mentioned the energy but did not record it on the iPad.
Group B

1 Brittany: So we have to find the ….. So this is the most stable conformation
2 Farrah: The most stable conformation … well anti conformation is just when both groups are 180 degrees apart
3 Brittany: So basically the same thing we just did, so then we have to draw the least stable aaahh
4 Farrah: Least stable one, so the least stable one would be the eclipsed conformation, so when the methyl groups, well the ethyl groups or whatever are right on top of each other, so that would look like …
5 Brittany: I’m just gonna rotate the back one
6 Farrah: Yea it will be easier to rotate the back one, Yep.
7 Brittany: And it says compare, compare would be the umm
8 Farrah: Did you write the back carbon on the left or the right side?
9 Brittany: I wrote it on the left
10 Farrah: I never know ..
11 Brittany: So its where the ethyl groups are overlapping, taking up, unstable … It says to compare, so it needs more energy
12 Farrah: I know they said because it’s the least stable because umm the what do you call it, the forces are more attractive, oh no more repulsive because they’re so close together, that why the energy leaves … well no, no I’m sorry the highest energy but the least stable .. I guess that wanna go to lower energy … I don’t know how to write that out
13 Brittany: It’s basically like, It has the highest energy because the two CH₂ groups are overlapping and that takes energy to do, but then it’s the least stable because they need to be anti, like they wanna be anti (with hand motions)
14 Farrah: Okay we will help Jasmine write that
15 (Full group writing)
16 Brittany: Wait so does the most stable one have to be eclipsed as well? Because it says draw the most stable anti and the least stable eclipsed
17 Farrah: the most stable conformation would be an anti, the least stable would be an eclipsed
18 Brittany: I know I’m just saying, is it trying to ask for the most and least stable eclipsed conformation, but I was wondering do they both have to be eclipsed, not the CH₂ groups
19 Farrah: So you’re saying is their like a least stable anti, and a most stable eclipsed?
20 Brittany: um huh
21 Farrah: are they asking for that?
22 Brittany: I was wondering because it didn’t say anything
23 Farrah: I think there is one, the least stable anti would be I guess gauche interactions
24 Brittany: I just don’t wanna put the wrong thing
25 (Calls instructor)
26 Farrah: So that’s that one
27 Jasmine: Is it supposed to be on that side or this side
28 Farrah: I wanna say she said it doesn’t matter as long as they’re close
29 Brittany: As long as its close, and it looks like we rotated it, be consistent
30 (Off-task conversation)

Figure 15 Group B’s Answer for Question 4

Brittany and Farrah were the primary participants in idea swapping and restating to solve question four. Farrah fully explained the details and reasoning to support her answer (line 4, 12). Brittany integrates the information in line 13 and prepares to explain it to the scribe. Their answer reflects the correct concept, even though the groups were with incomplete (Figure 15).

Discussion

Question 4 presented a Marzano level 3 analysis question. This question type requires students to use reasoning to solve problems about known information. Both groups drew the conformations correctly, although they drew the incorrect groups on the Newman projection. Group B’s discussion lead to a more in-depth answer using energy to describe stability. This exchange would be considered high quality dialogue. The answer was not perfect but as Farrah
explains and Brittany helps integrate the answer, she (Brittany) is learning the information. This type of dialogue includes reasoning, the contribution of two or more members and integration of thoughts to form an answer. Group A participated in low level dialogue and only used images to “compare” the two conformations. Group A discussed energy but did not include that pertinent information in their final response.

**Question 5**

Explain the stability of the least stable eclipsed conformations of butane defined for the rotation around the C2-C3 axis in comparison to that of octane defined for the rotation around the C4-C5 axis.

*Marzano Level: Level 3 Analysis*

**Group A**

1. (Candice reads question aloud)
2. Candice: 4 carbons, 8 carbons, I think more of us explaining, than drawing
3. Ashley: So were just explaining why that is?
4. Ashley: So the stability, it’s less stable in butane than in octane that’s what it said
5. Tiffany: So you’re saying butane is more, you said it’s more stable?
6. Ashley: That’s what it said, no its least
7. (Tiffany rereads question and talks about the previous question)
8. Ashley: I don’t know why...
9. Tiffany: Well like, it’s because it needs more energy to, because I know it takes a lot of kilojoules, to like, for something break, break apart, or it’s like how they’re close to each other
10. Ashley: When they're close together they’re high in energy, but they wanna be low in energy
11. Tiffany: So can we say that for butane the groups may be closer to each other than that of octane
12. (Tiffany Writes on iPad)
13. Tiffany: So is that a good enough answer?
14. Ashley: I think it is
15. Tiffany: Because I don’t know what else it would be
Figure 16 Group A's Answer for Question 5

Group A exclusively used idea swapping to solve question 5. Ashley offered an explanation of stability and then admitted not understanding why (lines 3-7). Tiffany understands that when high energy groups are closer to each other it effects the stability. Although, no one in the group recognized that octane, having a longer chain would be more unstable than butane with the shorter chain. Their reasoning included how close together the groups were, but since they drew them incorrectly they did not reach the correct answer (Figure 16).

**Group B**

1  (Brittany reads question)
2  Farrah: So the least stable of the butane will be an eclipsed of the butane right?
3  Brittany: Yea
4  (Working independently)
5  Farrah: So it’s the least stable of both?
6  Brittany: Yea
7  (Working independently)
8  Brittany: The structures will pretty much look the same, but we just have to...it’s probably something that has to do with how big it is
9  Farrah: The only difference I have is just the groups that are on it, like butane are ethyl groups I mean methyl groups and then for octane I just gave them CH₂’s like for heptane, but still 4-5
10 Brittany: Is it methyl groups for that one
11 Farrah: For butane?
12 Brittany: Yea it just says for carbons 2 and 3 so I was looking at the middle ones
13 Farrah: For butane it still should be that
14 Brittany: CH₃?
15 Farrah: Yea this (pointing to paper) is 2 and 3, if you’re looking at what’s on the ends these are just methyl groups
16 Brittany: I wasn’t looking at the ends I was looking at the carbons 2 and 3, but we need to look at the end?
17 Farrah: Yea that’s gonna determine like what’s up and what’s down
18 Brittany: Right, you’re right
19 Farrah: So yea just what we were doing before, see the butane one looks like this
20 Brittany: So for octane it will be the CH₂
21 Farrah: Yea it literally looks the same as heptane, it’s just a CH₂, CH₂, up and down
22 Brittany: So wouldn’t the butane have the higher energy with the CH₃ and therefore be more stable?
23 Farrah: Yes, CH₃ are worth more than CH₂’s I would think
24 Farrah: What do you call that, not cost, their overall energy cost?
25 Brittany: Yes, energy cost is greater for the CH₃
26 (Brittany restates the integrated form of the answer)

Figure 17 Group B’s Answer for Question 5

Group B also used idea swapping and closed questions to solve this problem. Following the same pattern of the previous quiz questions this group drew the eclipsed-conformations correct, but they mislabeled the Newman projections. Similarly, Farrah knew to look at the groups on the
ends to determine how the conformations would look on the Newman Projection (line 12), but she did not know how to correctly draw them (Figure 17).

**Discussion**

Question 5 presented a Marzano level 3 analysis question. This question type requires students to use reasoning to solve problems about known information. Group A used words to describe the answer and Group B used images and words. Group B has the correct reasoning while describing their answer, but the incorrect groups drawn on the Newman projections caused them to get the answer wrong. Group A was unable to use the information provided by group members to come up with a satisfactory answer. Analysis of the group dialogue showed that the students were on the right track but missing the vital information on how to correctly draw the molecules. This question required a basic understanding of Newman projections. If each group would have drawn the correct groups on their Newman projections, they would have arrived at the correct answer.

**Question 6**

**Develop an analogy that explains why the stability of a molecule will decrease as the two largest substituents begin to interact.**

**Marzano Level: Level 3 Analysis**

Both answers for question 6 were developed by one student in each group. One student introduced the idea and scenario and the other students agreed. Both students described how the molecule stability increases when the high energy groups are furthest apart.
**Figure 18 Group A's Answer for Question 6**

Develop an analogy that explains why the stability of a molecule will decrease as the two largest substituents begin to interact.

Magnet analogy:
Things that are like do NOT like to be together.
Try putting two positive ends of a magnet together. These ends to do attract to each other and when you try to push them together it creates resistance and a force making the stability less stable (high in energy). However the farther away the positive ends are from one another the less the force and more stable (low energy).

**Figure 19 Group B's Answer for Question 6**

Develop an analogy that explains why the stability of a molecule will decrease as the two largest substituents begin to interact.

When you're babysitting a few kids, there is a lot of energy but you are still in control. When more kids present there is too much energy and the babysitter becomes unstable.

**Discussion**

Question 6 presented a Marzano level 3 analysis question. This question type requires students to use reasoning to solve problems about known information. Dawn (Group B) discussed a babysitter with a lot of children to watch, and Tiffany (Group A) discussed like sides of a magnet coming together. Interestingly, Dawn of Group A helped to form the entire response to question six after being withdrawn since question one. This question allowed for freedom of expression. Dawn who already showed some basic knowledge of the topic was excited to share her thoughts on the last question. The dialogue type in both cases is low-level being that not many group members worked together to form the response, and no one questioned the ideas of their group members (Figure 18 and
Figure 19). This question also shows that other group members can form correct answers when given the chance.

Active engagement is when the students are actively working together to solve problems which include actions such as: Idea swapping, open/closed questioning, and restating. Passive engagement includes: writing, working independently, and observing. Disengaged includes the codes of off-task, and withdrawal.

Group engagement as described in figure 20 and 21 were characterized by the percentage of time students spent doing certain actions within a group to answer quiz questions. Active engagement is when students are actively working together to solve problems, these actions include asking/answering questions, idea swapping with peers, and integrating the information to form an answer. Passive engagement describes when the students were working on the quiz but not participating in group exchanges to solve the problems. Disengaged describes moments where students were off-task discussing non-chemistry related topics or on their cell phones. Group A Tiffany acted as the group scribe, often reading the question, or re-reading the answers thus increasing her active engagement level (Figure 20). Candice offered ideas without much support, she also did not question her group members that posed opposing views, she mostly observed throughout the quiz. These actions caused Candice to have a low percentage of active engagement. (Figure 20). Ashley attempted to dominate until she learned her ideas were not completely accurate for the problems being discussed. This group’s overall active engagement level was low (Figure 20).
Overall Group B was more actively engaged while answering the questions (Figure 21). They used closed/open questioning, restating, idea swapping, and verification of answer to uncover the quiz answers. Although only two of the four students participated, they typically performed at higher level dialogue when discussing quiz answers. One group member, Farrah, recalled most of the information about Newman projections, she gave detailed descriptions of her proposed answers, thus triggering her group to recall important information. Both groups had limited success using these engagement profiles.
3.6.2 Group Quiz 3

Group quiz 3 presented questions about “Alcohol Substitution Reactions.” The questions asked students to compare the trend in leaving group ability based on bond length and pKa and to describe reactivity in a nucleophilic substitution reaction. The groups were probed to describe the relationship each element had on one another and to use their responses to rank reaction speeds while considering the leaving group. The students were also asked to complete reaction schemes and describe the underlying mechanisms. Figure 22 shows the questions, ideal answers as described by the researcher and the Marzano type for each question on the Alcohol substitution group quiz. Table 1 shows the pseudonyms of the students in these two groups (Group B and Group C). Each group consists of 4 individuals. The Questions for this group quiz can be found in Appendix H.
## Figure 22 Alcohol Substitution Group Quiz Questions, Ideal Answers, and Marzano Type

<table>
<thead>
<tr>
<th>Marzano Level</th>
<th>Questions</th>
<th>Ideal Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 2- Comprehension</strong></td>
<td>1. Draw the possible leaving group.</td>
<td>Leaving group with charge</td>
</tr>
<tr>
<td><strong>Level 3-Analysis</strong></td>
<td>a. Explain the difference between an alcohol and an ether in terms of leaving group ability</td>
<td>Alcohol is the better leaving group, weaker base.</td>
</tr>
<tr>
<td><strong>Level 3-Analysis</strong></td>
<td>b. Explain the difference between an alcohol and an ether in terms of leaving group ability</td>
<td>Alcohol is more reactive, less hindrance.</td>
</tr>
<tr>
<td><strong>Level 3-Analysis</strong></td>
<td>c. Describe the relationship between bond-length, pKa, leaving group ability, and reactivity.</td>
<td>Strong acid=better leaving group=more reactive</td>
</tr>
<tr>
<td><strong>Level 2- Comprehension</strong></td>
<td>2. Based on your responses to number 1, which reaction will occur the fastest?</td>
<td>Compound with SH</td>
</tr>
<tr>
<td><strong>Level 2- Comprehension</strong></td>
<td>3. Which compound would react the fastest with concentrated HCl to yield an alkyl halide? Explain.</td>
<td>D, Tertiary alcohols react the fastest</td>
</tr>
<tr>
<td><strong>Level 3-Analysis</strong></td>
<td>4. Predict the product for each reaction below.</td>
<td>Removal of OH addition of Halide</td>
</tr>
<tr>
<td><strong>Level 3-Analysis</strong></td>
<td>5. a. Draw the product(s) for the reaction shown.</td>
<td>Ether</td>
</tr>
<tr>
<td><strong>Level 1- Retrieval</strong></td>
<td>b. What is the name of this reaction?</td>
<td>Williamson ether synthesis</td>
</tr>
<tr>
<td><strong>Level 2- Comprehension</strong></td>
<td>c. Explain in words, the mechanism of the product formed in the reaction on the previous slide.</td>
<td>The NaH removes H from OH, an Alkoxide ion is formed, negatively charged oxygen attacks alkyl carbon, the Cl is displaced.</td>
</tr>
</tbody>
</table>
Figure 23 Observation Data Group B and Group C for the Alcohol Substitution Group Quiz
Table 7 Group Quiz 3 Student Pseudonyms

<table>
<thead>
<tr>
<th>Group Quiz 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Group B</strong></td>
</tr>
<tr>
<td>Brittany</td>
</tr>
<tr>
<td>Dawn</td>
</tr>
<tr>
<td>Farrah</td>
</tr>
<tr>
<td>Jasmine</td>
</tr>
</tbody>
</table>

**Teaching Presence**

Similarly, to group quiz two, the alcohol substitution quiz was designed and implemented by the instructor. The instructor was solely responsible for the presentation of course materials and the implementation of the course work. The students were not permitted to use any outside materials to assist them in answering the quiz questions. However, during this group quiz the instructor used scaffolding techniques to assist Group B who had reached a roadblock while attempting a mechanism problem. Group C also needed assistance from the instructor while attempting this alcohol substitution quiz.

**Social Presence**

Group B often had off-task conversations which allowed them to project themselves into the community of inquiry and therefore is coded as social presence. Jasmine, the group scribe, shared her feelings about her drawing in a conversation with Farrah. Also, Farrah offered Brittany peer encouragement when she reached a roadblock. Most of the time two of the four group members were forming quiz answers. Group C rarely displayed social presence throughout the
quiz. Most conversations were on task, discussing the subject at hand. Each student in Group C participated to arrive at the quiz answers.

**Cognitive Presence**

In this section we will evaluate each question and the dialogue that follows to understand how the engagement type and level of discourse affected the quality of the group’s answers.

**Question 1: Draw the possible leaving group.**

**Marzano Level: Level 2 Comprehension**

**Group B**

Group B used exploration in the form of idea swapping, closed questioning, and argumentation to answer their quiz questions. In this group, the group dynamic remained, two group members carry most of the conversation to answer the questions (Brittany and Farrah) while the other two group members offered ideas and posed questions seldomly (Dawn and Jasmine).

1. Farrah: Begins reading question two…
2. Brittany: No we gotta do one
3. Farrah: Isn’t it..oh, it’s not..
4. Brittany: We have to predict the leaving, the leaving group
5. Farrah: Um k
6. Brittany: Draw the possible leaving group and enter the pKa for each molecule
7. Dawn: The pKa is already there, right?
8. Brittany: Right its already there, so maybe we need to pick the leaving group, so here would be OH right?
9. Jasmine: I mean I would say so, yes
10. Farrah: What they mean by draw in they already drew it
11. Brittany: Right, it says compare the.. (mumbles)Oh I’m just gonna draw out the leaving group because that’s not even..I don’t even know what to do with that, are we recording?
12. Jasmine: Um huh
13. Brittany: Ok, So for the ether.. it would..wouldn’t it just be the OCH(CH₃)₂
14. Farrah: I just put the whole thing
15. Brittany: Yea the whole thing would leave
16. Dawn: What was she say… she separated something
17. Brittany: Um
18. Dawn: You know what I’m talking about?
Brittany: I think all of it would leave though, because like these electrons are leaving too, like the whole bond is leaving, in then you have SH

Figure 24 Group B’s Answer for Question 1

1. This quiz focuses on how to generate good leaving groups from alcohols, ethers, thiols, and thioethers. To compare the trend in leaving group ability among atoms in the same column of the periodic table, the length of the bond should be considered. The bond lengths for C-OH and C-OR are given below along with the pKa's of the leaving group created by each molecule. Draw the possible leaving group and enter the pKa for each molecule. Write the responses on your individual sheets for easy reference on the next questions.

<table>
<thead>
<tr>
<th>Functional Group</th>
<th>Electrophile</th>
<th>Bond Length</th>
<th>pKa of Leaving Group</th>
<th>Leaving Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcohol</td>
<td>O</td>
<td>1.424</td>
<td>15.7</td>
<td>OH</td>
</tr>
<tr>
<td>Ether</td>
<td>OCH(CH₃)₂</td>
<td>1.43</td>
<td>17.1</td>
<td>OCH(CH₃)₂</td>
</tr>
<tr>
<td>Thioether</td>
<td>SH</td>
<td>1.824</td>
<td>7.04</td>
<td>SH</td>
</tr>
</tbody>
</table>

Group B primarily used idea swapping to answer question 1. Farrah and Brittany shared their answers with the group and after a few open questions they formed the answers above (Figure 3). Overall, Group B had the concept correct although they omitted the charge of the leaving group (Figure 3).

Group C

Each student in Group C contributed to the formation of quiz answers. First, they worked through problems individually and then they discussed the answers they chose aloud to finalize what is to be written on the iPad. Figure 2 shows the specific actions taken by each group during this quiz.

1 Morgan: So we have to fill in this? I’m confused about this table
2 Michelle: She’s talking about what is the leaving group on here, so here (pointing to paper) it’s the OH
3 Morgan: Ohh, what, are you sure
4 Michelle: yeah, think so, I don’t know it look like it.
5 Morgan: ok
6 Morgan: Are we ready to start recording?
7 Lisa: I don’t know
8 Lisa: Okay so the first one gonna be OH (writing on paper)
9 Morgan: This whole thing
10 Nicole: I think so
11 Michelle: I put the whole thing
12 (Lisa: writes answer on iPad)
13 Lisa: Okay the part about the pKa’s
14 Michelle: what part?
15 Lisa: It says enter the pKa of the molecule
16 Michelle: Oh it’s already there
17 Nicole: Yea the pKa of each molecule is there

Figure 25 Group C’s Answer for Question 1

Group C used idea swapping to fill in the chart for question 1. After very little dialogue they formed the answers in figure 22. Their answers also omitted the charge associated with leaving groups.
Discussion

Question 1 presented a Marzano level 2 comprehension question. This type of question requires students to identify important information and symbolize the information. The students were asked to complete a chart with the leaving group of various chemical molecules. Group B and Group C were able to identify the correct leaving groups. Both groups used low level dialogue to discuss question 1. In this case, not much conversation was needed to identify the leaving groups. Although, both groups omitted the charge of the leaving group.

Question 1a: Explain the difference between an alcohol and an ether in terms of leaving group ability.

Marzano Level: Level 3 Analysis

Group B

1 Brittany: Reads question one aloud
2 Dawn: So we know because an alcohol is a strong base it’s a bad leaving group
3 Brittany: Um huh
4 Jasmine: Um huh
5 Farrah: So I think a ether isn’t it also a strong base but not as strong as an alcohol
6 Brittany: Isn’t the ether like, the one with like... like the pimp of the two?
7 Farrah: I think that the ether is the R-OH and that would be weak nucleophile, so weak nucleophile is
8 Jasmine: What did you put?
9 Farrah: Um honestly I can’t think
10 Brittany: Let’s think, let’s think, let’s think
11 Jasmine: You okay?
12 Dawn: Yea, I’m trying to think too
13 Brittany: Now is not the time to discuss that
14 Jasmine: I’m sorry
15 Brittany: (Rereads question) So is it like one’s strong and one’s, Like one’s, good one’s bad?
16 Farrah: Alcohol has a hydrogen, Ether is just an oxygen with two
17 Brittany: I know but were talking about the leaving group ability...Oh yea that one’s weak, bad, R-OH is bad, I remember
18 Farrah: Leaving group?
19 Brittany: Yea
20 Farrah: So both of them are
21 Brittany: OH is a bad one too?
22 Farrah: Alcohols are bad leaving groups
23 Brittany: I was thinking about that chart or am I getting it confused?
24 Farrah: It just says that strong, okay so it says that um weak bases make for
great leaving groups, they’re weak, so they can leave, but since OH is a
strong base that would make it a bad leaving group
25 Brittany: K so they’re both bad, so we have to give a difference, so I’m saying
what are we saying is the difference, in terms of the leaving group ability,
because one has to be better or worse than the other, honestly.
26 Farrah: Yea I think an alcohol is a stronger base than an ether, so that was
my only justification, an alcohol is a stronger base, than an ether, both are, I
don’t know
27 Jasmine: An alcohol is a stronger base, that’s what you said?
28 Farrah: I don’t know let me think…ether
29 Brittany: I think it would be because it says like the pKa of OH is 15.7 and
that’s relatively weak, well as a acid so that would mean it’s a strong base,
ever mind, you’re right
30 Farrah: It looks like an ether would be a stronger base than an alcohol, I
guess because if it was an acid, the alcohol is the stronger acid, but were
looking at it in terms of bases, the ether would be the stronger base?
31 Farrah: Lord
32 Brittany: I don’t know let’s just skip the one for now, let’s just come back to
that, were spending too much time on it

Figure 26 Group B’s Answer for Question 1a
Group B used idea swapping to develop the answer to question 1a. Farrah had the concept correct (line 24) when she expressed that strong bases are weak leaving groups, she even stated the correct answer followed by uncertainty (lines 28-31) but the group ultimately could not analyze the difference between an alcohol and an ether.

**Group C**

1 Nicole: (Reading question 1a)
2 Michelle: Isn’t ether….wait, no they both have a...
3 Nicole: pKa’s larger, so it’s a weaker acid
4 Morgan: The larger the pKa the weaker the acid? Yeah.
5 Nicole: Yeah
6 Michelle: So that means it’s going to be a bad leaving group
7 Morgan: (Reading question 1b)
8 Morgan: I thought OH was a bad leaving group
9 Michelle: Yeah they both are, Alcohol is the worse leaving group since the pKa is...
10 Nicole: I thought ether..
11 Michelle: Oh yea ether I’m sorry
12 Nicole: That's why is it, like they're both weak alcohols and both bad leaving groups but it’s just because alcohol has a higher pH so
13 Lisa: So it’s a worse leaving group that sounds pretty bad (trying to figure out what to write on iPad)
14 Michelle: So ether is a poorer, put poorer leaving group than alcohol

**Figure 27 Group C’s Answer for Question 1a**

Problem #1 continued – Based on the data from the table completed for problem 1:

a) Explain the difference between an **alcohol** and an **ether** in terms of leaving group ability.

The larger the pKa the weaker the acid (alcohol has a smaller value and is the weaker acid). Ether is a poorer leaving group.
Group C used idea swapping to answer question 1a. Nicole provided the group with the basis of the conversation by discussing the pKa value of each molecule (line 3). Michelle added to her ideas by adding what effect a weak acid has on leaving group ability (line 6). Group C was able to form a satisfactory answer.

**Discussion**

Question 1a presented a Marzano level 3 analysis question. This question type requires students to use reasoning to solve problems about known information. Question 1a asked the groups to compare an alcohol and an ether based on leaving group ability. Group B had the overall concept correct but when choosing the correct answer to fit the criteria they fell short. Despite their shortcomings, Group B used high quality dialogue including asking questions and clarifying the topic of discussion while discussing Question 1a. Group C reached a satisfactory answer although they used a lower level of dialogue (less questioning and discussion) to form their answer.

**Question 1b: Explain the difference between an alcohol and an ether in terms of reactivity in a nucleophilic substitution reaction.**

**Marzano Level: Level 3 Analysis**

**Group B**

1 Brittany: Reads question three aloud.
2 Farrah: So we know that the alcohol we said it was a strong base
3 Brittany: Yea
4 Farrah: So it’s a weak acid and reactivity deals with nucleophiles, so we said that an OH is a strong nucleophile
5 Brittany: Yea
6 Farrah: So it’s very reactive, but I think an ether is not very reactive using that other side
7 Brittany: It’s not the greatest nucleophile because its bigger and it can’t like get into things as easily as like the small OH, we don’t know what that R group is and it might make it sterically hindered to attack
Group B used high quality dialogue to discuss Question 1b. Farrah listed details about alcohols to help solve the problem (line 2,4,6), and Brittany integrated her ideas to form a complete thought. Figure 5 shows what was recorded by the scribe (Jasmine). While Farrah and Brittany were listing details about each group Jasmine (scribe) limited the answer to a summary of their thoughts.

**Group C**

1 Michelle: (Reading question 1b)
2 Morgan: It’s just the ability for like, it’s the same thing, because the leaving group has to leave for the nucleophile to attack it
3 Michelle: So whether its primary, tertiary, doesn’t that affect reactivity as well?
4 Morgan: Yeah But
5 Nicole: Yeah but they're all the same they're both kinda secondary
6 Michelle: I don’t know then.
7 Michelle: I just feel like it's the same type of concept like
8 Nicole: Oh it definitely is I just forgot how to explain it
9 Morgan: They’re both the leaving group, what did she say about leaving groups? How bad leaving groups, it was something about the stability, yea when bad leaving groups leave, I can’t remember..
10 Lisa: it’s definitely at the bottom of the page, I know what you are talking about
Lisa: yeah I searched the whole thing
Michelle: and it’s like right here
   (Reaches road block, goes to next question)
Morgan: We have to go back and answer B
Nicole: Yea
Morgan: Rereads question
Michelle: Okay this is my thought could it be that since they’re both secondary, that’s out, so could it be that OH is less reactive
Instructor: Are you guys done?
Lisa: Can we get a hint for B?
Instructor: For B? Base all of your answers off of your sheet
Nicole: That’s what we tried but it’s not
Michelle: it’s not coming up the right way
Morgan: Is it going to be repetitive? Because it’s like we answered and now its B it’s like, is it repetitive?
Instructor: I think you should answer it based off of what you have here
Morgan: Ok
Nicole: So I mean what you’re saying does make some sort of sense
Michelle: But then, what I said has nothing to do with this chart
Michelle: Ok so alcohol, so then obliviously ether is more reactive right based off of this table
Lisa: Based off its pKa values?
Nicole: Yeah, it’s more reactive then

Figure 29 Group C’s Answer for Question 1b

Problem #1 continued – Based on the data from the table completed for problem 1:

b) Explain the difference between an alcohol and an ether in terms of reactivity in a nucleophilic substitution reaction.

ether is more reactive because it is less acidic (higher pKa)
Group C reached a roadblock on question 1b, they left the question and revisited it at the end of the quiz. The instructor redirected the group back to the previous chart to answer their question (lines 19, 23). Group C ultimately were unable to develop a satisfactory answer (Figure 7).

**Discussion**

Question 1b also presented a Marzano level 3 analysis question. Group B presented a high level dialogue when discussing this question. Brittany listened to Farrah’s thoughts and integrated the information which shows a high level of cognitive presence. Jasmine the scribe left out important details of the discussion when transferring the information to the iPad. Group C used low-level dialogue to discuss question 1b. No one in Group C could recall information about nucleophilic substitution reactions. After assistance from the instructor they were not able to form a satisfactory answer.

*Question 1c: Describe the relationship between bond-length, pKa, leaving group ability, and reactivity.*

*Marzano Level: Level 3 Analysis*

**Group B**

1 Brittany: We did not talk about how pKa relates to bond length and leaving group ability and reactivity, did we?
2 Farrah: We talked about three of them but not the first one bond length, pKa we know that
3 Jasmine: Is it possible that the longer the bond the stronger? let me think..
4 Brittany: Uh un It’s the shorter the bond the stronger
5 Jasmine: The weaker?
6 Brittany: (Shakes head no)
7 Farrah: well just looking at what they gave us
8 Jasmine: Oh that’s with like triple bond
9 Farrah: yes so the shorter bond the stronger the acid the more acidic it is
10 Brittany: Yea the more acidic
11 Farrah: In terms of leaving groups, leaving groups deal with acids and bases right?
12 Brittany: Yeah
13 Farrah: So we said that a strong base is a bad leaving group, then a weak acid is also a bad leaving group
14 Brittany: Um huh, So the shorter the bond length the lower the pKa that makes it better yeah that makes it a better leaving group
15 Dawn: And the lower the pKa, the stronger the acid, the weaker the base
16 Farrah: Yea
17 Brittany: Yea
18 Brittany: So the smaller the bond length,
19 Jasmine: I hate this pencil thing
20 Brittany: I think it would be better if it was it's like an actual pin like a ball point
21 Jasmine: Yea if this could come off it would be better but I don’t know, okay so smaller bond length
22 Brittany: Um the smaller the pKa and just write another equals sign, equals um more acidic and better leaving group
23 Farrah: I’m thinking about reactivity, since we said although OH is a great nucleophile it’s a bad leaving group, so would that apply to all things that are strong acids or are they all?
24 Brittany: I don’t know, I don’t think so because um, I’m trying to remember that list, off the top of my head
25 Farrah: I just remember that alcohols are on this side, the ether is on this side (pointing to the opposite side from alcohols)
26 Brittany: I just know that strong acids are good leaving groups because they dissociate and if they're weak they're going to stay together you won't get a reaction
27 Farrah: So are they, strong acids are more reactive?
28 Brittany: Yeah, cause they will dissociate in whatever you put it in and you will get a reaction....If they're weak they won't break apart
29 Farrah: Weakly dissociate, got it.
30 Jasmine: So a better leaving group equals
31 Brittany: Um more reactive
32 Dawn: The greater the reactivity,
33 Jasmine: Anything else were missing?
34 Brittany: Nope
Brittany and Farrah swapped ideas until they resolved at a satisfactory answer. Farrah asked for clarity several times (line 11, 23, 27) throughout the quiz. Dawn assisted in forming the answer to this problem (line 15). Brittany organized the information and repeated it for the group scribe (line 22, 31).

**Group C**

1 Nicole: Reading question 1c
2 Morgan: I know larger bonds are…..
3 Nicole: Well looking at this it has a longer bond length and it has umm smaller pKa that last one
4 Morgan: Yeah
5 Lisa: So the stronger the bond…
6 Morgan: No, the larger the bond the easier it is to break I believe, because when it’s like, because single bonds are stronger than double bonds
7 Nicole: Yea
8 Nicole: The larger the bonds…
9 Morgan: Longer, this is length not strength
10 Nicole: The longer the bond (restating the answer as she writes) the lower the pKa, this makes
11 (Nicole repeats answer for Lisa to write on iPad)
Group C used idea swapping to answer question 1c. Morgan provided an example to help her group members understand her reasoning (line 6). Morgan’s reasoning was used to create the group response (Figure 9).

**Discussion**

Question 1c also presented a Marzano level 3 analysis question. Group B presented a high level dialogue when discussing this question. Brittany and Farrah offered ideas and questioned each other to clarify. Dawn offered ideas to summarize what they (Farrah and Brittany) discussed. Overall, Group B was able to reach a satisfactory answer (Figure 8). Group C used high-level dialogue when answering question 1c. Morgan gave her thoughts and provided examples. Group C was also able to reach a satisfactory answer (Figure 9).

**Question 2: Based on your responses to number 1, which reaction will occur the fastest?**

**Marzano Level: Level 1 Retrieval**

**Group B**
Farrah: I would say A
Brittany: OKAY Um okay, because the pKa is the lowest for SH
Farrah: It’s a strong acid than, yea
Brittany: Yea
Farrah: Or wait, it’s not a stronger acid
Brittany: Um huh
Farrah: Oh yes it is, yea it’s a stronger acid

Figure 32 Group B’s Answer for Question 2

Farrah gave her answer and Brittany agreed giving reasoning behind the answer (lines 1-2).

Group C

1 Nicole: Reading question 2, the one with the SH
2 Morgan: Yea with the thiol (circles answer on iPad)

Figure 33 Group C’s Answer for Question 2
Nicole and Morgan agreed on the correct answer.

**Discussion**

Question 2 presented a Marzano level 1 retrieval question. This type of question requires students to produce important information from their memory. Based on their previous answers, they were asked to identify the best leaving group. Without hesitation Farrah and Brittany agreed on the correct answer. Similarly in Group C, Nicole and Morgan agreed upon the correct answer (Figure 12).

**Question 3: Which compound would react the fastest with concentrated HCl to yield an alkyl halide? Explain.**

**Marzano Level: Level 2 Comprehension**

**Group B**

1. Farrah: Reads question
2. Brittany: Rereads question aloud
3. Brittany: Right, I gotta, (laugh)
4. Farrah: Okay so you know because they are all alcohols they are all bad leaving groups
5. Brittany: Right, all of them
6. Farrah: And HCl would be a strong nucleophile
7. Brittany: Um huh
8. Farrah: So I guess you should figure out what type of um reaction they all are
9. Brittany: Yea it says which one produce an alkyl halide
10. Farrah: Well the first one I got um second degree.. not degree what do you call that? Two, I thought it was called a degree what is it called when you have the two and a little bubble? Not two degrees it’s called…
11. Jasmine: Two prime?
12. Brittany: Tertiary, secondary
13. Farrah: Yea that
14. Brittany: Yea the first one I got secondary
15. Farrah: What do you think about primary for the…?
16. Brittany: For the first one?
17 Farrah: No, the second one, sorry B, I got secondary for the first one
18 Brittany: I think the third one is… secondary
19 Brittany: D, so there’s a methyl group and an alcohol in the two position?
20 Farrah: For D? Yea
21 Brittany: So would that be….
22 Dawn: Tertiary?
23 Brittany: I think it’s tertiary, were not counting the bonds of the OH, yea it’s tertiary
24 Brittany: I know the higher up you go tertiary it’s a higher something, highest substitution
25 Farrah: Well it’s more, more stable in tertiary
26 Brittany: Okay, that’s what I was thinking of
27 Farrah: (Rereads question) So tertiary would mean you would have an SN1 reaction right? You have a good nucleophile but SN1 reactions probably don’t have good nucleophiles
28 Brittany: Yea, yea they have bad nucleophiles
29 Farrah: So let’s see if we can mark that one off quickly
30 Brittany: But alkyl halide, what are we trying to achieve? because that’s what we’re trying to figure out, which one will give us an alkyl halide
31 Farrah: So we get the halide from the chlorine, but um which should react the fastest, so I’m assuming if we have anything that’s a good nucleophile like the one that reacts the fastest would be something like an SN2 reaction so we probably have to just find the one that’s an SN2 reaction
32 Brittany: Okay, so SN2 reaction has good leaving group, it has to be primary or secondary, it has to have a um
33 Farrah: Good nucleophile
34 Brittany: Yea strong nucleophile
35 Farrah: And it’s a concerted mechanism so there’s um
36 Brittany: one step
37 Farrah: Loss of the leaving group and the proton transfer occur in the same step
38 Brittany: K, and the nucleophilic attack happens
39 Farrah: Not proton
40 Brittany: So which one of these, they all have a OH, so OH a good leaving group or a bad leaving group
41 Jasmine: I thought it was a good leaving group
42 Farrah: An OH no, it’s a strong base so it’s a um
43 Brittany: Weak acid?
44 Farrah: Yea
45 Brittany: So they all have that so we can disregard the OH on it, so which one is primary or secondary? So that cancels out D, D is tertiary
46 Farrah: Um huh
47 Brittany: And then good leaving group, um nucleophile, so
48 Farrah: I guess we can…
49 Brittany: Were talking about the nucleophile, were looking at the Cl right? Cause that’s what’s gonna attack
50 Farrah: Um huh, the Cl, what’s it called the electrons from the Cl, or I think we’re looking for something that would reactive the fastest
51 Brittany: It’s still strong isn’t it?
52 Farrah: Yea, we want it to be more stable, but isn’t secondary more stable than primary?
53 Brittany: Yea
54 Farrah: So should we x out B? Because B is the only one that’s primary
55 Brittany: Yea, Um
56 Dawn: Did you guys eliminate B?
57 Brittany: Yea
58 Farrah: Yea
59 Brittany: Now it say, I think, so for c did you draw the alcohol in the two position?
60 Farrah: No I drew it on the three
61 Brittany: That’s what I’m sorry, that’s what I meant to say, this is why I think it’s a because it has more space
62 Farrah: Yea, it’s also a little less complicated
63 Brittany: So yea if it attacks like at C they have that methyl group in the way and it might not have enough room, so I think it’s A because it will have more room

Figure 34 Group B’s Answer for Question 3

3. Which compound would react the fastest with concentrated HCl to yield an alkyl halide? Explain.

- a. 2-pentanol
- b. 2,2-dimethyl butanol
- c. 3-methylcyclopentanol
- d. 2-methyl 2-pentanol

Group B used idea swapping and closed questioning to discuss many details of SN1 and SN2 reactions. Throughout the discussion Brittany kept the group on track by mentioning the goal of the question (line 30). They were able to eliminate two options using the information that was gathered (lines 52-58). Brittany selected choice A, she provided reasoning and Farrah agreed (line 63).
Group C

1 Nicole: Reading question 3, Probably the one that’s not on the…. least complex I would say
2 (The entire group works independently)
3 Michelle: Wait for substitution reactions, is it first degree and second degree
4 Morgan: For which one?
5 Michelle: Question 3, but I’m just saying like just generally speaking is it primary and secondary that are only reactive for that
6 Morgan: No, they all are its just for SN1 and SN2
7 Nicole: They all are, so I mean the fastest that does have a point would be SN2,
8 Morgan: Because it happens at the same time
9 Nicole: So we will be looking for ones that are secondary and tertiary so we can cross out c
10 Morgan: Why?
11 Nicole: Well never mind, because I didn’t draw it
12 Morgan: I drew them, I think I drew them
13 Nicole: Well B is tertiary
14 Morgan: I didn’t finish drawing D
15 Lisa: What’s C?
16 Morgan: Cause I’m confused
17 Lisa: The other ones are secondary
18 Morgan: yea they are
19 Lisa: So should we draw them all out?
20 Morgan: Um, would it be two substituents on 2 and one is the alcohol
21 Nicole: 2 methyl, 2 pentanol
22 Morgan: So would it be the same thing here
23 Nicole: D is tertiary
24 Lisa: Aww (laughs)
25 Nicole: So I’m going to cross off C and D
26 Morgan: Why?
27 Nicole: Because it’s tertiary
28 Lisa: All three are tertiary
29 Nicole: Because SN1 is tertiary, SN2 is primary or secondary
30 Morgan: Oh
31 Morgan: It’s looking like A
32 Nicole: I was gonna guess A, but I don’t know how to explain why
33 Lisa: process of elimination at this point
34 Morgan: You could just explain that…
35 Lisa: this would break off.
36 Morgan: Well it’s a bad leaving group
37 Nicole: Yea, it is.
38 (Morgan writes answer on iPad)
Michelle questioned her group members to better understand which type of substrates would be ideal for SN1 and SN2 reactions (lines 3, 5). Nicole assumed that since the question stated “fastest” they should look for substrates ideal for SN2 reactions (line 7).

Discussion

Question 3 also presented a Marzano level 2 comprehension question. They were asked to choose the best starting material to react with HCl. Although Group B used high level dialogue to discuss question 3, they were unable to select the correct answer. Both Farrah (Group B) and Nicole (Group C) assumed SN2 reaction when looking at the wording “fastest” which could have affected the responses.
**Question 4a-c: Predict the product for each reaction below.**

The dialogue and answer responses will be given, followed by each group comments and overall discussion.

**Marzano Level: Level 2 Comprehension**

**Group B**

**4a**

1 Brittany: Oh how fun predict the product, how fun
2 Farrah: Okay so..that’s a secondary
3 Brittany: Yea
4 Farrah: You have a strong nucleophile
5 Brittany: This is probably an SN2
6 Farrah: Yea leaving group, we have a bad leaving group
7 Dawn: Yes
8 Brittany: But everything else weights out, cause everything else looks like its SN2, so does the SO go along with the CO₂ or does that just go away, because I think only the Cl₂ is bonding
9 Farrah: The SO that doesn’t just dissociate into another ion?
10 Brittany: Yea
11 Farrah: Like the Cl would go there and the SO just by itself
12 Brittany: I think so yea
13 Dawn: So you’re treating that as a spectator ion?
14 Brittany: Yes
15 Farrah: Yea
16 Brittany: So just draw it (drawing on paper)
17 Jasmine: I’m an artist
18 Brittany: Yes Picasso over there
19 Jasmine: Truly, Frida Kahlo
20 Brittany: Just draw plus like the leaving group and then the plus SO, or do we need to draw all that?
21 Farrah: Draw what?
22 Brittany: Like the plus CH₂ that left afterward, or do we just need to draw the plus SO, I wonder
23 Farrah: What do you mean the plus? Like the...
24 Brittany: Like add it on to this, like plus this (pointing to paper) that left
25 Farrah: So you mean that whole thing doesn’t leave? (Shocked) Just the OH leaves?
26 Brittany: What do you mean?
27 Farrah: Like that whole thing doesn’t leave just the OH does?
28 Brittany: I ain’t say that, I drew it like this, like you
29 Farrah: Yeah but you have that drawn over there, so that’s the leaving group
30 Brittany: As in it leaves like the whole thing is off and it’s just its own separate thing, I’m not drawing it a part of that
31 Farrah: I know but I thought the leaving group like left the reaction
32 Brittany: Oooohhhhh
33 Farrah: Like how SH (points to paper)
34 Brittany: I think, I thought it was still like around
35 Farrah: That’s the thing I don’t know
36 Brittany: No I think when we did it in class
37 Farrah: Sometimes it left
38 Dawn: I remember you asking that question
39 Farrah: Yea
40 Brittany: OH the way I’ve been doing it, I’ve been just keeping it there
41 Farrah: On the other side
42 Brittany: Yea, not of course attached or anything just there
43 Jasmine: So it’s not going on?
44 Brittany: I would draw the plus CH₂CH₂OH
45 Jasmine: Ok I will just erase this whole thing
46 Brittany: No we don’t have the time, and what do you do you erase it
47 Jasmine: It was ugly and making me very self-conscious
48 Brittany: How does the structure make you self-conscious?
49 Jasmine: Because… it just…
50 Brittany: We got to work on that
51 Jasmine: Because I just want it to look pretty and it doesn’t look pretty at all
52 Brittany: Okay let’s do the next one

Figure 36 Group B’s Answer for Question 4a

4. Predict the product for each reaction below.

a. \[
\begin{align*}
\text{CH}_2\text{CH}_2\text{OH} + \text{SOCl}_2 & \rightarrow \\
\text{Cl}_2 + \text{C}_1\text{H}_2\text{C}_1\text{H}_2\text{OH} + \text{SO}
\end{align*}
\]
4b
1 Farrah: Reads question aloud
2 Brittany: And Br is a strong nucleophile
3 Farrah: Strong nucleophile
4 Farrah: But PBr is gonna, she has a
5 Brittany: She ain’t there
6 Farrah: Oh that’s not gonna be there
7 Brittany: And this is the, this is the primary
8 Farrah: So the thing is wouldn’t it go under the one that’s secondary?
9 Brittany: The?
10 Farrah: The Br, cause it always wants to go where its most stable and its
     most stable right there (pointing to paper)
11 Brittany: Right here? (Pointing to paper)
12 Farrah: Yea
13 Brittany: Yea, Ok
14 Farrah: So, the OH leaves
15 Brittany: Yes its gone and you gotta erase that bond too,
16 Farrah: Right
17 Brittany: It’s not there and then
18 Farrah: You put the Br on the, that okay
19 Brittany: On the… Yea and then I guess the Oh H goes with the P or
     something cuz sometimes they form together like the leaving group and the
     spectator ion
          I would write POH, that’s what I’m doing I’m serious
20 Jasmine: Um okay

Figure 37 Group B’s Answer for Question 4b
Dawn: I remember seeing this one
Brittany: You do?
Dawn: Yes this whole thing leaving
Brittany: Oh yea I remember that, wait this all left?
Dawn: Yea
Brittany: So this left and not the OH
Dawn: (Shakes head yes) No? that’s what I recall mam
Brittany: Okay so this is a tert-butyl
Brittany: Okay see, so you draw what you remember in your mind
(Speaking to Dawn)

Brittany: She says she remembers this (Speaking to the rest of the group)
Dawn: Yea I remember this whole thing right here moving as the leaving
group and not the OH but I don’t know
Farrah: But was that when it was up here? Like when it was like Br in that
ting
Dawn: Oh yea on top of the, yea never mind
Farrah: I’m like I’ve seen that somewhere before
Brittany: So the tert-butyl group stays?
Farrah: Yes
Brittany: And it replaces the OH
Farrah: Um huh
Brittany: Okay, okay and Oh my God we can form water you guys
Jasmine: Oh my God
Brittany: Why you looking at me like that?
Jasmine: Because you’re weird
Brittany: So
Figure 38 Group B’s Answer for Question 4c

4. Predict the product for each reaction below.

Farrah and Brittany idea swapped to form the answers to question 4. Dawn also assisted a few times throughout the quiz. They used a low level of dialogue to discuss the answers to this question. The students did not recall the reactions of alcohols. Each reaction in this set were reactions used to create better leaving group from alcohols. Group B was focused on SN1 and SN2 reactions. Throughout the quiz students stated facts about alcohol reactions but they did not follow up with the ideas to gain a further understanding. Using the skills they had, they were able to correctly answer 4c, in which the chlorine group was attached directly to a cyclohexane ring.

**Group C**

1 Lisa: So this whole thing leaves and this goes here? (pointing to paper)
2 Michelle: Yea, I think the Cl would go here (pointing to paper)
3 Nicole: The Cl would go there
4 Lisa: What happens to the SO? Would it be like plus SO
5 Michelle: No it would be plus the leaving group, I don’t know how to express it
6 Michelle: For A is it the whole thing that goes away or just the OH?
7 Morgan: I think it’s the just the OH
8 Nicole: Um wait, so would that mean that, never mind….
9 Morgan: I think it’s the whole thing, the entire leaving group, yea it’s the leaving group
10 Nicole: Yea that’s what I think (revisits question)
11 Nicole: And for the first one is it just the Cl or is it the S
12 Morgan: I don’t even know what compound that is (SOCl₂)
13 Nicole: What this? (pointing to paper)
14 Morgan: Yea
15 Nicole: Yea, I don’t know either, I see Sulfur, Oxygen and
16 Nicole: What? What did you say?
17 Lisa: It’s not real, its not like
18 Morgan: You’re funny
19 Morgan: So what is the product?
20 Lisa: Is it this like with the Cl?
21 Morgan: No
22 Michelle: I think it is that
23 Morgan: Ok

Figure 39 Group C's Answer for Question 4a

4. Predict the product for each reaction below.

a. \[ \text{CH}_2\text{CH}_2\text{OH} + \text{SOCl}_2 \rightarrow \]

Figure 40 Group C's Answer for Question 4b

4. Predict the product for each reaction below.

b. \[ \text{CH}_3\text{CH}_2\text{OH} + \text{PBr}_3 \rightarrow \]
Figure 41 Group C’s Answer for Question 4c

4. Predict the product for each reaction below.

Group C swapped ideas until they formed the answers to question 4. They discussed leaving groups and the other reactants. Morgan, Nicole, and Lisa expressed that they did not know what the reagent SOCl$_2$ was. With limited conversation they were able to satisfactorily answer 2 out of 3 of the questions. Only on question 4a did they remove more than just the OH leaving group.

Discussion

Questions 4a-c were all Marzano level 3 analysis questions. This question type requires students to use reasoning to solve problems about known information. Both groups used a low level of dialogue to discuss the answers to question four. The students in Group B did not recall reactions of alcohols. Without this basic knowledge it was difficult for them to reach a satisfactory answer. The students in Group C recalled some reactions of alcohols and were able to answer more accurately. Although the students in Group C did not completely remember the reagents and reactions they were able to remember the halide groups replaced the OH on 4b and 4c.

Question 5a: Draw the product(s) for the reaction shown.

Marzano Level: Level 2 Comprehension

Question 5b: What is the name of this reaction?
**Marzano Level: Level 1 Retrieval**

**Question 5c: Explain in words, the mechanism of the product formed in the reaction on the previous slide.**

**Level 3 Analysis**

**Group B**

1. Farrah: Reads question aloud
2. Brittany: So we have to do it in two steps, so this is, what’s the first step, is the first step the nucleophilic attack? I know we have to draw it and
3. Farrah: I wanna say, I think it’s all gonna leave
4. Brittany: Oh okay, I know we have to do it in two steps
5. Dawn: But they occur at the same time don’t they
6. Brittany: If they’re showing the two steps I thought it was showing that it doesn’t happen at the same time
7. Dawn: Oh okay
8. Farrah: So okay, so I’m pretty sure we get rid of the leaving group, and then I can’t remember if its, well what kind of mechanism is it? Is it SN1 or SN2, that would help us figure out
9. Brittany: Well if it’s happening in two steps its SN1
10. Farrah: Huh
11. Brittany: If it’s happening in two steps its SN1
12. Farrah: It’s a SN1 reaction so it don’t happen at the same time
13. Brittany: Yea
14. Farrah: So possible leaving group
15. Dawn: Is there a proton transfer in there?
16. Brittany: But the leaving group leaves because of the nucleophilic attack, so I think that happened first, something because the leaving group, it leaves because the nucleophile knocks it out
17. Farrah: Ok
18. Brittany: Um.. I don’t know what else, I don’t know how to show that.
19. Farrah: Nucleophilic attack. But the thing is you can have a nucleophilic attack unless you have that plus, you only get the plus if you leave, like the leaving group leaves, you know like if you get rid of that OH here you would have that plus here then you do your nucleophilic attack and that fills that
20. Brittany: Okay
21. Farrah: You know? I don’t know
22. Brittany: No, no I see what you mean
23. Farrah: I’m so lost
24. Brittany: So now we have a plus here, this is our leaving group
25. leaving, so now we show the attack
26. Brittany: But the thing is what’s attacking the Na or the H because it’s not both
27 Farrah: It’s gotta be the Na cause H
28 Brittany: But they’re both positive
29 Dawn: They are
30 Farrah: It says that, Cl is definitely the nucleophile but that’s in the second step
31 Brittany: So what do we do, you’re right because
32 Farrah: We bout to…. the question is wrong it’s not possible
33 Brittany: I think it might be flipped because I feel like NaH that the solvent, it’s the protic solvent
34 **Farrah calls the instructor to the table**
35 Jasmine: We think this question is backwards five part A
36 Instructor: Nope
37 Farrah: It’s not?
38 Instructor: There’s not solvent identified on the question
39 Brittany: But there is one?
40 Instructor: There’s no solvent on there
41 Brittany: But both Na and H are positive
42 Instructor: Na is positive, H is not positive that a hydride, H minus
43 Farrah: That is true for it to be neutral
44 Instructor: H minus is a base
45 Farrah: So that is the one that’s giving away
46 Brittany: Okay, okay
47 Instructor: Think, first think acid base chemistry, if this is a base and this is your acid what’s gonna happen?
48 Instructor: Where’s your acidic hydrogen here?
49 Farrah: A salt in water, huh?
50 Instructor: So where’s your acidic hydrogen here?
51 Farrah: Where like in the?
52 Instructor: In this molecule
53 Farrah: Oh the H
54 Instructor: Right so you have a base, the hydrogen is a base, the base is going to react with the acid and what’s going to happen?
55 Farrah: It’s gonna leave right?
56 Instructor: What’s gonna leave?
57 Farrah: The OH
58 Instructor: Not the whole OH, just the hydrogen
59 Farrah: Just the H leaves, oooohhhhh
60 Instructor: That’s the acidic hydrogen right?
61 Farrah: OH hold on, hold on got something working here, cooking something up
62 Brittany: Okay what’s cooking? Good looking (laughs)
63 Farrah: Okay she’s saying that the H is you know the negative so that’s your acid so this is your base, no I lied this is your acidic hydrogen and this is the base, she said what’s gonna happen is you have this and its gonna attack this, this is gonna wanna leave, not the whole thing
64 Brittany: Just the H?
Farrah: The H is gonna wanna leave then I after that is where we get, oooohhhh is that a proton transfer, a proton transfer?

Brittany: OH it might have to be

Farrah: And then you do nucleophilic attack

Brittany: With the Cl? Ok.

Brittany: Ok so the H attacks that, okay

Farrah: Okay so all I got, if this **** ain’t right, then I have this all I did was draw the H then that **** leaves and you get a positive and then we go to the second step and the Cl is gonna attack the positive and then you gone get some **** I don’t know, Help me!

Brittany: alright hold on I have to follow, How is it positive if the H leaves? Cause I thought the O was neg

Farrah: It has to go somewhere

Brittany: Wait is there another part on there that?

Brittany: Nooooo

Farrah: Could it go here (pointing to paper)? Cause this is like tertiary

Brittany: But it has nothing to attack there though, there’s nothing that it wants it wants the positive

Farrah: Right, right

Brittany: Instructor! What the heck?

Brittany: One more question about this, so I’m having trouble trying to understand this, so, so, so the H in this is the acidic hydrogen, right as you mentioned, and then…

Instructor: So you remove the hydrogen, do you think that, why do you think it would become positive?

Brittany: So I thought that the Hydrogen and it’s electrons left

Instructor: Un un, this is the base, this is the acid (Pointing to paper) negative charge, oxygen doesn’t want to have a positive charge, oxygens only want to have a negative charge

Brittany: Right

Instructor: Take that information and run with it

Brittany: But this has to attack somewhere, so it just becomes OH again?

Instructor: Un un, just come on run with it, make it negative

Brittany: I’m jogging I can’t run

Instructor: Pick up the pace

Brittany: I’m jogging

Instructor: So you got that and you go to step two

Brittany: So in step two, the Cl...

Dawn: That’s gonna attack that has to

Instructor: Wait, so identify your nucleophile, identify your electrophile, when you get to step two, the same like that
Brittany: Okay
Farrah: Oooohhhh how’s it gonna be a nucleophilic attack if…
Brittany: It’s a electrophilic attack to be honest, but the thing is, maybe it’s the part because Cl is not attracted to negative a negative charge it has to be the CH₃CH₂CH₂ that's I think that’s what attacks because it cannot a Cl cannot attack a negative
Farrah: We gone do that we just gone..
Brittany: We just gone run,
Farrah: We gone run with it
Brittany: I’m putting CH₃CH₂ClO
Farrah: No
Jasmine: No
Dawn: No, no, no.

Figure 42 Group B's Answer for Questions 5a,b

5. Draw the product(s) for the reaction shown.
   a. [Diagram with chemical structures]

b. What is the name of the reaction?
   [Answer: SN1]
The group reached a road block on question 5. The instructor attempted to guide them into figuring out the steps of the reaction (lines 35-58). She probed the students to think about acid base chemistry (line 84). The group was able to figure out that the base NaH reacts to undergo an acid/base reaction, but they were unsure about the ether formation. The students were stuck on nucleophilic and electrophilic attacks instead of acid base chemistry. Sodium Hydride (base) deprotonates an alcohol to yield an ether. They were unsuccessful at figuring at the next step in which the negatively charged oxygen molecule attacked the electrophile to form the ether.

**Group C**

1 Nicole: Wait, first we should name the reaction  
2 Morgan: Well you have kinda try and do something to that, this is tertiary  
3 Nicole: Um huh  
4 Morgan: First this is a bad leaving group  
5 Nicole: Nope, it’s primary, secondary, secondary  
6 Morgan: Umm NaH is it the solutions?  
7 Michelle: Solvents?  
8 Morgan: Yeah, Aprotic, aprotic has hydrogens correct?
9 Nicole: Yeah
10 Lisa: I know it’s was a chart in the CLC
11 Morgan: Protic solvents lack hydrogens
12 Nicole: Pretty sure
13 Morgan: This hydrogen by itself, this is a strong nucleophile Chlorine, correct?
14 Nicole: I didn’t hear what you said, you were saying it really lightly
15 Morgan: Umm hydrogen.....Wait when we had problem with this was it steps, like step one that was the solvent
16 Nicole: Oh step one the solvent and you said step two is to umm
17 Morgan: So this OH is gonna leave
18 Nicole: So it’s SN1 right?
19 Lisa: I can’t, I just knows what happens, I don’t know how to... name them
20 Morgan: This (pointing to iPad) is gonna leave then the hydrogen is going to replace it?
21 Michelle: It has to be a proton transfer so...
22 Morgan: So it’s gonna be H2, H2O
23 Nicole: Yeah
24 Michelle: I think so, yeah because it’s gonna make it a better leaving group
25 Yes girl, yes
26 Lisa: Say it one more time
27 Michelle: So, this this is gonna do a proton transfer here, to make OH a better leaving group, you can’t make OH a leaving group without it
28 Nicole: So it’ll be that
29 Morgan: Right and now, okay so this is not right here
30 Nicole: But it will be H2O instead right, Not?
31 Morgan: Okay, so this goes here, now this H2O breaks off
32 Nicole: Yeah H2O breaks off
33 Morgan: And it reacts
34 Nicole: And it reacts with this number 2
35 Morgan: Number 2
36 Nicole: So yea this is SN1
37 Nicole: That with the Cl, Girl you better know what you are talking about these reactions
38 Morgan: And then Sn1
39 And then, (Reading question 5c)
40 (Morgan proceeds to write the mechanism in words on the iPad)
Nicole thought it was a good idea to first name the reaction given in question 5 (line 1).
Morgan thought they should just figure it out as they go (line 2). The group proceeds to idea swap.
until they form an answer. Instead of identifying the first step in the reaction (acid/base chemistry) by looking at the strong base, they begin discussing leaving groups. They proceeded to answer question five as they did question four, by just replacing the \(-\text{OH}\) with a \(-\text{Cl}\) (Figure 41).

**Discussion**

Both group B and C used high-level dialogue to discuss the possible answers to question 5. Despite the idea swapping and open/closed questioning neither group was able to form a satisfactory answer. Group B received a lot of scaffolding from the instructor and still could not reach the solution. Group C was confused about what was going on in the reaction, they did not know what each component was supposed to do.

Group B used a similar approach for group quiz three. They participated in closed/open questioning, restating, idea swapping, and verification of answer to uncover the quiz answers. Again, most of the dialogue can be attributed to two of the four group members (Figure 46). Farrah and Brittany discussed most of the information about SN1 and SN2 reactions, they gave detailed descriptions of their proposed answers. Group B used low-level and high-level dialogue to discuss their answers. Overall with limited participation from two of the members, Group B was actively engaged 40% of the time. During their disengaged moments, the students discussed personal memories and food preferences.
Each student in Group C contributed to the formation of quiz answers. First, they worked through problems individually, then they discussed the answers they chose aloud to finalize what is to be written on the iPad. They used idea swapping and closed/open questioning to develop their answers. The students were active 57% of the time participating in idea swapping, questioning, and restating to come up with answers to the group quiz (Figure 47). Group C used both low-level and high-level dialogue to discuss their answers. This group was found to be 3% disengaged with a few occurrences of off-tasked behavior such as looking at a cellular device. Passive engagement included writing down answers and working independently (Figure 46).
Figure 47 Engagement Summary Alcohol Substitution Quiz Group C
3.7 Discussion and Implications

The present work desired to make a statement about the success of minority students in a community-based, collaborative learning environment. It has many implications on teaching and learning of organic chemistry and more widely, in the sciences. The results of the observations of students’ participation in a group-quiz show that certain types of engagement lead to successful discourse. The community of inquiry framework focuses on the interaction of three critical presences that shape the educational experience. Cognitive and social presences had a large impact on this in-class group activity. Cognitive presence and Social presence, which is described here as engagement, plays a critical role in the formation of group quiz answers. Social presence was mostly seen during off-task conversations (risk-free expression), and peer-encouragement.

Cognitive Presence

Cognitive presence promotes the analysis, construction, and confirmation of meaning and understanding between the students in a community of inquiry (Gutiérrez-Santiuste, Rodríguez-Sabiote, & Gallego-Arrufat, 2015). Group discourse is supported by cognitive and social presences. The students used low-level and high-level dialogue to complete their group quizzes. High level dialogue uses high level information exchange which includes open questioning, integration, and resolution of the ideas. Low-level information exchange include: affirmations, closed questioning, and verification of answer. The students participated in these exchange types by presenting ideas, discussing them, and forming reasonable answers.
Question Level and Engagement

Limited dialogue was observed on definition and multiple-choice questions. The questions that are developed for group collaborative studies should be more thought provoking, instead of simple definition questions the students should be required to go beyond the shallow understanding into deep understanding. Research confirms that question type can affect the level of engagement, deeper learning (Chi & Wylie, 2014; Docktor, Strand, Mestre, & Ross, 2010) Cognitive engagement is supported by social engagement or social presence.

Social Presence

Social presence promotes open communication, group cohesion, and emotional expression. Group B showed consistent social presence during group quiz 2 and 3. They used risk-free expression in the form of humor, self-disclosure, and complimenting throughout each quiz. Findings suggest even off topic conversations contribute to comfortability and bonding among group members. Group A and Group C rarely projected any personal characteristics into the community of inquiry. When students have a positive social presence they also are invested in the completion of the activity. In one instance, the group scribe who was not an active contributor of ideas, wrote an answer that only included shallow information. Overall the members of Group A and Group C remained focused on the quiz. A noticeable difference between the three groups was the group member participation. On average two of the three members contributed to the answers in Group A, comparably only two of the four members in Group B. Group C was the only group in which each one of the four members were actively contributing to form quiz answers. Group C was found to have the most group members participating and the most correct responses.

Some may infer that if you place a few individuals into a group they should be able to work together and solve problems with ease, but researchers argue that students need the proper skills if
they are going to work together successfully. It has been found in a past study that training students on how to effectively work in groups has a positive effect on learning outcomes (Prichard, Bizo, & Stratford, 2006). Students who were trained in this manner showed higher skills ratings and increased learning outcomes (Prichard et al., 2006) as compared to students who received no training. We cannot assume that group work skills will just appear when students are placed into a group, proper training will give the students the ability to add to and get the most from collaborative activities. The trainings can help the students work more effectively and teach them to ask the right questions:

Where do we start?
What to do if you reach an impasse?
What if other group members are not participating?
How do we move the group conversation forward?
What kinds of questions should we be asking?
Do you understand why an answer was chosen?

Along with training, having a stronger teaching presence could enhance the group environment. Studies show the use of peer leaders boost pass rates in chemistry courses, the pass rate increased from 54% in the traditional course to 69% in the flipped course (Báez-Galib, Colón-Cruz, Resto, & Rubin, 2005). Classes adopting the Flipped peer-led team-learning pedagogy consistently outperformed the classes with traditional lectures (Robert, Lewis, Oueini, & Mapugay, 2016).

3.8 Limitations

There are some limitations of the present study that should be discussed. The data herein is from a single course at a single institution. This can affect the degree of generalizability of the
results. However, we have given a deep description of a group of students that is currently understudied in the literature.

3.9 Conclusion and Future Direction

The present study described the engagement types that lead to the successful answering of organic chemistry I questions. Engagement both social and cognitive were seen throughout the commission of the two quizzes. The actions present give insight to the actions that are necessary to successfully answer questions as a group. This study also expands the use of the COI framework beyond on-line or virtual environments to learning environments that are blended or flipped in which content is delivered online and active collaborative learning in class is encouraged. The findings give rise to adjustments that can be made to the curriculum as well as suggestions on training the students to work in a group more effectively.

Effective group work includes asking the right questions and providing evidence for proposed answers. During this quiz, we also saw that idea swapping and open questioning often lead to success in this group environment. Input from each member of the group is also necessary to formulate quality answers to group quiz problems.

In relation to the findings of the present study, further research is warranted to understand the roles that motivation, self-efficacy, and student agency play in the active involvement of students during a group quiz. Individual student observations will also be analyzed to understand which group roles need to be employed for successful discourse during a group assignment. These studies will provide insight on how instructors should structure their groups and their overall course.

Another area for further research, is the social engagement among this particular groups of African American women in a chemistry course. It was apparent that these students engaged in
conversations about topics that spoke specifically to the experiences of minorities and women of color that can be described as “risk-free expression.” Conversations of this type may not have been forthcoming in another environment. Therefore, exploring this aspect of their social engagement through the lens of “Black Feminist Thought” or “Critical Race Theory” is needed.
4 DESIGN, IMPLEMENTATION, AND ASSESSMENT OF A GREEN CHEMISTRY LEARNING MODULE

4.1 Abstract

The need for more sustainable practices is in high demand. Green chemistry encompasses practices that would lead to less harmful chemical products ending up in the environment. Herein, we describe an interactive green chemistry learning module that introduces high school students to the topic of green chemistry. Three hands-on activities were done to illustrate a few of the twelve principles of green chemistry. The students picked suitable solvents, built ball and stick models of molecules, and made ‘green’ paint during an interactive case-based green chemistry module. The students expressed their enjoyment of the activities and they showed green chemistry knowledge gains after participating in the module.

4.2 Introduction

Modern chemicals are responsible for nearly all aspects of our lives. Our daily routine would be severely disrupted if we discontinued the use of chemicals. Overall, chemistry has changed our lives. However, the public has a negative depiction of chemists and chemistry for the hazardous materials produced, and the impact they have on our environment. Green Chemistry proposes to reduce the production of hazardous wastes. Paul Anastas and John Warner developed twelve principles of green chemistry to educate scientists on how they can make a greener chemical, process, or product (Anastas & Kirchhoff, 2002). This information is vital to advance our society into a sustainable future.

Song, Wang, and Geng emphasized "While green chemistry is commonly used in industrial applications, the concepts of green chemistry can be incorporated into educational pedagogy. Along with chemistry concepts, knowledge of which processes present the minimum hazard to human health, or the environment should be part of the curriculum (Collins). Chemists trained in
Scientists have placed the need for more green chemistry concepts in the curriculum at the top of the list of academic advancements to be made (Bodner George, 2017; Middlecamp, 2018; Plotka-Wasylka et al., 2018). The general public has also expressed concerns regarding our environment and the state of our atmosphere (Howard, 2019). Now is a perfect time to change the dialogue from what caused the problem, to how we will mediate the problem. What a better way than to start with the future scientists and adult citizens?

This chapter presents an interactive module that intends to use a real-world study to promote the enjoyment of chemistry. By participating in this module, the students will be able to form an appreciation for sustainable chemistry, including reduced hazardous waste, and conservation of our natural resources. The presentation and activities aim to highlight specific green chemistry topics including waste prevention, atom economy, designing safer chemicals, and using safer solvents. The students are prompted to solve a real-world case-based problem using green chemistry. Anastas and Zimmerman emphasize “Without context, the origin of chemical reagents is mostly a mystery, and students may give little thought to what happens to the materials poured into the hazardous waste collection jars at the end of every experiment (Anastas & Zimmerman, 2018). Here, we give students knowledge, context, and the ability to apply the knowledge to solve a real-world problem. Students often appreciate the benefits of learning green chemistry concepts (Hjeresen, Boese, & Schutt, 2000). The insertion of sustainability and green chemistry into the curriculum is necessary to change our current destructive path (Belford & Bastin, 2013). By inserting this knowledge early on, we begin to create a sustainable mindset for future generations.
Statement of Problems

The current use of a linear approach to teaching chemistry is inadequate. Not enough of the concepts in the classroom connect chemistry to the real world. This format of teaching students makes it difficult for them to understand and enjoy chemistry. Chemistry with a real-world context focused on a systems approach to solve problems will spark more interest in chemistry. Students are naturally curious about the world around them. If we can connect our problems with chemistry, it will create a paradigm of new learning and teaching experiences. It is imperative that we educate our youth to achieve a sustainable future, not just for the future of science but the future of our world.

Purpose of Study

The current study investigates the effect an interactive green chemistry learning module has on students' attitudes about chemistry, and their ability to learn green chemistry concepts. This work seeks to highlight the effects of a well-engineered learning module has on students' attitudes and knowledge base.

Research Questions

RQ1: Is there a difference in student perceptions before and after participating in an interactive green chemistry module?

RQ2: Do students exhibit green chemistry knowledge gains after they participate in an interactive green chemistry module?

Hypothesis

Hypothesis: There is a difference in students’ perceptions about chemistry after they participate in an interactive chemistry module. The students do exhibit green chemistry knowledge gains after they participate in an interactive chemistry module.
**Null Hypothesis:** There is no difference in students’ perceptions about chemistry after participating in an interactive green chemistry learning module. The students did not exhibit green chemistry knowledge gains after they participate in an interactive chemistry module.

**Significance of Study**

"Education must be at the center of the movement for a sustainable future, and we must incorporate sustainability into all levels of education (Belford & Bastin, 2013)."

It is important for us to incorporate green chemistry learning goals into our curriculum to increase the knowledge of future chemist. Students in high school will have an unique advantage to shape the future with much more forethought. This module aims to grasp students who are interested in science, and even spark interest in the uninterested student by using real-world content. Green chemistry offers solutions to problems that affect everyone. This opportunity to research student attitudes about chemistry and students’ ability to retain information not taught in their curriculum will also benefit my future work as an educator by fostering my abilities to design meaningful, and enjoyable instructional materials.

**4.3 Literature Review**

This literature review will explore the background of green chemistry, emphasize the need for green chemistry educational materials, and showcase the work already done by green chemistry educators.

**Green Chemistry**

“...The most alarming of all man’s assaults upon the environment is the contamination of air, earth, rivers, and sea with dangerous and even lethal materials. This pollution is for the most part irrecoverable; the chain of evil it initiates not only in the world that must support life but in living tissues is for the most part irreversible. In this now universal contamination of the environment, chemicals are the sinister and little recognized partners of
The words echoed loudly as *Rachel Carson’s Silent Spring* reached mainstream media. Calling out chemicals as dangers not only to insects [pesticides] but to human and environmental health. Linda Lear summarized “Silent Spring compels each generation to reevaluate its relationship with the natural world (Carson, Wilson, Lear, Darling, & Darling, 2002).” In a rush to innovate, had we forgotten the possible consequences? Steaming from societal concerns, President Richard Nixon formed the Environmental Protection Agency [EPA]. The EPA was put into place to establish and enforce environmental protection standards, conduct research on the adverse effects of pollution and methods to control them, assisting others, through grants who also want to prevent pollution, and recommending new policies to protect the environment to the president. The EPA created The Pollution Prevention Act, in 1990, which was America’s first policy that proposed pollution source reduction. This act pushed for research on ways to avoid or diminish pollution at its source not allowing it a chance to enter our environment.

Considering chemicals are the cause of most of the harmful pollution, it is consistent with advancing the focus of pollution prevention to chemistry. Green chemistry addresses the ways we can reduce harmful substances from entering our environment (Hjeresen et al., 2000 2000). More specifically, green chemistry is a discipline of chemistry focused on creating products and processes that minimize the use and origination of hazardous substances. Paul Anastas and John Warner pioneered the green chemistry movement by outlining twelve principles that describe how to make a greener chemical, process, or product. The benefits of chemical production and use frequently overshadow the risks we are taking by creating and using such chemicals. More forethought is needed in the laboratory to help save our planet, and green chemistry addresses this.
After years of complacency, now it has become increasingly urgent to change our destructive ways. Nearly 50 years later the consequences of our lack of urgency are still wreaking havoc on our environment. “Chemist have been challenged to change the practice of chemistry to address the apparent global crisis. They have also been tasked with reinventing chemistry education to help scientist and non-scientist alike learn their roles in our sustainable future (Anastas & Zimmerman, 2018).” A study at Yale revealed that 29% of survey respondents are “very worried” about global warming, and 73% of respondents think that global warming is happening (Howard, 2019). Considering the current dialogue, now is the perfect time to plant the seeds for a sustainable future with education.

Green Chemistry and Education

Public concerns over global warming and greenhouse gases prompt students to want to learn how humans are affecting our planet (Hjeresen et al., 2000). Students around the world are also extremely interested in the sustainability of their world (Hjeresen et al., 2000). Current chemistry education practices lack real-world connections that would broaden a student’s point of view on the subject.

*Mahaffy, Brush, Haack, & Ho question, “how can educators replace existing course material with material that integrates sustainable and green chemistry lessons and principles into chemistry education?"

We must include real-world studies that address the problems we are facing. In an overview of science education standards, scientists believed that everyone should have experiences that create excitement and fulfillment that is associated with learning about the natural world (National Research Council, 1996). Educators around the world are taught to teach based on standards that state what students should know about science. We must go beyond the standards to bridge the gaps and make science more interesting and relatable to our students. Science educators are urged
to create a deeper meaning of science through in-class studies and activities (National Research Council, 1996). *Blatti expressed* “…it is necessary for science educators to inspire students, realize aptitude for scientific discovery, and bring out passion for science through hands-on, engaging activities (2017).”

Although leading educators have pioneered the green chemistry movement, most chemistry instructors lack a broad understanding of green chemistry, and the current chemistry learning objectives fall short to support teaching green chemistry (Kent Voorhees, 2015). There are no standards in the current chemistry curriculum that include green chemistry, but educators around the world are tasked to teach students chemistry concepts that have green chemistry goals, without compromising the integrity of chemical knowledge (Collins, 1995). This form of teaching is considered a systems approach to teaching chemistry. Teaching chemistry through a systematic approach challenges students to apply scientific principles to solve real-world problems, demonstrates chemistry’s role as an essential science in finding solutions to global challenges, and prepares future scientists for the collaborative interdisciplinary work required in the workforce (Mahaffy, Brush, Haack, & Ho, 2018). Adding green chemistry to the curriculum will create chemists who are knowledgeable about pollution-prevention concepts, which gives them the ability to identify, develop, and implement techniques that reduce pollution. Building students’ capacity to integrate systems thinking into their chemistry problem-solving toolkit can yield new insights and create new opportunities for design and innovation (Mahaffy et al., 2018). Beyond the classroom and the individual, green chemistry requires interdisciplinary awareness. A multidisciplinary approach to green chemistry education allows students to develop interdisciplinary communication and contacts early on, thus promoting concerted efforts for attacking problems and developing sustainable technologies with global awareness. Throughout
the last 25 years educators have developed and implemented many educational materials that have added green chemistry into the curriculum see (Haack & Hutchison, 2016).

**Green Chemistry Educational Content**

In response to the public outcry many programs have been put into place to educate individuals about green chemistry. The American Chemical Society (ACS) created a division focusing on green chemistry. On the ACS green chemistry webpage, there are resources for green chemistry activities, curriculums, and experiments (American Chemical Society, 2016). Websites such as “Beyond Benign” educate instructors on how to integrate green chemistry into the curriculum (Benign, 2019). It is vital that we as educators go beyond the surface of our curriculum to explore opportunities for in-depth thinking and learning.

Studying green chemistry in secondary school classes has been shown to increase students’ interest in chemistry (Karpudewan, Roth, & Ismail, 2013). In connection, many exciting green chemistry activities and labs have been implemented. Undergraduate students enjoyed making green soap using avocado oil with the less hazardous solvent ethyl acetate (Sutheimer, Caster, & Smith, 2015). The students expressed their enjoyment of the lab and the ability to use organic chemistry to make a useful substance (Sutheimer et al., 2015). Many labs have been created to synthesize and analyze green paint (Blatti, 2017). The students often responded with enthusiasm when discussing the green paint activity (Blatti, 2017). This activity helped to build a connection between chemistry and their everyday lives. Many green chemistry activities have been successfully added to the chemistry curriculum. One thing many of these studies have in common is the use of a “story” to create motivation towards learning. These stories are often in the format of a “case-study.”
**Case-Based Learning Pedagogy**

In order to make connections between theory and applied knowledge the curriculum must support real-world studies (Mayo, 2004). Case studies are educational materials that include a text that contains the details, and questions to support and guide students through the topic. The case studies can be used to connect course content to real-life scenarios. Case-based learning has been used for over a hundred years to actively engage students with learning materials. In modern times, case-based learning has continued to be a driving force in education with cases available in distribution centers. In this context distribution centers are large databanks online and in literature that contain case-studies. The National Center for Case Study Teaching In Science publishes and makes many cases created by educators available to the public ("National Center for Case Study Teaching in Science," 2019). Although cases are often used in biology and health science instruction, chemistry-based cases account for less than ten percent of all cases (Herreid, 2013). Past studies have shown the use of case-based learning increases students’ interest and attitude towards the course (Yalçınkaya, Boz, & Erdur-Baker, 2012). Case-based learning methods should be used to increase chemistry students’ motivation to learn the important topics covered in the course. Motivation for learning is vital for the educational process. The addition of case-based studies in the classroom will foster scientific skills and practices that will greatly influence the future scientific success of our students and they will create a deep interest in chemistry based on the connection it [chemistry] has on their lives.

In response to the critical need for green chemistry concepts to be added to the curriculum, this module, focused on green chemistry concepts, aims to encompass critical scientific knowledge and practice through a fun and interactive case-based module.
4.4 Theoretical Framework

The elements of effective science instruction were used to create the module *Cleaning our World through Green Chemistry* (Banilower, 2010). This framework outlines elements that are needed to create a meaningful learning experience for students. The model presented here is derived from the learning theory described in the National Research Council’s volumes *How People Learn: Brain, Mind, Experience, and School* (2000) and *How Students Learn: Science in the Classroom* (2005). The elements of effective science instruction were built upon Piaget’s ideas about constructivism (Piaget, 1952). In constructivism, students are active learners that construct knowledge using existing knowledge (Piaget, 1952). This framework includes five elements, motivation, eliciting students’ prior knowledge, intellectual engagement with relevant phenomena, use of evidence to critique claims, and sense-making. This section will explain each of the five elements and how they helped to shape the module.

**Motivation**

Simply put, lessons should “hook” students by addressing things they have heard of, thought about, or things they care about. Motivation can be extrinsic or intrinsic. Extrinsic motivation means the students are motivated to complete assignments based on the outcome, which can be a grade, prize, or praise (Vallerand et al., 1992). Intrinsic motivation is doing an assignment for the pleasure and satisfaction one will receive from doing the assignment alone (Deci & Ryan, 2010). *Cleaning our World through Green Chemistry* strives to increase students’ intrinsic motivation to learn science. This module begins with a quote from the EPA about hazardous wastes, “Each person in the United States produces an average of 4 pounds of household hazardous waste each year for a total of about 530,000 tons/year (Environmental Protection Agency, 2016).” This quote connects the lesson to the students and attempts to reveal
that they are also contributing to our hazardous waste problems. This module is centered around making predictions and doing research. Having the students make predictions before starting an investigation has been shown to boost interest (Banilower, 2010). Recently, we have been experiencing more intense storms which can be attributed to global warming (National Aeronautics and Space Administration, 2019). Hurricane intensities are projected to increase as the climate continues to warm. This module discusses the effect a hurricane could have on stored hazardous wastes. The module *Cleaning our World through Green Chemistry* includes a case-study (discussed further in literature review) that discusses the effects hazardous wastes have had following a category four storm that disrupted hazardous wastes that were properly stored. This module also includes a “role-play” element in which the students play the role of students in Puerto Rico that are attempting to figure out what caused the disparity after the storm. This element provides the students to interact with the information being taught by “teaching” it to their classmates through role-playing. Using role-play in scientific settings encourages students to be actively involved in their lessons. Role-play allows students to express themselves scientifically and develop understandings of difficult concepts (Taylor, 1987). Students are experienced in “play,” Piaget noted that play is the way children develop their knowledge and intelligence (Piaget, 1952).

*Eliciting students’ prior knowledge*

Students come to school with ideas and beliefs that they inquire outside of school in books, on television, from their parents and their environment. This element focuses on making connections with students’ prior knowledge. In this module, we used “open-ended teacher questions” to elicit students’ ideas. Before every major section in the presentation, the students were asked to answer a question that would lead them into the next topic.
Sample questions from the module:

“Which types of industries create hazardous wastes near you?”

“We know these industries use and dispose of tons of solvents but, what are solvents?”

“Do you know any examples of solvents?”

“Can we predict the impact our wastes are going to have on the environment?”

“What can a scientist do to prevent something like this from happening in the future?”

“How can we use green chemistry to create safer paint for future use?”

*Intellectual engagement with relevant phenomena*

Information must be presented in a meaningful way to engage students with important science content. Using this module, the students are allowed to investigate a meaningful question while participating in engaging class activities. White and Gunstone (1992) expressed “Classroom activities must be explicitly linked to learning goals so that the students understand the purpose of the instruction and feel motivated to engage with the ideas, not just the material. The information presented in this module is both relevant and vital for the sustainability of our future. The students also learn about atom economy. They build ball-and-stick models and calculate the atom economy of selected reactions. After calculating the atom economy, the students discussed their results and classified the reaction as high/low atom economy, and discussed the implications. Also, paint being one of the single things we see every day, it facilitates a scientific discussion about our practices at home as well.

*Use of evidence to critique claims*

The use of evidence to support and critique claims helps students make connections between their existing knowledge and new knowledge. This process shows a level of understanding not seen in rote learning processes. These experiences give students the background
of how scientists “know” the information they give us. The use of evidence to critique claims can also be called argumentation in science education research. Argumentation is the driver of scientific research. In science research claims, theories are open to challenge and progress in research is made through dispute and paradigm change (Driver, Newton, & Osborne, 2000). Argumentation can be used to strengthen content knowledge. Junior high school students were found to have a stronger content understanding by using argumentation techniques (Astuti, Suyono, & Nur, 2016). This module mostly relies on informal class discussions to gain backing for student answers throughout the presentation. Students were asked questions that were followed by why to prompt them to back-up their claims with the new information they were presented.

Sense-making

Sense-making is just as it sounds, the action of making sense of new experiences. In order for a science lesson to be effective, it must give opportunities for students to make sense of the ideas they have discussed during the lesson. Sense-making helps students connect previously learned knowledge to new knowledge. Students may present their sense-making in different ways. Students have been observed presenting their ideas with multiple stops, starts, and revisions both verbally and physically (Crowder, 1996). These unpolished performances may indicate that they are actively constructing knowledge (Crowder & Newman, 1993).

Cleaning our World through Green Chemistry is driven by questions. Each question used during the presentation of this module is used to help the students make sense of the information they are presented. This module utilized commonly shared knowledge about solvents and hazards to ask questions, and have essential class discussions that connected all of the new information. Although this element of effective science instruction is not seen directly during the presentation
of this module, sense-making remains important, and this background will help in the development of more in-depth classroom experiences in the future.

4.5 Methodology

Purpose of study

A new module has been piloted in high school classrooms that result in the active engagement of students. The current study investigates the effect of an interactive green chemistry learning module on students’ attitudes about chemistry and their ability to learn information about green chemistry. This work seeks to highlight the effects a well-engineered learning module has on students’ attitudes and knowledge base.

Research Questions and Hypothesis

RQ1: Is there a difference in student perceptions before and after participating in an interactive green chemistry module?

RQ2: Do students exhibit green chemistry knowledge gains after they participate in an interactive green chemistry module?

Hypothesis

Hypothesis: There is a difference in students’ perceptions about chemistry after they participate in an interactive chemistry module. The students do exhibit green chemistry knowledge gains after they participate in an interactive chemistry module.

Null Hypothesis: There is no difference in students’ perceptions about chemistry after participating in an interactive green chemistry learning module. The students did not exhibit green chemistry knowledge gains after they participate in an interactive chemistry module.
4.5.1 Research Design

Setting of study

This research was performed at several high schools in the State of Georgia. The students were enrolled in Environmental Science or Chemistry at their respective high school, and their grades ranged from 9th-12th grade. During their chemistry or environmental science class time, students were actively engaged in activities and a PowerPoint presentation that discussed green chemistry concepts.

Module Design and Implementation

“Cleaning our World through Green Chemistry” was designed based on elements of effective science instruction (Banilower, 2010). The module includes a PowerPoint presentation and three hands-on activities. It takes 75 minutes total (35 minutes of instruction, 40 minutes of activities) to present and complete the activities. The module was designed using a backward design approach (Wiggins & McTighe, 2005). Objectives were determined, and the PowerPoint and activities were based upon them. In this module, we discussed five of the twelve principles of green chemistry (prevent wastes, atom economy, use renewable resources, prepare green products, and use catalyst). The PowerPoint is available in Appendix C.

Learning Objectives

Students will

- Summarize what is meant by “Green Chemistry”
- Describe the meaning of “Hazardous Waste”
- Use reasoning to determine which solvents are “green” solvents (desirable) or non-green solvents (undesirable) by using the given characteristics of each solvent
- Illustrate knowledge of safety procedures in the lab
- Identify the role of a catalyst
- Describe the meaning of atom economy
- Compute the atom economy of various reactions
- Define the meaning of “Volatile Organic Compounds”
4.5.2 PowerPoint & Activities

This section will give an overview of each of the major sections of the PowerPoint and the activities associated with them.

Introduction

This module begins by giving the students a perspective on how much they are contributing to the build-up of hazardous wastes on our planet. With a quote from the Environmental Protection Agency “Each person in the United States produces an average of 4 pounds of household hazardous waste each year for a total of about 530,000 tons/year” we begin the lesson (Environmental Protection Agency, 2016). After gathering feedback, we introduce the definition of hazardous wastes. Next, an article designed as a case study is presented.

Case Study

This news article describes the aftermath of a hurricane which released toxic waste into the environment. In this article hazardous waste is discussed and linked to deaths of many citizens in Puerto Rico. The students are then prompted to give their feedback on the article and some possible examples of local industries [near them] that may have similar effects on the health of humans, animals, and the environment.

Figure 48 News Article

Waste floating around San Juan, has already claimed hundreds of lives

SAN JUAN, Puerto Rico (AP) – The pace of deaths quickened on Puerto Rico immediately after Hurricane Maria, well beyond the number of deaths caused by the Category 4 storm. Officials in the U.S territory on Wednesday reported at least 30 deaths per day attributed to the environment and health of individuals.

(Continued) Thousands of pounds of toxic waste were disturbed in the storm and allowed to escape landfills and take a new home in the flood water running through the city. The CDC has begun their initial investigation and has placed a banner of national emergency to figure out the cause of this great disparity.
Scripted Role Play

Throughout the presentation students are asked to volunteer and play the roles of four characters. The characters are students in Puerto Rico that are trying to help figure out the cause of mass deaths. Scripts are provided. The students agree to do more research to come up with more definitive answers.

Hazardous Wastes

Next, industries that contribute to the generation of hazardous wastes are discussed. The top three industries are chemical manufacturing, paint manufacturing, and paper manufacturing. Many solvents are used in the mentioned industries, and this leads to a discussion about solvents.

Solvents

The definition of a solvent is given. Next, the students are probed to list solvents that they may have at home. Then, they are given two examples of solvents they may use, acetone (nail polish remover), and ethanol (perfume/cologne). Next, we discuss the use of hazardous solvents to make new products. The students are introduced to Safety Data Sheets (SDS). Finally, the students break out into groups of 4-5 to complete a risk assessment on solvents.

How hazardous is it? (activity)

Time: 8 minutes

The students are given a foam board that separated into two halves. Half of the board is green and has the words “low-risk solvents,” the other half is red and has the words “high-risk solvents.” The students are given the board and a zip-lock bag filled with cards that have the solvent name, an example picture, and its chemical formula on the front, the back had data from the chemical’s SDS sheet. The students were asked to place the solvent card under the appropriate classification based on the SDS information. The results were discussed aloud.
The students (role play) come together again to discuss their research findings. Two of the possibilities they stated previously had the potential to be the cause. Next, an announcement from the CDC introduced the concept of Volatile Organic Compounds (VOC).

VOC’s

The definition of volatile organic compounds is given. For clarity, organic in this context is defined, so they are not confused with the ordinary meaning of organic used for food. The students (role play) come together again to discuss the result of their research and the key to the case. The VOC’s from paint production was the cause of the mass deaths around Puerto Rico. At this point, we transition from the case-study into green chemistry.

Green Chemistry

Students are asked, “What can scientists do to prevent something like this from happening in the future?” This question was made to introduce the students to green chemistry. Reduction (green chemistry) and Remediation (cleaning up pollution) were compared. The definition of green chemistry and background of the twelve principles was discussed.

Atom Economy (activity)

Time: 12 minutes
Atom economy was defined as a way to measure the atoms “wasted” during a chemical reaction. The students were given an example using easier terms to increase their understanding. The students created a ball and stick model of given reactions using small dowels and painted Styrofoam balls before calculating the atom economy.

*Figure 50 Students Participating in the Atom Economy Activity*

**Making paint (activity)**

Time: 20 minutes

The students were asked the question “How can we apply Green Chemistry to create safer paint for future use?” This question prompted them to say “we must change the components in the paint to make it safer.” The next few slides discuss the components that make paint. Making green paint is the closing activity in which they synthesize green paint and use it to paint a picture.
Participants

Participants were selected using purposive sampling (Etikan, 2016). The schools were chosen based on their socioeconomic status (SES). For this study we chose low SES schools which included five groups of high school students. Each group contained about 23 students. We gathered data on a total of 100 students. High schools were chosen from the Bio-Bus program at Georgia State University’s database. The contact teacher at the school received a request to pilot the module and three schools accepted and scheduled their Bio-Bus visit. We chose to evaluate students’ attitudes about chemistry, and their knowledge of green chemistry concepts before and after the presentation of the module “Cleaning our World through Green Chemistry.”

Prior Knowledge

Prior to our visit the students had been exposed to many chemistry topics including: Bonding, Molar Conversion, Stoichiometry, Solutions, Molarity, Periodic Tables and Balancing Chemical Equations. The students had also been previously taught about ecology, and biology in their science classes.

4.5.3 Data Collection

Surveys were administered before and after the presentation of the module. The attitudinal questions were taken from the “Chemistry Attitude and Experience Questionnaire” (CAEQ)
(Dalgety, Coll, & Jones, 2003). The green chemistry content questions came from “ACS Green Chemistry High School Test Questions (American Chemical Society, 2016).” This survey can be found in Appendix B. The CAEQ probed the students’ attitudes about chemists, chemistry research, and chemistry jobs. The Green Chemistry questionnaire assessed their knowledge of green chemistry. The CAEQ items used a Likert scale format, and the green chemistry questionnaire questions included five answer choices. The students were asked to put their student number on the top of each survey so that their pre-survey could be compared to their post-survey while preserving anonymity. All surveys were administered by the researcher, who has done Human Subject Training through the CITI (Collaborative IRB Training Initiative) program (Braunschweiger & Goodman, 2007). The Bio-Bus fellows that assisted with the survey administration have undergone CITI training for human subjects as well. CITI training provides training in human subjects research (Braunschweiger & Goodman, 2007). The training includes ethical issues, and current regulatory information. The Bio-Bus program also holds an IRB for the outlined research. During the administration of the surveys, the students could not use any supplemental information to answer the questions or rely on each other. They were encouraged to complete the surveys using their knowledge.

4.5.4 Data Analysis

The data were analyzed using SPSS 25 (IBM, 2017). SPSS is a statistical software package used for batched and non-batched statistical analysis (IBM, 2017). Reliability (Cronbach alpha) was calculated for each of the three subscales used from the CAEQ. Reliability was also calculated for the green chemistry questionnaire. Several dependent samples t-tests were performed to compare the means of pretest and posttest results of each of the subsections of CAEQ, and the green chemistry questionnaire. If multiple hypotheses are tested, the chances of incorrectly
rejecting a null hypothesis or making a Type I error increases. Therefore, we used a Bonferroni adjusted significance criterion of 0.0125 (0.05/4) to correct for multiple t-tests.

An item difficulty analysis was determined to examine the quality of the questions used in the questionnaire. The item difficulty refers to the probability that students will get the item correct. This value can range between 0.0 and 1.0, with a higher value indicating that a greater proportion of examinees responded to the item correctly, and it was therefore an easier item. Item discrimination was also calculated to evaluate the green chemistry questionnaire’s ability to differentiate among students according to how well they know the material being tested. Item discrimination compares a student’s performance on the given item (correct or incorrect) and the student’s score on the entire test. That is, for highly discriminating items, students who answers the items correctly also did well on the test or students who answered incorrectly did poorly on the test. The possible range of the discrimination index is -1.0 to 1.0.

4.5.5 Validity & Reliability of Instruments

Chemistry Attitudes and Experiences Questionnaire

The CAEQ subscales; attitudes about chemist, attitudes about the role of chemistry in society, and career interest in chemistry were found to be valid and reliable tools to investigate attitudes about chemistry (Dalgety et al., 2003). The items used are located in Appendix B.

Green Chemistry Questionnaire

Items from the green chemistry questionnaire were pulled from the ACS Green Chemistry High School Test Questions (American Chemical Society, 2016). This instrument has not
undergone any reliability or validity testing, therefore this is a limitation of using this instrument. The questionnaire consisted of six items and responses were given using five multiple-choice alternatives. For each correct answer to a green chemistry item, students received one point, for an incorrect answer they received zero points. The green chemistry questionnaire is located in the Appendix B.

4.6 Results

Student responses to the Activity

After the presentation, we gave the students a feedback form with two questions to gain insights on the module.

When asked “Are there any improvements that should be made to Cleaning our World through Green Chemistry the module?” most students answered “no.” Some students went into further detail “No, it was very informational. I learn new things and it was very fun.” Another student answered “No there are no improvements that should be made to “Cleaning our world through green chemistry.” The PowerPoint was well displayed and could be easily interpreted.” One student expressed “No the Presentation was Amazing. I learned lifelong adjustments that will improve my way of life.”

When asked “What memory stands out the most from Cleaning our World through Green Chemistry the module? Students wrote about the milk paint activity, the ball and stick model activity, limiting pollution, and chemicals that are harmful to living things. For example, students liked making and using the milk paint, “The memory that stands out from the module is painting using the paint that was made to be more safe.” Students also remembered important topics “The VOC’s stand out, having harmful products in the environment really makes you realize they aren’t healthy.” Another student remembered an image of hazardous waste containers “The barrels full
of hazardous waste.” Overall the module was well received and seemed to have a positive impact on the students.

Table 8 CAEQ Literature Reliability Data
Reliability data (Cronbach alpha) for chosen subscales of Chemistry Attitude and Experience Questionnaire (CAEQ) from literature (n=669)

<table>
<thead>
<tr>
<th>Subscale</th>
<th>Reliability (Cronbach α)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Start of year</td>
</tr>
<tr>
<td>Attitude toward chemists</td>
<td>0.66</td>
</tr>
<tr>
<td>Attitude toward the role of chemistry in society</td>
<td>0.86</td>
</tr>
<tr>
<td>Career interest in chemistry</td>
<td>0.69</td>
</tr>
</tbody>
</table>

Note. Pearson’s correlation coefficient. All the correlations were significant (p < .01)

Table 9 CAEQ Reliability Data
Reliability (Cronbach alpha) for chosen subscales of Chemistry Attitude and Experience Questionnaire (CAEQ) (n=150)

<table>
<thead>
<tr>
<th>Subscale</th>
<th>Number of items</th>
<th>Reliability (Cronbach α)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pretest</td>
<td>Posttest</td>
</tr>
<tr>
<td>Attitudes toward chemists</td>
<td>8</td>
<td>0.61</td>
</tr>
<tr>
<td>Attitudes toward the role of chemistry in society</td>
<td>4</td>
<td>0.81</td>
</tr>
<tr>
<td>Career interest in chemistry</td>
<td>5</td>
<td>0.76</td>
</tr>
</tbody>
</table>

Note. Pearson’s correlation coefficient. All the correlations were significant (p < .01)

Table 3 shows the Cronbach α for the subscales of the CAEQ survey. Reliability was tested for each subscale to determine the degree to which a result of calculation from it can be depended on to be accurate. The attitudes towards chemist subscale consisted of eight items, the pretest and posttest Cronbach’s alphas were 0.61 and 0.79, respectively. The pretest Cronbach alpha 0.61 is lower than acceptable, but these results are consistent with the literature where they found
Cronbach alpha scores of 0.66 (start of year) and 0.72 (end of semester). The attitudes toward the role of chemistry in society was found to be highly reliable for both Pretest (4 items, $\alpha = 0.81$) and Posttest (4 items, $\alpha = 0.86$). Cronbach’s alphas for the career interest in chemistry subscale were 0.76 (pretest) and 0.73 (posttest). These results indicate that the instrument can be considered reliable to measure what it is intended to measure. Students answering positively on an item will most likely answer positively on the items intended to measure the same thing, and vice versa.

Table 10 Reliability (Cronbach alpha) of Green Chemistry Questionnaire ($n=100$)

<table>
<thead>
<tr>
<th>Scale</th>
<th>Number of items</th>
<th>Pretest</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Chemistry Questionnaire</td>
<td>6</td>
<td>0.28</td>
<td>0.61</td>
</tr>
</tbody>
</table>

Note. Pearson’s correlation coefficient. All the correlations were significant ($p < .01$)

Reliability was calculated for the green chemistry questionnaire to determine the degree to which a result of calculation from it can be depended on to be accurate. The green chemistry questionnaire consisted of 6 items. Table 4 shows the pretest Cronbach alpha was 0.28 and the posttest Cronbach alpha was 0.61. These results indicate a low reliability of the items tested.

Table 11 Group Statistics for Each Subscale used in the Pre/Posttest

<table>
<thead>
<tr>
<th>Subscale</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attitudes about chemist</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretest</td>
<td>147</td>
<td>41.25</td>
<td>6.37</td>
<td>0.53</td>
</tr>
<tr>
<td>Posttest</td>
<td>147</td>
<td>47.27</td>
<td>9.16</td>
<td>0.76</td>
</tr>
<tr>
<td>Attitudes toward the role of chemistry in society</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretest</td>
<td>148</td>
<td>21.22</td>
<td>4.47</td>
<td>0.37</td>
</tr>
<tr>
<td>Posttest</td>
<td>148</td>
<td>24.26</td>
<td>4.29</td>
<td>0.35</td>
</tr>
<tr>
<td>Career interest in chemistry</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretest</td>
<td>150</td>
<td>25.14</td>
<td>5.68</td>
<td>0.46</td>
</tr>
<tr>
<td>Posttest</td>
<td>150</td>
<td>28.30</td>
<td>4.85</td>
<td>0.40</td>
</tr>
<tr>
<td>Green Chemistry Questionnaire</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretest</td>
<td>153</td>
<td>31.44</td>
<td>23.48</td>
<td>1.90</td>
</tr>
<tr>
<td>Posttest</td>
<td>153</td>
<td>65.31</td>
<td>23.33</td>
<td>1.89</td>
</tr>
</tbody>
</table>
Several dependent-samples t-tests were conducted to compare the pretest and posttest results of the subscales attitudes about chemist, attitudes toward the role of chemistry in society, career interest in chemistry, and a green chemistry questionnaire (Table 5). There was a significant difference in students’ scores on the attitudes about chemist subscale for the pretest (M = 41.25, SD = 6.37) and the posttest (M = 47.27, SD = 9.16), conditions; t (147) = -7.90, *p* < .01. There was also a significant difference in the scores of attitudes toward the role of chemistry in society subscale for the pretest (M = 21.22, SD = 4.47) and the posttest (M = 24.26, SD = 4.29), conditions; t (148) = -8.26, *p* < .01. There was a significant difference in the scores of career interest in chemistry subscale for the pretest (M = 25.14, SD = 5.68) and the posttest (M = 28.30, SD = 4.85), conditions; t (150) = -7.89, *p* < .01. There was a significant difference in the scores for the green chemistry questionnaire for the pretest (M = 31.44, SD = 23.48) and the posttest (M = 65.31, SD = 23.33), conditions; t (153) = -14.33, *p* < .01. These results suggest that the presentation of the module (Cleaning our World through Green Chemistry) does have an immediate effect on students’ attitude towards chemistry and their knowledge of green chemistry concept.

### Table 12 Item Difficulty of Green Chemistry Questionnaire

<table>
<thead>
<tr>
<th>Item</th>
<th>Pretest</th>
<th>Item Difficulty</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Chemistry Aim</td>
<td>0.58</td>
<td>0.83</td>
<td></td>
</tr>
<tr>
<td>Greenest Solvent</td>
<td>0.38</td>
<td>0.71</td>
<td></td>
</tr>
<tr>
<td>VOC meaning</td>
<td>0.32</td>
<td>0.71</td>
<td></td>
</tr>
<tr>
<td>Atom Economy Definition</td>
<td>0.21</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td>Catalyst Definition</td>
<td>0.11</td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td>Components of Paint</td>
<td>0.42</td>
<td>0.65</td>
<td></td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>0.34</td>
<td>0.66</td>
<td></td>
</tr>
</tbody>
</table>

An item difficulty analysis was done to examine the item quality of the questionnaire used to evaluate the students’ green chemistry knowledge. The average item difficulty for the pretest and posttest were 0.34 and 0.66, respectively (Table 6). The item difficulty of the pretest indicates
that the questions may have been hard for the students because at that time they did not have any knowledge of most of the items. However, after the material was presented the item difficulty was considered moderate (ideal). These results suggest that the questionnaire used for evaluation of students’ knowledge of green chemistry concepts has the ability to discriminate which students know the tested material from those who do not.

An item discrimination analysis was done to examine the ability of the items on the questionnaire to differentiate among students on the basis of how well they know the material being tested. The average item discrimination score for the pretest and posttest were 0.24 and 0.35, respectively (Table 7). The item discrimination for the pretest was “fair.” However, in the posttest the discrimination increased to “good.” These results tell us that items in our questionnaire have the ability to determine how students will answer items if they know the material versus if they do not.

### Table 13 Item Discrimination of Green Chemistry Questionnaire

<table>
<thead>
<tr>
<th>Item</th>
<th>Item Discrimination</th>
<th>Item Discrimination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Chemistry Aim</td>
<td>0.27</td>
<td>0.36</td>
</tr>
<tr>
<td>Greenest Solvent</td>
<td>0.15</td>
<td>0.20</td>
</tr>
<tr>
<td>VOC meaning</td>
<td>0.29</td>
<td>0.39</td>
</tr>
<tr>
<td>Atom Economy Definition</td>
<td>0.29</td>
<td>0.36</td>
</tr>
<tr>
<td>Catalyst Definition</td>
<td>0.23</td>
<td>0.33</td>
</tr>
<tr>
<td>Components of Paint</td>
<td>0.21</td>
<td>0.44</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>0.24</strong></td>
<td><strong>0.35</strong></td>
</tr>
</tbody>
</table>

**4.7 Discussion**

The internal reliability, Cronbach alpha, was found to be low for the subscale “attitudes towards chemists” during the pretest. In the original work that outlined the development of CAEQ the authors also found that the reliability of the pre-scores (0.66) to be low and that the reliability increased (0. in the post exam (Dalgety et al., 2003). All of the subsections measuring students’
attitudes about chemistry were found to be highly reliable during the post survey. High reliability means that the questions of a test tended to “pull together.” Students who answered a given question with a certain attitude were more likely to answer other questions in the same manner.

The internal reliability was found to be low for the green chemistry questionnaire for the pretest and posttest. This may implicate that the test needs to be supplemented by other measures. The test was very short (6 items), which could also affect its reliability scores. We chose to use a short exam to save time and energy for the presentation and activities, but if we were to increase the number of items, the observed reliability score should increase.

The item difficulty of the green chemistry questionnaire was found to be low prior to the presentation of the module and ideal upon the completion of the module and activities. Item difficulty is relevant for determining whether students have learned the concept being tested (Thorndike, Cunningham, Thorndike, & Hagen, 1991). It also plays an important role in the ability of an item to discriminate between students who know the tested material and those who do not. The item will have low discrimination if it is so difficult that almost everyone gets it wrong or guesses, or so easy that almost everyone gets it right. The ideal item difficulty for a five-response multiple-choice is 0.70. The posttest shows the true measure of item discrimination because after participating in the module the students should have obtained the knowledge to answer the questions.

The item discrimination of the green chemistry questionnaire was found to be fair for the pretest and good from the posttest results. Item discrimination is the ability of an item to differentiate among students on the basis of how well they know the material being tested (Thorndike et al., 1991). Items with low discrimination indices are often ambiguously worded and should be examined. The posttest shows the true measure of item discrimination because after
participating in the module the students should have obtained the knowledge to answer the questions.

The dependent samples t-test conducted for pretest and posttest scores for the subsections of the CAEQ indicated that the green chemistry intervention effectively improved students’ attitudes about chemist, chemistry research, and chemistry jobs.

The dependent samples t-test conducted for pretest and posttest scores for the green chemistry questionnaire indicated that the green chemistry intervention effectively improved students’ green chemistry knowledge base.

In summation, *Cleaning Our World through Green Chemistry* improved students attitudes about chemistry (chemist, chemistry jobs, and chemistry research). The students showed knowledge gains following the presentation of the module. The students made connections between science and their own lives after completing the module and it’s activities.

### 4.8 Implications and Future Work

The design and implementation of *Cleaning our World Through Green Chemistry* learning module has shown that green standards can be added into the curriculum. Additionally, educators should be creative when developing learning activities to engage students by including real-world studies.

In the future, we would like to broaden our data by including more subjects from various races, ethnicities and SES groups. I would also like to develop a high school green chemistry course.

### 4.9 Conclusion

The synthesis of green paint has been used to captivate students’ interest in previous studies (Blatti, 2017). Using a similar approach, this module has been used in high school environmental
science and chemistry classrooms to boost students’ interest in chemistry and teach them about green chemistry. This module emphasizes the remediation of hazardous wastes. After participation in this interactive chemistry module, the students showed attitudinal changes and green chemistry knowledge gains. The students showed enjoyment after participating and they took away essential points from the presentation that may change their way of life or how they think of chemistry.

The green chemistry learning activities created using the *Elements of Effective Science Instruction* presented to secondary school students showed premature success. This shows that more green chemistry topics and activities should be added into the curriculum to educate our future chemist on sustainable practices. A cool hands-on experience is not enough. Students enjoy working through real-world problems and creating solutions. Activities/labs should be created keeping the *Elements of Effective Science Teaching* at the forefront of its design. These elements provide guidelines of how to motivate our students to learn science. It also provides the real-world application our students need to see how science affects them.

5 CONCLUSION

The research presented in this dissertation has been done to gain skills that can be used to educate high school and college students. This dissertation consisted of three chapters: Small molecule inhibitor discovery, group quiz analyses, and design and implementation of a high school learning module. Small-molecule inhibitor discovery provided context and deep chemistry understanding. The group quiz analysis shows that high level dialogue and full group participation is necessary for effective group work. The module *Cleaning our World through Green Chemistry* shows that adding real-world context to chemistry lessons boost attitudes about chemistry and chemists. Using the analysis of effective engagement types curricula can be developed to engage students and help them gain the most out of their educational experience. Similarly, the results
from the green chemistry module implementation can be used to design activities for high school students. Lastly, the knowledge behind the benchwork can be used to expand teaching topics and techniques as a science teacher.

REFERENCES


Howard, J. (2019, January 22, 2019). Record number of Americans 'very worried' about climate change, report finds.


APPENDICES

Appendix A Spectra

Compound 2a $^1\text{H}$ NMR
Compound 2a $^{13}$C NMR
Compound 2a Mass Spec
Compound 3c $^{13}$C NMR
Compound 3c Mass Spec
Compound 4a $^1$H NMR

Compound 4a $^{13}$C NMR
Compound 4a Mass Spec
Compound 4b Mass Spec

RT: 2.41-3.09
AV: 50
NL: 6.99E7

T: FTM + ESI POS [100.00-1000.00]
Appendix B Survey Materials

PRE-SURVEY

Creating a Cleaner World Through Green Chemistry

School Name:
Date:
Grade (circle): 9th 10th 11th 12th
Gender (circle): Female Male
Race (circle): Asian African American Hispanic Native American/Alaskan White Multiracial Other: 

Chemists are....
unfit ___________ athletic
socially unaware ______________ socially aware
environmentally unaware ___________ environmentally aware
fixed in their ideas ______________ flexible in their ideas
only care about their results ___________ care about the effects of their results
unimaginative ______________ imaginative
indifferent ______________ inquisitive
impatient ______________ patient

Chemistry Research....
harms people ______________ helps people
decreases quality of life ___________ improves quality of life
creates problems ______________ solves problems
causes society to decline ___________ advances society

Chemistry Jobs....
easy ______________ challenging
repetitive ______________ varied
boring ______________ interesting
unsatisfying ______________ satisfying
tedious ______________ exciting
PRE-SURVEY

1. Green chemistry aims to?
   a. Design chemical products and processes that maximize profits
   b. Design safer chemical products and processes that reduce or eliminate the use and generation of hazardous substances
   c. Utilize non-renewable energy
   d. Design chemical products and processes that work most efficiently
   e. I don’t know

2. Which of the following is the greenest solvent?
   a. Ethanol
   b. Water
   c. Benzene
   d. Methanol
   e. I don’t know

3. ______, or VOCs, have been replaced and were banned in some paints?
   a. Versatile Organic Compounds
   b. Volatile Organic Components
   c. Volatile Organic Compounds
   d. Versatile Odorless Components
   e. I don’t know

4. Atom economy refers to:
   a. A way to measure the atoms wasted when making a chemical
   b. The amount of money that is spent on purchasing atoms
   c. The total amount of atoms used to make a chemical
   d. The amount of money made on the atoms
   e. I don’t know

5. A catalyst increases the rate of a reaction by which of the following mechanisms?
   a. Elevating the temperature of the reaction
   b. Making the reactants less energetically stable
   c. Lowering the activation energy
   d. Raising the activation energy
   e. I don’t know

6. What components are used in making paint?
   a. Binder
   b. Pigment
   c. Solvent
   d. All of the above
   e. I don’t know
POST-SURVEY

Creating a Cleaner World Through Green Chemistry

School Name: 
Date: 
Grade (circle): 9th 10th 11th 12th
Gender (circle): Female Male
Race (circle):
Asian African American Hispanic Native American/Alaskan White Multiracial Other: 

Chemists are....

unfit ____________________ athletic
socially unaware _______________ socially aware
environmentally unaware _______________ environmentally aware
fixed in their ideas ____________________ flexible in their ideas
only care about their results _______________ care about the effects of their results
unimaginative _______________ imaginative
indifferent _______________ inquisitive
impatient _______________ patient

Chemistry Research....

harms people _______________ helps people
decreases quality of life _______________ improves quality of life
creates problems _______________ solves problems
causes society to decline _______________ advances society

Chemistry Jobs....

easy _______________ challenging
repetitive _______________ varied
boring _______________ interesting
unsatisfying _______________ satisfying
tedious _______________ exciting
POST-SURVEY

1. Green chemistry aims to?
   a. Design chemical products and processes that maximize profits
   b. Design safer chemical products and processes that reduce or eliminate the use and generation of hazardous substances
   c. Utilize non-renewable energy
   d. Design chemical products and processes that work most efficiently
   e. I don’t know

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3. ________ or VOCs, have been replaced and were banned in some paints?
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   e. I don’t know

6. What components are used in making paint?
   a. Binder
   b. Pigment
   c. Solvent
   d. All of the above
   e. I don’t know
POST-SURVEY

Feedback

Are there any improvements that should be made to “Cleaning our World through Green Chemistry” the module?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

What memory stands out the most from “Cleaning our World through Green Chemistry” the module?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________
Appendix C Cleaning our World Through Green Chemistry PowerPoint
Survey

This part of the questionnaire investigates the perceptions you have about chemistry and related topics. For example: If you feel chemistry is mostly about the study of natural substances, and only a little bit about the study of synthetic substances then you would answer the following questions as shown:

Chemistry  Natural Substances _√_ Synthetic Substances

Creating a Cleaner World Through Green Chemistry

By: Joy Ballard
Hazardous Waste

Each person in the United States produces an average of 4 pounds of household hazardous waste each year for a total of about 530,000 tons/year.
BREAKING NEWS FROM THE CDC!!!!

SAN JUAN, Puerto Rico (AP) – The pace of deaths quickened on Puerto Rico immediately after Hurricane Maria, well beyond the number of deaths caused by the Category 4 storm. Officials in the U.S territory on Wednesday reported at least 30 deaths per day attributed to the environment and health of individuals.
Thousands of pounds of toxic waste were disturbed in the storm and allowed to escape landfills and take a new home in the flood water running through the city. The CDC has begun their initial investigation and has placed a banner of national emergency to figure out the cause of this great disparity.
Public Service Announcement
!!!!!!

WE NEED YOUR HELP! PLEASE SUBMIT ANY POSSIBLE INDUSTRIES IN SAN JUAN, PUERTO RICO, WHOSE WASTE COULD HAVE SERIOUS EFFECTS ON THE HEALTH OF INDIVIDUALS!
Enrique: “I think we should do something!”

Gabriela: “What do you mean?”

Enrique: “I think we should help the CDC figure out what’s causing all these deaths.”

Santiago: “I think it’s that huge coal ash pile in Guayama. It’s no secret that waste has been causing our fellow Puerto Ricans health problems for years.”

Yajaira: “I saw a lot of trash floating around when we were first hit. Do you think plastics and other materials could be causing this?”

Gabriela: “That is a good point, it could be the cause. Also, I think the waste from PR Paint Specialist may have been in the water as well. I saw many swirls of colors in the flood water near my home.”

Enrique: “Great points let’s do some research and come together tomorrow to discuss.”

**Solvents**

- Liquids capable of dissolving other substances
- They can dissolve grease, oil, or paint
- They can be used to clean electronics, automotive parts, tools, engines, and to make other chemicals
Do we know any examples of solvents?

**Acetone**

Can we predict the impact our wastes are going to have on the environment?

**Safety Data Sheet**
- Shows the hazards of chemical
- Identifies Composition of chemical
- Outlines First-Aid Measures
- Outlines Accidental Release Measures
- Provides information on how to handle and store chemical
How Hazardous is it?

You decide!!

How Hazardous is it?

Water

- Liquid
- Colorless
- Not a hazardous substance
- No explosive properties known
- No possibility of hazardous reactions known
- No known significant effects or critical hazards
The following day the students meet up to discuss their research.

**Enrique**: “Santiago, I did some research on the coal piles and you are right. The coal ash is very toxic, and it could be causing the mass deaths around the island.”

**Gabriela**: “The chemicals in paint making can be emitted, and have pretty bad health effects.”

**Yajaira**: “I don’t think plastics could have caused deaths so rapidly.”

**Santiago**: “Okay we have the facts, so how do we figure out the actual cause?”
BREAKING NEWS FROM THE CDC!!!!

VOC’S WERE FOUND IN THE FLOOD WATER. BUT, WHERE DID THEY COME FROM?
VOC
VOLATILE ORGANIC COMPOUNDS

- Organic compounds that are emitted as gases from certain solids or liquids
- Used in many household products
- Can have serious health effects such as:
  - Damage to liver, kidney, and central nervous system

What are Organic Compounds?

Carbon containing compounds associated with life processes

![Carbohydrate Isomers](image)
Enrique: “Did you guys see the update?! Gabriela, you were right! The paint from PR Paint Specialist was the cause of the VOC’s invasion in our waters! Paints are one of the many household items that contain harmful volatile chemicals.”

Gabriela: “Wow, who would have known an everyday product that we see everywhere could have such dramatic effects on our health?”

Santiago: “Great job Gabriela, you may be a scientist one day ; )”
What can scientists do to prevent something like this from happening in the future?

**Green Chemistry vs. Pollution Clean-up**

**Reduction**
- Keeps hazardous materials away from environment
- Lessens/eliminates hazard from existing in products

**Remediation**
- Recycling
- Safe disposal
- Treatment of hazardous waste
What is Green Chemistry?

Green Chemistry is the design of chemicals that reduce or eliminate hazardous substances.

12 Principles of Green Chemistry

Outlines what would make a greener chemical, process, or product.
Atom Economy

A way to measure the atoms “wasted” during a chemical reaction

Atom Economy

2 Children
1 wants French Fries
1 wants Potato Wedges
Atom Economy

Atom Economy Activity
Ball & Stick Model
Atom Economy =
\[
\frac{\text{(Mass of atoms in desired product)}}{\text{(Mass of atoms in reactants)}} \times 100\%
\]

=_______%

Atom Economy is a way to measure the atoms “wasted” during a chemical reaction. Higher % = Higher Atom Economy

Catalyst

A substance that speeds up a chemical reaction that would normally happen slowly by LOWERING THE ACTIVATION ENERGY
How can we apply Green Chemistry to create safer paint for future use?

Components of Paint
Components of Paint

Pigment
- Coloring material
- Usually powder
  - ex. Clays

Chromium Oxide Green
Yellow Iron Oxide

Components of Paint

Binder

- Holds the pigment particles together
- ex. Wax, Oil, Gum
Components of Paint

- Volatile Liquid
- Keeps solid components of paint in suspension
- Helps paint stick to surface
Let’s make our own “green” paint!

**Milk Paint Experiment**

**Materials**
- Vinegar
- 1-quart skim milk
- Sieve
- Cheesecloth
- Dry color pigment

**Procedures**
1. Mix 1 cup of vinegar and 1 quart of skim milk in a large bowl to induce curdling.
2. Line the sieve with cheesecloth.
3. Pour the mixture (curdled milk) through the sieve.
4. Add 4 tablespoons of dry color pigment to curd.
5. Stir until pigment is evenly dispersed.
Appendix D Photo Consent Form

Sir/Madam,

This is to certify that Georgia State University’s Bio-Bus program has the right to use and publish photographs or videos of the students or their work of Shiloh High School, for editorial, public relations, or institutional advancement purposes without restriction and to copyright same. I hereby release Georgia State University’s Bio-Bus program, its representatives and assigns from all claims and liability relating to said photographs taken on the date indicated below.

_________________________  _________________________
(Printed name)  (Signature)
Appendix E Code Book

Code Book

I. Introduction
   a. Overview of Coding Categories

II. Categories
   a. Collaboration
      i. Argumentation
      ii. Idea Swapping
      iii. Verification of Answer
      iv. Affirmation
      v. Restating
      vi. Help Seeking
         1. Closed Questioning
         2. Open Questioning
      vii. Road Block
   b. Group Dynamics
      i. Peer Organization (Leading)
      ii. Engagement-Productive vs Passive
      iii. Peer Domination
      iv. Aggressive engagement (disruptive)
      v. Encouragement
      vi. Observing
      vii. Working Independently
      viii. Excluded
      ix. Withdrawal
      x. Off-Task
Overview of Coding Categories

1. **Group Engagement.** The group engagement category refers to the manner in which students work together solve problems.

2. **Group Dynamics.** Group Dynamics refers to the interactions between students while completing assignments together.

**Group Engagement**

*(Interactions that help students solve problems)*

**Argumentation**

When students make a claim and provide reasoning or support of an idea, action, or theory.

Example: Lisa says, “I think it’s R configuration *because* the oxygen connected to carbon has a higher priority than just carbon connected to the carbon atom, first its oxygen, then carbon connected to another carbon, then carbon connected only to hydrogens, and then the hydrogen by itself so it’s clockwise or R configuration.”

Lisa provided a claim: R configuration
Lisa provided reasoning/support for her claim: the oxygen connected to carbon has a higher priority than just carbon connected to the carbon atom, first its oxygen, then carbon connected to another carbon, then carbon connected only to hydrogens, and then the hydrogen by itself so it’s clockwise or R configuration

**Idea Swapping**

When students provide information to help solve a problem.

Exchanging chemistry content knowledge to explain the topic.

Example: (The students try to figure out whether the reaction is SN1 or SN2.) Erica says “SN1 occurs in two steps and SN2 occurs in one step.” Tonya adds “SN1 reactions generally have a weak nucleophile.” Brittany agrees and adds “This is right and SN2 reactions have strong nucleophiles that generally bear a negative charge.” Erica says “Okay since the nucleophile here is KCN and there is little steric hindrance, we can assume that this is an SN2 reaction.”

The students input their knowledge about a topic to come up with facts that will help solve the problem.

**Verification of Answer**

When students state their answers and wait for confirmation or affirmation from other group members.

Example: Stephanie asks “This is an alkane, right?” Brittany answers “yes.” Students ask simple question to confirm the answer that they believe is true.

Stephanie: Asks for verification
Brittany: Confirms answer
Affirmation
When students provide feedback about the correctness of the answer or ideas leading to the answer.

Example: Stephanie asks “This is an alkane, right?” Brittany answers “yes.” Students ask simple question to confirm the answer that they believe is true.

Brittany: Provides affirmation by stating “yes”
Stephanie: Asks for verification

Restating
When a student restates the question out loud for the group.

Example: Student reads the question listed word for word out loud instead of reading it to his/herself.
Chelsea states “Classify each reaction as SN1, SN2, E1, or E2 using the nucleophile and solvent listed.”

Help Seeking
Behaviors and statements regarding students seeking help from other students or instructor.

Closed Questioning
When students ask questions that initiate yes/no responses.

Example: Tori asks “Would this substrate be sterically hindered?” Ashley answers “No.” The question asked did not elicit further explanation.

Brittany asks “Would this substrate have a stable carbocation?” Tiffanie answers “Yes.” The questions asked did not elicit further explanation.

Open Questioning
When students ask questions often in “how” and “why” form that prompt group members to explain.

Example: Tori asks “Would this substrate be sterically hindered?” Ashley answers “No.” Tori asks “why not?” Ashley answers “Because it is a primary substrate there are no other groups blocking the backside attack, and thus the reaction would proceed quickly.”

Brittany asks “Why would this substrate have a more stable carbocation?” Tiffanie answers “Because this carbon atom is tertiary or connected with three other atoms that it can distribute the positive charge to, the more the positive charge can be spread out the more stable it is.”
Road Block
A moment when students are not sure how to begin to solve the problem, or how to finish solving the problem.

Example: Road blocks are seen once students begin a problem or have been working on a problem for a while and cannot figure out how to answer it.

Group Dynamics (the processes involved when people in a group interact with each other)

Peer Organization (Leading)
When a student provides a proposed outline or format to undergo an activity/quiz. When a student moves focus back to the activity, when the group may have gotten off topic.

Example: Tiffany says, “First I think we should outline the properties of each reaction and then determine which one fits.” Tiffany is proposing a plan of action to answer the question.

Students laugh at off task comment. Seema says “I think we should get back to the question.” Brittany says, “Yes let’s focus.” Both ladies are trying to put the focus back on the topic at hand after a brief off-task moment.

Peer Domination
When a student takes over in the group and is solely providing the conclusions he/she thinks are correct without consulting others.

This student may constantly provide the answers to the questions, even sometimes undermining other group members input.
Example: Jill says “I think I remember this from class, the answer would be the elimination product.” Nicole (peer dominator) responds, “Are you sure, I guess we can go with it, since she says she remembers it from class” in a very condescending fashion. This response causes Jill to rescind her answer and show uncertainty of the answer.

Aggressive engagement (disruptive)
When a student pursues one’s thoughts and theory’s forcefully.

This category is different from the previous peer domination category because now the student may be very forceful, and start an argument with other group members if they try to challenge the answer they pose.

Encouragement
When a student gives another student support, confidence, or hope about their abilities.

In group settings sometimes students may be reluctant about the answers they think are correct. Sometimes in this situation other students can offer encouragement to such student.

Observing
When students observe others solving problems and do not offer any input or assistance; When students accept or allow others to form conclusions without trying to add their own thoughts and ideas to assist in the process.

**Working Independently**
When students work on the problem alone before discussing answers within the group.

**Excluded**
When a student is dismissed by a team member or the rest of the group.

Students in the group may ignore one student or not ask the student for any input towards task at hand.

**Withdrawn**
When a student shows no interest in the topic at hand and is mostly off-task during the duration of the activity.

**Off-Task**
When students are doing or talking about things that are not on topic with the subject/activity at hand.
Appendix F IRB Approval GSU

INSTITUTIONAL REVIEW BOARD

Mail: P.O. Box 3999
Atlanta, Georgia 30302-3999
Phone: 404/413-3580

In Person: 3rd Floor
58 Edgewood
FWA: 00000129

July 26, 2019

Principal Investigator: Suazette Mooring

Key Personnel: Boozer, William S, Ph.D.; Granville, Harley; HAMELBERG, DONALD; Hendrick, Robert; Kilpatrick, Nancy; Mooring, Suazette; Ogletree, Susan; Yancey, Joy D

Study Department: Chemistry

Study Title: Student Engagement in a Community-based, Blended Learning Environment: Perspectives from a Minority Serving Institution

Funding Agency: National Science Foundation

Review Type: Expedited Continuing Review Category 6, 7

IRB Number: H17042

Reference Number: 355913

Approval Date: 07/26/2019

Expiration Date: 07/25/2020

The Georgia State University Institutional Review Board (IRB) reviewed and approved the above referenced study in accordance with 45 CFR 46.111. The IRB has reviewed and approved the research protocol and any informed consent forms, recruitment materials, and other research materials that are marked as approved in the application. The approval period is listed above. Research that has been approved by the IRB may be subject to further appropriate review and approval or disapproval by officials of the Institution.

Federal regulations require researchers to follow specific procedures in a timely manner. For the protection of all concerned, the IRB calls your attention to the following obligations that you have as Principal Investigator of this study.

1. For any changes to the study (except to protect the safety of participants), an
Amendment Application must be submitted to the IRB. The Amendment Application must be reviewed and approved before any changes can take place.

2. Any unanticipated/adverse events or problems occurring as a result of participation in this study must be reported immediately to the IRB using the Unanticipated/Adverse Event Form.

3. Principal investigators are responsible for ensuring that informed consent is properly documented in accordance with 45 CFR 46.116.
   - The Informed Consent Form (ICF) used must be the one reviewed and approved by the IRB with the approval dates stamped on each page.
   - A Waiver of Documentation of Consent has been approved for this study in accordance with the requirements set forth in 45 CFR 46.117 c.

4. For any research that is conducted beyond the approval period, a Renewal Application must be submitted at least 30 days prior to the expiration date. The Renewal Application must be approved by the IRB before the expiration date else automatic termination of this study will occur. If the study expires, all research activities associated with the study must cease and a new application must be approved before any work can continue.

5. When the study is completed, a Study Closure Report must be submitted to the IRB.

All of the above referenced forms are available online at http://protocol.gsu.edu. Please do not hesitate to contact the Office of Research Integrity (404-413-3500) if you have any questions or concerns.

Sincerely,

Cynthia A. Hoffner, IRB Chair
NOTIFICATION OF CONTINUING REVIEW APPROVAL

PI: Leyte Winfield
TITLE: DUE 1626002: Collaborative—Student Engagement in a Community-based, Blended Learning Environment: Perspectives from a Minority Serving Institution
DATE: July 24, 2019
Review Type: Continuing Review
IRB Protocol #: 7A21E4
This approval is valid from 06/21/2019 until 06/20/2020

Your research proposal referenced above and the associated informed consent process was reviewed and APPROVED by the Institutional Review Board.

Your approval period is noted above. Thereafter, continued approval is contingent upon the submission of a renewal form that must be reviewed and approved by the Institutional Review Board prior to the anniversary or expiration date of this study. Any serious reactions resulting from this study should be reported immediately to the Committee, to the Departmental Chairperson, and to any sponsoring agency or company. Approval is granted based upon your agreement to abide by the policies and procedures of Spelman College with regard to use of human subjects in research and to keep appropriate records concerning your subjects.

Failure to receive a notification that it is time to renew does not relieve you of your responsibility to provide the IRB with a “Request for Renewal” in time for the request to be processed and approved before your expiration date.

Please note that this protocol has been assigned the above referenced IRB protocol number. All inquiries and correspondence concerning this protocol must include: 1) The IRB Protocol number, 2) Name of the Principal Investigator, and 3) Full Title of Study.

If you have any questions or concerns or do not agree to the terms of the approval letter, please contact Mark Lee (marklee@spelman.edu) IRB co-chair, at 404-270-5718, or Shani Harris (sharrisp@spelman.edu) IRB co-chair, at 404-270-5645 or go to the Spelman College website to review IRB guidelines and procedures.

Sincerely,

Mark E. Lee, Ph.D., Co-Chair
Spelman College Institutional Review Board

Shani Harris, Ph.D., Co-Chair
Spelman College Institutional Review Board

Spelman College  350 Spelman Lane SW  Box 2022  Atlanta, Georgia 30314-4399
Continuing Review Approval Notification

Your signature below indicates that you understand the terms of your approval. Please sign below and return this document to the Office of Sponsored Programs, Science Center, Room 342, Spelman College (Fax: 404-270-5884).

Leyte Winfield, Ph.D.
Printed Name
Principal Investigator
Signature
Principal Investigator

PI: Leyte Winfield
TITLE: DUE 1626002: Collaborative—Student Engagement in a Community-based, Blended Learning Environment: Perspectives from a Minority Serving Institution
DATE: July 24, 2019
Review Type: Continuing Review
IRB Protocol #: 7A21E4
This approval is valid from 06/21/2019 until 06/20/2020
Appendix H Quiz Questions

Group Quiz 2
Conformations

Take a picture of your group roster and insert it here.

- From the menu bar on the left, select the plus (+) sign under the hand.
- Select picture.
- Select “ok”
- Take the photo.
Define the anti conformation.

Draw a template to illustrate the anti conformation of an alkane.
Draw the most stable anti conformation of heptane for the rotation around the C3-C4 axis.

Compare the most stable anti and the least stable eclipsed conformations of heptane for the rotation around the C3-C4 axis.
Explain the stability of the least stable eclipsed conformations of butane defined for the rotation around the C2-C3 axis in comparison to that of octane defined for the rotation around the C4-C5 axis.

Develop an analogy that explains why the stability of a molecule will decrease as the two largest substituents begin to interact.
Group Quiz 3
Alcohol Substitution

Take a picture of your group roster and insert it here.

• From the menu bar on the left, select the plus (+) sign under the hand.
• Select picture.
• Select “ok”
• Take the photo.
1. This quiz focuses on how to generate good leaving groups from alcohols, ethers, thioles, and thioethers. To compare the trend in leaving group ability among atoms in the same column of the periodic table, the length of the bond should be considered. The bond lengths for C-OH and C-OR are given below along with the pKa’s of the leaving group created by each molecule. Draw the possible leaving group and enter the pKa for each molecule. Write the responses on your individual sheets for easy reference on the next questions.

<table>
<thead>
<tr>
<th>Functional Group</th>
<th>Electrophile</th>
<th>Bond Length</th>
<th>pKa of Leaving Group</th>
<th>Leaving Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcohol</td>
<td>OH</td>
<td>1.424</td>
<td>15.7</td>
<td></td>
</tr>
<tr>
<td>Ether</td>
<td>OCH₃</td>
<td>1.43</td>
<td>17.1</td>
<td></td>
</tr>
<tr>
<td>Thioether</td>
<td>SH</td>
<td>1.824</td>
<td>7.04</td>
<td></td>
</tr>
</tbody>
</table>

Problem #1 continued – Based on the data from the table completed for problem #1:

a) Explain the difference between an alcohol and an ether in terms of leaving group ability.
Problem #1 continued – Based on the data from the table completed for problem 1:

b) Explain the difference between an alcohol and an ether in terms of reactivity in a nucleophilic substitution reaction.

c) Describe the relationship between bond-length, pKa, leaving group ability, and reactivity.
2. Based on your responses to number 1, which reaction will occur the fastest?

\[
\begin{align*}
&\text{SH} \quad \text{H}^+ \text{Nu} \quad \text{Nu} \\
&\text{OH} \quad \text{H}^+ \text{Nu} \quad \text{Nu} \\
&\text{OCH}_3 \quad \text{H}^+ \text{Nu} \quad \text{Nu}
\end{align*}
\]

3. Which compound would react the fastest with concentrated HCl to yield an alkyl halide? Explain.

a. 2-pentanol
b. 2,2-dimethyl-1-butanol
c. 3-methylcyclopentanol
d. 2-methyl-2-pentanol
4. Predict the product for each reaction below.

a. \[\text{CH}_3\text{CH}_2\text{OH} + \text{SOCl}_2 \rightarrow \]

b. \[\text{OH} + \text{PBr}_3 \rightarrow \]
4. Predict the product for each reaction below.

\[ \text{C} \quad \text{[structure]} \quad + \quad \text{HCl} \quad \rightarrow \]

5. Draw the product(s) for the reaction shown.

a.

\[ \text{[structure]} \quad \xrightarrow{1. \text{NaH}} \quad \xrightarrow{2. \text{CH}_3\text{CH}_2\text{CH}_2\text{Cl}} \]

b. What is the name of the reaction?
5c. Explain in words, the mechanism of the product formed in the reaction on the previous slide.