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ORIGINAL ARTICLE

The Effectiveness of POGIL on High School Student Chemistry End-of-Course Examinations

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ABSTRACT

The purpose of this quantitative, causal-comparative research study was to determine if and to what extent there were differences in chemistry end-of-course (EOC) examination scores between high school chemistry students taught using POGIL pedagogy and non-POGIL pedagogy in the state of Utah. Piaget's cognitive development theory and Johnstone's cognitive load theory served as the theoretical foundations. A large, public school district in the state of Utah provided the deidentified, archival data for this study, which consisted of students that took a chemistry course and chemistry EOC examination in 2015−2016 or 2016−2017. The research question sought to find whether there was a statistically significant difference in chemistry EOC examination scores for high school students in both groups. A one-way ANOVA demonstrated a statistically significant difference between the POGIL and non-POGIL student groups on the dependent variable of chemistry EOC examination scores, $F(1, 314) = 29.91$, $p < 0.001$, partial $\eta^2 = 0.087$, ($p < 0.05$). This study supported POGIL pedagogy as an effective instructional strategy for improving student chemistry EOC examination scores.

KEY WORDS: Chemistry EOC examination; high school chemistry; POGIL

INTRODUCTION

The main goal of the educational system in the United States has been to improve student performance that will produce high school graduates who are able to compete in the global workforce (Sargent, 2017). Unfortunately, America students are behind their European and Asian counterparts in both science and mathematics (National Science Board, 2018; USDOE, 2016). The result from this lack of American performance has produced a huge movement in the Science, Technology, Engineering, and Mathematics (STEM) pipeline, from kindergarten through college, aimed at educating students by enhancing their essential academic skills while encouraging students to pursue STEM majors in college that will lead to STEM careers after college (Eddy and Brownell, 2016; Kelly, 2016). According to Richardson (2017), approximately 75% of the fastest-growing occupations require a postsecondary degree with STEM-related careers leading the field. One of the main challenges facing United States companies will be a lack of qualified STEM workers necessary to replace the positions of retiring STEM workers (Berg, 2018).

Giffi et al. (2015) have reported that this potential shortage of qualified STEM workers could create over 2 million job vacancies during the next decade. Noonan (2017) has stated that STEM-qualified workers are in high demand, and that STEM occupations in the United States are projected to increase 8.9% from 2014 to 2024. According to Jackson et al. (2017), the STEM workforce in the United States will have a projected increase of 17% in available STEM jobs for the same time frame. Despite these projections for a national STEM worker shortage, there are some researchers that dispute a STEM occupation labor shortage in the United States (Cappelli, 2015; Smith, 2017).

The United States reported a persistent shortage of STEM workers in 2016 that resulted in a shortage of 3 million STEM workers (New American Economy, 2017); however, STEM jobs accounted for only 6% (8.6 million jobs) of the overall employment (149 million jobs) in the United States economy for 2018 (Bureau of Labor Statistics, 2018). The perceived STEM worker shortage could be caused by slowed pay growth when STEM workers change jobs or leave current high-skill occupations for better paying positions (National Science Board, 2015). There is also a perception that the United States has a gap between higher education and the needs of industry to hire enough recent STEM college graduates (Heaton et al., 2016). Predictions of widespread emerging technologies may cause the loss or shortage of tens of millions of jobs in the United States STEM workforce (Winick, 2018), with some estimates as high as 47% of the United States jobs being lost due to automation (Frey and Osborne, 2017), and some estimates as low as 9% of the United States jobs at risk (Arntz et al., 2016).

Randazzo (2017) stated that one of the critical equity issues facing American students is the lack of access to STEM math and science classes, especially for students in urban and rural communities, which is reflected in these students' low college entrance rates. This lack of access may have far-reaching effects on the United States economy, technological superiority, and national security (Hanson and Slaughter, 2017; Randazzo, 2017; White et al., 2019) and may be one of the primary factors for the significant decline in American students' math and science performance compared with other countries (Mattern et al., 2015).

It is a fact that American high school students are scoring lower in math, science, and STEM benchmark rates (ACT, 2016), and American high schools have not been adequately preparing students for the 21st century workforce as evidenced by the United States becoming one of the leading nations in high school dropout rates (Allensworth, 2017). About half of American students do not successfully complete high school, and those that do complete high school and are able to advance to college usually require remedial coursework and many do not graduate from college (Allensworth, 2017). The United States ranks lower than other developed countries in math (38th), science (24th), high school completion rate (20th), and the ratio of college students earning undergraduate degrees in science or engineering (27th) (Desilver, 2017).

The United States was rated with an overall education proficiency grade of "C" in an educational report card comparing all 50 states and Washington, D.C. versus the rest of the world (Education Week Research Center, 2015). This average proficiency grade has generated valid concern, among education and political decision-makers, regarding the ability of the United States to compete successfully in a global economy (Mau, 2016). Although the United States is still considered a world leader in innovation, other nations are producing a higher skilled workforce that outpaces the American workforce (Sargent, 2017). A potential fix to this problem might be an increase in STEM education that could produce a higher quality and competitive American workforce. However, this solution will require significantly increased investment in STEM education to entice students to enter STEM careers (Mau, 2016). Researchers agree that American students lack necessary STEM skills and that there is a need to develop and implement innovative STEM education programs to better prepare American students for STEM careers (Dejarnette, 2016; Sargent, 2017).

Educational researchers and policy-makers worldwide have focused on promoting student success in STEM areas of study (Skinner et al., 2017), which is essential to better student preparation for the global STEM workforce (World Economic Forum, 2017). Unfortunately, most K-12 STEM education seems to focus on theory instead of real-world learning experiences with practical applications for students, which leads to a larger gap and disconnect among STEM disciplines (Nadelson and Seifert, 2017).

The implementation of new and innovative learning strategies may help bridge this disconnect for students and motivate them to pursue STEM majors and careers in college. One such innovative learning strategy is known as Process-Oriented Guided Inquiry Learning (POGIL). The POGIL model is a student-centered, inquiry-based strategy that was developed by Farrell and Moog (2014) to help their college chemistry students perform better in their 1st year chemistry classes. POGIL has been shown to be effective at both the college and secondary levels at increasing higher-level reasoning skills and improving content mastery for students in chemistry and other science subjects (Balasubramaniam, 2015; Barthlow and Watson, 2014; DeGale and Boissele, 2015; DeMatteo, 2016; Farrell and Moog, 2014; Meeks, 2015).

POGIL is an instructional strategy that is student centered and provides students an opportunity to nurture and develop the processing skills for essential content which includes time management, self-assessment, communication skills, teamwork building, problem-solving skills, and deductive reasoning (Vishnumolakala et al., 2017). POGIL incorporates the learning cycle with an active learning format, that is, both student centered, and effective at developing and enhancing students' critical thinking skills (Haryati, 2018). Unfortunately, many undergraduate students that start STEM programs end up dropping before completing their program, which does not help increase the number of STEM majors in the STEM pipeline (Freeman et al., 2014).

Gehrke and Kezar (2016) conducted a study that included the POGIL Project as one of four undergraduate STEM reform communities that have successfully engaged large numbers of faculty members (4000–10,000) for a sustained period (12–30 years). All four of these communities have made contributions to undergraduate STEM reform using multiple strategies that include the combining public issues in science, dissemination of research-based pedagogies, leadership development, and using data and technology in science education (Gehrke and Kezar, 2016). The POGIL Project has transformed into a nationally recognized professional development and curriculum reform program incorporating the improvement of learning environments focused on student-centered pedagogies. The POGIL community currently supports approximately 65,000 members in both secondary and postsecondary education (Gehrke and Kezar, 2016).

In a meta-analysis study conducted by Walker and Warfa (2017), 21 studies were analyzed that compared POGIL instructional strategies with standardized lecture instructional strategies. The POGIL pedagogy provided process skill improvement opportunities for students during content learning using guided inquiry activities, which produced improved student outcomes in both small and medium classroom environments compared with standardized lecture pedagogy (Walker and Warfa, 2017). Providing students opportunities to develop their process skill abilities improved their scientific practice to solve content-specific problems, increased student success rate, and reduced failure rates for students in POGIL classrooms (Walker and Warfa, 2017). Finally, POGIL classrooms demonstrated passing rates twice as high and reduced the risk of failing the course by approximately 38% versus standard lecture classrooms (Walker and Warfa, 2017).

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Qureshi and Vishnumolakala (2018) examined how POGIL taught pre-med chemistry courses develop student understanding of complex chemistry concepts. Their results showed student understanding of chemistry concepts improved significantly on post-test instruments and that POGIL pedagogy had a positive impact on student understanding of these concepts, and supported student-centered pedagogy methods, like POGIL, can help students better understand complex chemistry concepts more effectively using self-learning groups of student learning materials.

The theoretical foundations for this study included the Cognitive Development Theory and the Information Processing Model. The Cognitive Development Theory (CDT) examines how the human mind progresses through the different stages of cognitive development over time. This theory was developed by Jean Piaget (1973) and assumes that a learner builds on previous knowledge to enhance cognitive development and growth in complexity with increased interactions resulting in more complex understandings, cyclical growth, and maturation (Piaget, 1973). The use of POGIL pedagogy to increase higher-level reasoning skills would support the Cognitive Development Theory that learning is hierarchical and dependent on previous learning to increase content mastery in student learners.

The Information Processing Model (IPM) was developed based the work of Johnstone (1997) and refinement of the Cognitive Load Theory (Chandler and Sweller, 1991) which examines short- and long-term memory. Johnstone (1997) examined how the Cognitive Load Theory (CLT) applied specifically to chemistry learning. He discovered that students attempting to process too much information, which is common in traditional teacher-centered lecture pedagogy, developed an alternative conception (AC) regarding the chemistry content topic. The IPM focuses on the ineffectiveness of traditional, teacher-centered lecture pedagogies, which questions whether a student-centered pedagogy might be more effective at teaching specific chemistry topical subjects (Johnstone, 1997). The use of POGIL pedagogy to increase end-of-course (EOC) chemistry examination scores would support the IPM that a student-centered pedagogy, like POGIL, is more effective at increasing student concept mastery than traditional, teacher-centered lecture pedagogy.

The performance of high school students' chemistry end-of-course (EOC) examinations that were taught using student-centered POGIL instructional strategies and students taught using teacher-centered traditional instructional strategies was investigated in this causal-comparative study. This study evaluated the effectiveness of POGIL pedagogy on chemistry EOC scores to determine whether improved content mastery and higher-level reasoning skills were reflected in student performance on a standardized assessment. There existed a gap in the research literature to determine whether POGIL was an effective instructional strategy for improving high school chemistry student EOC scores. Researchers agree that American students lack necessary STEM skills, and there exists an urgent need to develop and implement STEM programs to better prepare American students for STEM careers (Dejarnette, 2016; Sargent, 2017).

A potential remedy to this situation would include increasing STEM education to produce a higher quality American workforce; however, this will require an increased investment in STEM education and better preparation of students to enter STEM careers successfully (Mau, 2016). The adoption and implementation of POGIL instructional strategies, at the high school level, may help improve this current situation. If the results of this study determine implementation of POGIL strategies as statistically significant at increasing student chemistry EOC scores, the next step could be the creation of a nationwide POGIL implementation revolution leading to a paradigm shift in science teaching strategies to better prepare high school students for STEM degrees and careers. The following research question guided this study: To what extent, if any, does POGIL pedagogy produce a statistically significant difference in high school EOC chemistry scores?

METHODOLOGY

Research Design: Causal-comparative Design

This study examined the effectiveness of POGIL pedagogy on American high school students' chemistry EOC examination scores. Quantitative methodologies emphasize objective measures and utilize statistical analysis of the collected data from questionnaires, surveys, or pre-existing statistical data (Babbie, 2016; Burke-Johnson and Christensen, 2014). Quantitative researchers seek objective data to determine whether variations in mean scores exist and whether any significant relationship exists between variables (Latimer et al., 2011). This study used pre-existing, statistical, deidentified, and archival data from a single public high school district located in the state of Utah. The POGIL test group consisted of a single high school that implemented POGIL instructional strategies during the 2015−2017 academic school years. The non-POGIL test group consisted of another high school, located in the same high school district, that taught the same chemistry curriculum, but did not implement POGIL instructional strategies for the 2015−2017 academic school years.

Furthermore, a causal-comparative study was determined to be the most appropriate research design, for the ex-post facto examination of deidentified archival data, to investigate differences in chemistry EOC examination scores for POGIL and non-POGIL high school students. The researcher ran descriptive statistics to determine mean and standard deviation for the dependent variable (chemistry EOC examination scores) and each level of the independent variable (POGIL vs. non-POGIL pedagogy). Both descriptive and inferential statistics are presented in this study, with descriptive statistics including specific procedures that were used to organize data, and inferential statistics that utilized specific techniques to analyze data and form conclusions about general populations (Gravetter and Wallnau, 2016).

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Research Context

The location selected for this study was a large, public school district, in the state of Utah, which included multiple high schools. Two high schools were selected within this school district and are referred to throughout this study with the acronyms *POGIL high school* and *non-POGIL high school.* Both high schools shared similar demographics including student populations of approximately 2500 students and similar ethnic and special populations. The ethnic populations were comprised of 78% Caucasian, 15% Hispanic, 1% African-American, and 1% Asian students. The special populations included approximately 19% socially-economically disadvantaged (SED), 3% of English-language learner (ELL), and 10% of students with disabilities (SWD) (USBE, 2018). Both high schools had similar Student Assessment of Growth and Excellence (SAGE) chemistry examination proficiencies of 44% for the 2015–2016 school year and 51% for the 2016–2017 school year (Table 1).

Both high schools employed 8–10 science teachers in their science departments with 2–3 of teachers teaching chemistry during the school year. All chemistry teachers taught a common district approved chemistry curriculum to ensure student preparation for the required statewide SAGE chemistry examination administered in the month of March. Chemistry teachers at the POGIL high school utilized POGIL instructional strategies in their classroom while chemistry teachers at the non-POGIL high school utilized traditional instructional strategies in their classrooms throughout the school year.

The selected general population for this study were 11th grade high school students who took chemistry in the state of Utah.

Table 1: Student demographics

Demographic	POGIL high school		Non-POGIL high school	
	n	Percentage	n	Percentage
Student population				
2015−2016 school year	2,199		2,733	
2016−2017 school year	2,280		2,761	
Ethnicity (based on 2016–2017 population)				
Caucasian	1,981	86.9	1,899	68.8
Hispanic	163	7.1	605	21.9
African-American	16	0.7	37	1.3
Asian	19	0.8	45	1.6
Special groups (based on 2016−2017 population)				
English-language learners (ELL)	30	1.3	132	4.8
Economically disadvantaged (ED)	303	13.3	688	24.9
Students with disabilities (SWD)	208	9.1	286	10.4
Student academic performance				
SAGE chemistry examination proficiency (2015−2016)		55.4		31.7
SAGE chemistry examination proficiency (2016−2017)		53.1		48.6

The target population for this study were 11th grade high school students that took chemistry during the 2015−2016 and 2016−2017 school years and who took the SAGE chemistry examination during the same year that they took chemistry. The study sample used in this study was derived through deidentified student archival data obtained from a large, public school district in the state of Utah that met the target population criteria. The data contained a total sample size of 316 student participants (158 POGIL and 158 non-POGIL) and excluded any type of identifiers to ensure anonymity of participants.

Ethical Issues

Ethical considerations for this quantitative, causal-comparative research study were observed to protect all individuals associated with this present study. Since there was no direct contact or interaction with human participants for this study, ethical concerns for harm to individuals were not an issue (Burke-Johnson and Christensen, 2014). This present study was free of any deception or research misconduct to avoid professional issues and STEM education and POGIL instructional strategies are a current societal and educational concern (Burke-Johnson and Christensen, 2014).

This study did not disclose any private or confidential data that would cause ethical concerns. Ethical considerations include maintaining the anonymity of the high schools and school district name to protect specific identities. Since this study used archival student data, there was no need for informed consent from students and parents; however, the researcher needed to obtain informed consent for science teachers who took the online teacher demographic survey. In addition, site approval from the school district to use the deidentified, archival student data, and principal approval at each school site was necessary before conducting the online teacher demographic survey.

The student SAGE chemistry examination scores consisted of a single continuous, interval dependent variable in the form of SAGE chemistry examination scores (684–983). Data compilation consisted of a Microsoft Excel spreadsheet, and high school students were deidentified using an alphanumeric code combination to identify whether students belonged to the POGIL comparison group or the non-POGIL comparison group.

The data did not benefit any individuals or groups, and all data are being stored and disposed of in compliance with research standards. All human rights were respected, and all rules and regulations were followed to create a minimum of confidentiality issues and to avoid any ethical violations.

Quantitative Approach: Causal-comparative Design

A causal-comparative research design was used for the purpose of investigating differences in chemistry EOC examination scores for POGIL and non-POGIL high school students. The dependent variable consisted of chemistry EOC examination scores and the independent variable consisted of the implementation of POGIL pedagogy versus non-POGIL pedagogy for each comparison group.

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Sample

The general population for this study included public high school students who took chemistry during the 2015–2016 or 2016–2017 school year and the chemistry EOC examination during this same time. From this general population, the target population for this study included all public high school students in the state of Utah that took chemistry during the 2015–2017 school years, and the chemistry EOC examination during the 2015–2017 school years. The study sample included high school chemistry students at two different high schools, in the same school district, in the state of Utah. The researcher collected student demographics for both high schools to determine the two comparison groups were similar. Specific high school demographic data were collected from the school district public website and included student population, ethnicity, English-language learner (ELL) population, socioeconomic status (SES) data, special education population (SPED), and graduation rates. The researcher confirmed that the two high schools had similar demographics (Table 1), and convenience sampling was utilized to form the two comparison groups for this study.

Convenience sampling was utilized using the POGIL Project's implementer survey, sent annually to teachers throughout the United States, to collect data on whether teachers implemented POGIL instructional strategies for the previous school year. This survey included teacher name, email, state, school name, school district, and specific subjects taught using POGIL instructional strategies. This POGIL implementer survey was used to identify one of the two high schools that implemented POGIL pedagogy during the 2015–2017 academic school years.

All students in this study sample were 11th grade students, between the ages of 16 and 18 years old, and their grade point averages (GPAs) were evaluated to ensure equal matching of participants for homogeneous subgrouping. This study focused on junior level high school students since this grade level usually takes chemistry before enrolling in more advanced science courses like AP biology or AP chemistry. Students GPAs were matched to control for chemistry EOC examination score performance differences by either matching subjects or homogeneous subgrouping which addressed any potential outliers.

The single independent variable for this study was the presence of POGIL, a categorical, nominal variable consisting of two comparison groups. The first comparison group was high school students taught chemistry using POGIL pedagogy, and the second comparison group was high school students taught chemistry using non-POGIL pedagogy. The dependent variable was the chemistry EOC examination scores, a continuous, interval variable.

Instrument

The SAGE chemistry test is the Utah state assessment administered at the end of the school year, to all high school chemistry students, to measure student academic achievement and concept mastery (USBE, 2018). The SAGE chemistry test was the chemistry EOC examination used for this study, and the terms chemistry EOC examination and SAGE chemistry examination are used interchangeably throughout this study. The SAGE instrument is aligned with the Utah Core Science Standards (UCSS), consists of 54 scored test items, and has a scaled score of 684–983 (USBE, 2018). The scaled cut scores for Approaching Proficient and Proficient categories are set at 820 and 840, respectively, and the SAGE chemistry test proficiency bands are established as below proficiency (<820), approaching proficiency (820–839), proficient (840–864), and highly proficient (865+) (USBE, 2018).

Quantitative Data Analysis

Since this was a causal-comparative study, before assessing the research question, the researcher ran descriptive statistics to determine the mean and standard deviation for the dependent variable (chemistry EOC examination scores) and for each level of the independent variable (POGIL vs. non-POGIL pedagogy). Both descriptive and inferential statistics were analyzed in this study. The process of descriptive statistics included specific procedures to organize data, and inferential statistics utilize specific techniques to analyze data and make conclusions about populations (Gravetter and Wallnau, 2016).

The first step in analyzing descriptive statistics is the examination of central tendency (e.g., mean), variation (e.g., standard deviation), and shape (e.g., skewness and kurtosis). Descriptive statistics help to summarize specific characteristics of high school students that develop participant profiles, frequency tables for the chemistry EOC scores, and frequency distributions to find the number of times a specific score occurs.

Inferential statistics were performed to determine if assumptions were met. The single research question addressed potential differences for a single dependent variable; therefore, a one-way analysis of variance (ANOVA) was utilized to analyze (Laerd Statistics, 2017) if and to what extent there were differences in chemistry EOC examination scores for high school chemistry students taught using POGIL pedagogy, and high school chemistry students taught using non-POGIL pedagogy in the state of Utah. The one-way ANOVA is a parametric statistical test and was run to perform inferential statistical analyses to indicate how likely the present study results could be replicated for an entire population (Fraenkel et al., 2015).

Preparation of the data file

The researcher utilized deidentified student archival data provided by the Director of Assessment for a large, public school district in the state of Utah. The deidentified student archival data were provided on a Microsoft Excel spreadsheet and included an original deidentified student ID number, high school attended by student, course enrollment and exit date, student grade level, student GPA (before taking chemistry), and SAGE chemistry examination raw score (Table 2).

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Table 2: Student archival data

Student deidentified number	School	Course enroll/exit date	Grade level	Cumulative GPA	SAGE chemistry score
MATA-01	POGIL	August 25, 2015–June 04, 2016	11	3.47	846
MATA-02	non-POGIL	August 25, 2015– June 04, 16	11	3.13	833

The next step was to clean the data by deleting participants with incomplete or missing information. Missing data in quantitative studies can cause loss of information, produce increases in standard errors, reduce overall statistical power, and weaken generalization of findings (Peng and Chen, 2018). Missing data are common in quantitative research and are normally found at a rate of 15–20% in educational studies (Peng and Chen, 2018). To clean the data, the researcher visually analyzed the Microsoft Excel document and screened the hard copy printout to identify missing or incomplete data.

While the initial target population from this deidentified student archival data consisted of 3878 potential participants, this number was quickly reduced during the data cleaning process. The Microsoft Excel spreadsheet document was missing SAGE chemistry scores for participants during the 2018–2019 school year, and there were no POGIL high school data provided for the 2017–2018 school year. Consequently, the 2017–2018 and 2018–2019 school years were eliminated from this data file, and the 2015–2016 and 2016–2017 school year participants remained. The researcher continued cleaning the data and removed any participants with missing SAGE chemistry examination scores (2302 participants) or missing GPA (before taking chemistry) values (751 participants).

The remaining POGIL and non-POGIL students were paired by matching their GPAs (before taking chemistry) to ensure the extraneous variable of GPA would not falsely favor either comparison group. POGIL student GPAs that could not be matched exactly with non-POGIL students' GPAs, or to within ±0.10 grade points, were omitted from the total sample size (70 participants). Table 3 shows the POGIL high school and non-POGIL high school student grade point average (before taking chemistry) mean and median values. The POGIL high school mean value was 3.60 compared with the mean value of 3.62 for the non-POGIL high school, and the POGIL high school median value was 3.77 compared with the median value of 3.76 for the non-POGIL high school (Table 3). These nearly identical mean and median values for the POGIL and non-POGIL high schools demonstrate that the GPAs (before taking chemistry) were evenly matched between the two comparison groups to ensure the extraneous variable of GPA would not falsely favor either comparison group.

Finally, any participant who entered the chemistry course more than 4 weeks after the school year began or left more than 4 weeks before the end of the school year were eliminated from the study (61 participants). This step was necessary to ensure that all participants for this study were enrolled in chemistry 70% or more before taking the SAGE chemistry examination in the month of March.

Table 3: School grade point average before taking chemistry

School	N	Mean	Median	SD	Min.	Max.
POGIL high school	158	3.602	3.765	0.443	2.11	4.00
Non-POGIL high school	158	3.620	3.760	0.438	2.04	4.00
Total	316	3.611	3.760	0.440	2.04	4.00

Table 4: Descriptive statistics: Academic performance for the total sample group on chemistry SAGE assessments

School	Mean	SD	N
POGIL high school	845.76	30.434	158
Non-POGIL high school	822.10	45.058	158
Total	833.93	40.173	

After cleaning the data, the final sample size consisted of 158 high school chemistry students that attended POGIL high school and 158 high school chemistry students that attended non-POGIL high school, from the same school district, for a total sample size of 316 participants. This total sample size met the minimum 206 sample size necessary to address the research question and complete the present study with an alpha of 0.05, power of 0.80, and medium effect size of 0.0625. All participants were 11th grade students when they were enrolled in chemistry during their 2015−2016 or 2016−2017 respective school year. The researcher inputted these 316 participants into SPSS version 26 software for inferential statistical analysis. Missing data are usually considered a study limitation; however, it was not considered a limitation in the present study since the sample size was still large enough to conduct the data analysis (Warner, 2013).

Results of Quantitative Analysis

Descriptive statistics

The total sample size for the study consisted of 316 high school participants, which included 158 eleventh grade high school students taught chemistry using POGIL instructional strategies and 158 eleventh grade high school students taught chemistry using non-POGIL instructional strategies for the 2015−2016 and 2016−2017 school years. SAGE chemistry examination scores were available for the entire sample (n = 316) included within the study.

Table 4 presents descriptive statistics for the sample groups in this study which include POGIL high school students' and non-POGIL high school students' academic performance on the SAGE chemistry examination. As shown in Table 4, the POGIL group had a total of 158 participants and the non-POGIL group had a total of 158 participants for a total sample size of n = 316. Closer examination of the descriptive

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statistics shows a higher mean (Mean = 845.76, SD = 30.43) for POGIL students than non-POGIL students (Mean = 822.10, SD = 45.06) for SAGE chemistry examination scores. While the respective groups reflect higher mean scores per category, the indication of statistical significance was determined by the univariate test that followed.

Inferential statistics (ANOVA)

A one-way ANOVA was used to answer the research question regarding whether there was a statistically significant difference between the two comparison groups of high school chemistry students when measuring the dependent variable, chemistry EOC examination scores. The level of significance was set at $p < 0.05$, meaning that there was a 5% chance that a difference existed in the two groups of students when there was not an actual difference. Furthermore, the present study determined whether a mean difference existed between the two groups of students, and an F-test was conducted to provide an overall comparison of whether the means of the two groups of students differed. If the obtained F was larger than the critical F, the null hypotheses would be rejected (Gravetter and Wallnau, 2016).

As presented in Table 5 (tests of between-subjects effects: Univariate ANOVAs), the univariate ANOVA result for the chemistry SAGE examination scores dependent variable was $F(1, 314) = 29.91$, $p < 0.001$, partial $\eta^2 = 0.087$ ($p < 0.05$). The dependent variable, SAGE chemistry examination scores exhibited statistically significant $p < 0.001$.

DISCUSSION

The POGIL group mean value was 23.66 points higher than the non-POGIL group (Table 4), which suggests POGIL students developed higher cognitive development and a more complex understanding based on their higher SAGE chemistry examination mean value. The results of this study supported the Information Processing Model that student-centered pedagogies, like POGIL, are more effective at increasing student performance and content mastery than traditional, teacher-centered pedagogies (Johnstone, 1997). The POGIL group higher mean values for SAGE chemistry examination scores serve as supporting evidence that a student-centered POGIL pedagogy was more effective than a teacher-centered pedagogy at increasing student performance.

The research question null hypothesis stated that there would be no statistically significant difference in the chemistry SAGE examination scores for POGIL high school students and non-POGIL high school students, and the alternative hypothesis stated that there would be a statistically significant difference in the chemistry SAGE examination scores for POGIL high school students and non-POGIL high school students. The univariate ANOVA test indicated a statistically significant difference in the chemistry academic achievement level for the independent groups, demonstrating that there was a statistically significant difference between POGIL high school participants and non-POGIL high school participants on SAGE chemistry examination scores of $p < 0.001$ ($p < 0.05$) (Table 5). The decision was to reject the null hypothesis and accept the alternative hypothesis for the research question.

There were no empirical studies conducted that examined the effects of different instructional strategies on chemistry EOC examination scores, and this study differed from other studies by addressing whether a student-centered instructional strategy, POGIL pedagogy, improved high school student SAGE chemistry scores. This present study addressed this gap in the literature and advanced scientific knowledge by determining that POGIL pedagogy is an effective instructional strategy at improving SAGE chemistry scores for high school students.

The study results advanced scientific knowledge by extending scholarly research on the Cognitive Development Theory which states learners' build on previous knowledge to develop cognitive development, resulting in more complex understandings (Piaget, 1973). This study showed that high school students taught chemistry using POGIL instructional strategies performed significantly better than students taught using non-POGIL instructional strategies, on SAGE chemistry examinations.

The results of this study determined that for this study sample, implementation of POGIL strategies was statistically significant at increasing student SAGE chemistry examination scores. In addition, this present study is the first to publish descriptive statistics with robust parametric statistics demonstrating statistically significant differences between the groups on the dependent variable of SAGE chemistry examination scores.

When examining the results of a causal-comparative research design of study, one must be cautious in formulating generalized conclusions. The causal-comparative design was the most appropriate research study design for this ex-post facto examination of deidentified archival data to investigate

Table 5: Tests of between-subjects effects: Univariate ANOVA

Source	Dependent variable	Type III sum of squares	Df	Mean square	F	Sig.	Partial eta squared
Corrected	Chem SAGE score	44,217.228[a]	1	44,217.228	29.912	0.000	0.087
Intercept	Chem SAGE score	219,759,001.532	1	219,759,001.532	148,663.919	0.000	0.998
School	Chem SAGE score	44,217.228	1	44,217.228	29.912	0.000	0.087
Error	Chem SAGE score	464,163.241	314,308	1478.227			
Total	Chem SAGE score	220,267,382.000	316				
Corrected total	Chem SAGE score	508,380.468	315				

[a]R squared=0.087 (adjusted R squared=0.084)

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differences in SAGE chemistry examination scores for POGIL and non-POGIL students. However, using a causal-comparative research design imposes limits on the researcher's ability to generalize conclusions to a larger population. In other words, the researcher cannot state a definitive cause and effect relationship among the variables examined, nor can a direct conclusion of causation be supported from this single study (Schenker and Rumrill, 2004). The researcher is limited to a statement of observed differences among the variables reviewed for this specific study. This researcher concluded that POGIL students, for this study sample, displayed higher achievement levels that were significantly higher than non-POGIL students on SAGE chemistry examination scores.

Implications

Theoretical implications

The theoretical implications for this study advanced scientific knowledge by extending scholarly research on the Cognitive Development Theory which states learners' build on previous knowledge to develop cognitive development that results in better complex understandings (Piaget, 1973). In addition, the results supported the Information Processing Model that student-centered pedagogies, like POGIL, are more effective at increasing concept mastery and student performance than traditional, teacher-centered pedagogies (Johnstone, 1997).

Practical implications

The practical implications of this study are subject to the results from the SAGE chemistry examination scores used to measure the difference in academic achievement between POGIL students and non-POGIL students. While this study produced statistically significant results regarding the use of POGIL pedagogy to improve SAGE chemistry examination scores, the effect size suggests a contrary view regarding practical implications of using POGIL at the high school level.

The effect size indicator from the ANOVA model is identified as partial eta squared (η^2), which measures the magnitude of a treatment (POGIL pedagogy) effect (Huck, 2012). Unlike significance tests, Pagano (2013) indicated that effect size indices are independent of sample size, and effect size measures are a commonly utilized method in meta-analysis studies that summarize findings from specific areas of research. According to Meyers et al. (2016), the effect size indicator is important because it signifies the magnitude of differences between means of a dependent variable (i.e., SAGE chemistry examination scores) for the two comparison groups (POGIL and non-POGIL groups). Mills et al. (2012) posited that effect size is important as a method to identify the practical strength of conclusions regarding group differences in post-test mean scores.

Partial eta squared (η^2) provided the strength of the difference between the means of high school students who participated in the POGIL instructional strategies and high school students who did not participate in the POGIL instructional strategies on the dependent variable of student performance on SAGE chemistry examination scores. Hewitt and Cramer (2014) suggest effect size indices of approximately 0.20 as typically small effects; of approximately 0.50 as medium or moderate effect, and 0.80 and above are considered a large effect.

The univariate ANOVA results showed statistically significance for SAGE chemistry examination scores ($p < 0.001$); however, the value of the effect size indicator (partial eta squared) suggested that POGIL instructional strategies had a small practical significance ($\eta^2 = 0.087$) for use as an effective intervention for improving SAGE chemistry examination scores (Table 5). Based on the Hewitt and Cramer (2014) guidelines for effect size, the 0.087 value suggests that only 8.7% of the variance for the SAGE chemistry examination scores can be explained by whether students received POGIL or non-POGIL instructional strategies.

Future implications

Future studies might incorporate the use of POGIL instructional strategies used by certified chemistry teachers in chemistry classes, along with the credential and experience of instructors of POGIL student participants and instructors of non-POGIL student participants. Utilizing this approach could allow for the examination into POGIL instructional methods of chemistry teachers to determine if differences exist among student participants receiving non-POGIL instructional strategies.

The results of this causal-comparative study advanced scientific knowledge by showing a statistically significant difference between the effectiveness of POGIL pedagogy on SAGE chemistry examination scores for high school students taught chemistry using POGIL instructional strategies versus high school students taught chemistry using non-POGIL instructional strategies; however, the small effect size should be considered before district implementation of the POGIL model. Causal-comparative studies examine relationships without any manipulation of the variables and are not useful in determining specific causation (Salkind, 2019); therefore, the researcher makes no causation claim due to the limited sample size and lack of demonstrating similar patterns in multiple settings. While the present study supports these findings, continued investigation of the POGIL model is highly recommended.

Ethics Statement

Ethical considerations for this quantitative, causal-comparative research study were observed to protect all individuals associated with this present study. Since there was no direct contact or interaction with human participants for this study, ethical concerns for harm to individuals were not an issue. This present study was free of any deception or research misconduct to avoid professional issues and STEM education and POGIL instructional strategies are a current societal and educational concern.

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