Original Article

The effectiveness of active learning to reduce students' misconceptions about solution chemistry

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ABSTRACT

This study aimed to investigate and compare the effect of POGIL and analogy methods in reducing students' misconceptions about solution chemistry. The research method was quasi-experimental with a pretest and posttest design with the control group. The statistical population included all students in the field of primary education at Farhangian University and the sample size was 120 students who were randomly assigned to girls and boys groups and some concepts of chemistry (concepts related to chemical solution) were trained by POGIL and analogy methods. A screening test was used to select the sample and a researcher-made questionnaire was used to collect information. The validity of the questionnaires was obtained through content and face validity and the reliability of the questionnaires using Cronbach's alpha was 0.7 and 0.82, respectively. In this study, descriptive statistics including mean and standard deviation, and inferential statistics including Kruskal-Wallis and Yumann-Whitney tests were used to analyze the data. Findings showed that POGIL pedagogy and analogy teaching models with equal roles have a positive and significant effect on correcting students' misconceptions of chemistry concepts. Also, there is no significant relationship between the effect of POGIL education and analogy among male and female students and no difference is observed between them. Due to the effectiveness of POGIL teaching and analogy teaching methods in correcting students' misconceptions, educators can use both methods in chemistry classes according to the subject and the characteristics of the audience.

Keywords: Misconception, Chemical solution, Active learning, Chemistry education

Introduction

Awareness of knowledge is crucial for everyone to understand the function of the world and its surrounding natural world [1]. Traditional teaching methods have not been successful in making beneficial changes in learners' perceptions [2]. Although traditional teaching methods may be successful in transferring the facts, laws, processes, and models of a field, they are ineffective in helping learners construct their own beliefs about scientific concepts [3]. In contrast, exploratory teaching methods are defined based on learners' involvement in the creation and evaluation of scientific concepts based on evidence. However, not all exploratory methods are equally effective in increasing the level of knowledge of learners. For example, in the "guided inquiry" method, learners look for a specific model among the data collected by the experiments presented to them, but in the "open inquiry" method, learners usually design their own experiments to address a general problem [4]. Proponents of the pure inquiry method believe that learners should be encouraged to creatively explore the world around them and that this exploration should not be influenced by the curriculum but should be based on learners' interests [5]. However, this method, like traditional methods, was not successful in persuading learners to think. In fact, the uncontrolled exploratory approach is based on the assumption that learners already have advanced cognitive abilities [6], while learners who are in unorganized environments never face their misconceptions [7]. Based on Dynamic Skill Theory, learning a complex science such as chemistry is often difficult and requires much time and practice

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[8]. The level of learners in the areas of learning varies and it depends on the executive abilities, emotional state and the type of support or scaffolding provided [9]. Johnstone specifically uses cognitive load theory to learn chemistry [10, 11]. In his model, namely the information processing model, it is assumed that information that is considered important and presented when needed, learned, or even temporarily remembered, should first pass through one's mental perception filter. The filter is information processing in the mind and results from one's environment. Thanks to a filtering system, human beings can ignore a large part of sensory information and focus on what is important [10].

According to Johnstone, in order that learners can learn the abstract concepts of chemistry, chemistry teachers must macroscopy the learning process, resulting in a reduced load of working memory. To transfer information from working memory to long-term memory, the learner must connect their new knowledge to a schema in long-term memory. When the learner tries to adapt the new knowledge to the existing but inappropriate schema, it results in the formation of alternative conceptions and misconceptions [11]. Studies on concept change show that owing to the difficulty of changing alternative concepts, current and conventional teachings have not been effective in eliminating these concepts [12]. Accordingly, the present study is an attempt to examine the effect of POGIL (Process Oriented Guided Inquiry Learning) and analogy methods on correcting the misconception of bachelor students to help create an appropriate learning environment for learners to achieve educational goals and create sustainable learning by implementing active teaching methods.

Theoretical study

Studies about POGIL

Teaching in the classroom is done based on three different aspects of the process, product, and content [13]. POGIL pedagogy is an example of differences in process, product, and content. Guided inquiry is defined in several ways [14]. The POGIL model is a guided method in which the content and process of learning are on a path where the learner's success is not blocked by alternative concepts. Due to a need to advance chemistry teaching at the bachelor level of education [15], the POGIL pedagogy was developed with the investment of the National Foundation of Science. POGIL was first developed for bachelor chemistry courses in 1990 and was extended to high school chemistry and biology classes. POGIL philosophy is based on learner-based research and the kind of pedagogy of science in which students are guided in small groups on an exploratory path with the help of carefully designed activities to construct and reconstruct knowledge of chemistry [16]. A POGIL class or laboratory has the following general characteristics [17]:

- Learners usually work in small groups (usually 3 or 4-member groups) and roles are assigned to them.
- The educator facilitates the learning process rather than being a speaker.
- The activities that learners do are carefully designed usually based on the learning cycle approach (activities do not just include the difficult questions at the end of each chapter).
- Learners think about both their learning and their learning process.

Studies have shown that learners prefer POGIL pedagogy to the traditional teacher-centered method [18] and only a small number of studies report negative results in learners' success when using the POGIL method [19].

The POGIL method facilitates the learning of complex concepts and skills of chemistry by reducing the cognitive burden on working memory and transferring information to a long-term storage site, where it will be used and learned easier in the future [20]. Learners' problem with the three levels of representation is compounded by those chemistry educators who change one of the levels of representation without discussing how these levels are interconnected [21]. To create a conceptual understanding, it is necessary to help learners observe the relationship among three levels of representation. The POGIL method is designed by providing patterns of microscopic phenomena that can remove alternative concepts from the minds of learners [22].

Studies about analogy

The analogy is used as a basic or simple model to represent scientific concepts. Teachers often begin their explanation in the classroom by stating phrases such as "like" and "similar". These phrases are an introduction to applying analogy. The analogy is the comparison of similarities between two concepts. The familiar concept is called analogy and the unfamiliar concept is called target. If analogy and target share important aspects, the analogy is formed between them [23, 24]. Also, analogy is a powerful tool for creating similarities to achieve different goals such as problem-solving, description, or discussion [25]. An analogy can play a motivating role in meaningful learning [26]. It can also make learning meaningful by taking on multiple roles. The first role is to help learners to organize information or pay attention to information from a new perspective. Additionally, an analogy can also structure the information learned by considering specific aspects of the goal domain or by distinct differences between the scope of the analogy and the goal [27]. Ideally, analogy helps to identify learners' conceptual errors, rejects misconceptions, and replaces new concepts that are accepted by the scientific community [28]. In the analogy model, the educator must make sure that the learners do not misunderstand. One method to achieve this goal is to ask focused questions about important features that are not common to the concept of analogy and target [29]. Lemke's findings suggest that learners pay three to four times more attention to the familiar language of analogy than to the unfamiliar scientific language [30].

However, as mentioned, the use of analogy, like any other teaching method, can have negative effects. If the educator follows certain guidelines, some of these negative effects will not occur [24, 31]. However, some restrictions are inevitable in any case. Learners may use analogy mechanically without considering the information that analogy transfers [32]. The mechanical use of analogy may be related to students' inability to distinguish between analogy and reality. Some studies have also indicated that analogies have little or no effect on learning [33]. Many findings suggest that analogies are useful only for teaching those concepts of target that are conceptually difficult or abstract [34]. Since most of the concepts are new and challenging or difficult to perceive or imagine in chemistry, the use of analogies has useful effects on learning [35]. Based on some recommendations, if educators are guided in teaching by analogy, they will use analogy more effectively. There are three main educational models in the analogy literature, including the Teaching with Analogy (TWA) model, the General Model of Analogy Teaching (GMAT), and FAR (Focus-Action-Reflection). Teaching with an analogy (TWA): Although the teaching with analogy model [36, 37] is widely used in the analogy literature, few studies have tested its effectiveness.

General model of analogy teaching (GMAT):

The general model of analogy teaching emphasizes the need to design an analogy before applying it to consider learners' prior knowledge and their abilities, evaluate the effects of analogy and modify analogy to meet learners' needs. There is no specific report on the effectiveness of this model [27].

Focus-Action-Reflection (FAR): The Focus-Action-Reflection model was developed after observing the experience of five teachers in applying the teaching with analogy model. Designing FAR guidelines is easier compared to TWA and GMAT. The developers of the Focus-Action-Reflection model believe that the previous two models have many steps that the teacher has to memorize. This guideline includes the following steps [31]:

Focus: Focus on the concept of teaching and the analogy to be used. Is the concept difficult, unfamiliar, or abstract? What ideas do students already know about the concept? Are students familiar with the analogy? Action: Explicitly linking similarities between the concept of analogy and target and discussing the limitations of analogy. Reflection: Assessing how learners deal with analogy and improve it when needed.

Materials and Methods

The present study is applied in terms of objective and quasi-experimental with a pre-test and post-test design with a control group in terms of method. The statistical population included all 250 students of an elementary school at Farhangian University in the year 2019, who completed the courses related to experimental sciences. All students were screened for the concepts of chemistry, and among them, students who gave false answers for more than three questions of the screening questionnaire were selected. Then, the students were randomly assigned to six groups of 20 people (3 female groups and 3 male groups). Two experimental groups (male and female) received the POGIL method and two other groups (male and female) received education using the analogy method, and two control groups did not receive an education. Due to dropout in subjects, the POGIL group was reduced to 16 girls and 15 boys, the analogy group was reduced to 15 girls and 15 boys, and the control group was reduced to 15 girls and 15 boys.

Researcher-made questionnaires were used for the screening test and to collect the required data to answer the research questions. The face and content validities of the questionnaires were approved by five chemistry experts and educators and one educational psychology expert and one psychometric professor with applying some changes and were prepared for implementation. The reliability of the questionnaires using Cronbach's alpha was obtained at 0.7 and 0.82, respectively.

In the present study, experimental groups that received education using POGIL and analogy models and a control group, separately for boys and girls, were prepared to answer the research questions: Is teaching the method of analogy effective in reducing the students' misconception about solution chemistry? Is the POGIL teaching method effective in reducing the students' misconceptions about solution chemistry? Which of the POGIL and analogy is more effective in reducing the students' misconception about solution chemistry?

Implementation method: In the present study, before applying the educational intervention, a pre-test related to the chemical solution concepts was performed in all groups. The educational intervention was performed in the first semester of the academic year of 2019-2020 and five 60-minute sessions, one session per week for the experimental groups. At the end of the course, a post-test of the misconception of the concepts of the chemical solution was performed on the experimental and control groups.

In the present study, educational packages approved by chemistry experts and educators, which included teaching worksheets and test equipment and supplies, were used in the POGIL and analogy experimental groups. Worksheets in both POGIL and analogy methods included sections to teach the basic concepts of chemical solution, including types of solutions, dissolution process, the effect of heat on dissolution, and saturated, unsaturated, and supersaturated solutions and analogy and POGIL activities were extracted from valid journals and references. In the analogy method worksheet, which was prepared according to the steps of the Focus-Action-Reflection guide, students learned chemical solution concepts with the help of colored sand/sand and magnetic iron filings analogy, visitor analogy, employer analogy, and bus analogy. In the POGIL worksheet, students learned the solution concepts with the help of designed activities based on the learning cycle approach and with the help of critical thinking questions in a working group.

Results: In the present study, descriptive statistics including mean and standard deviation were used to analyze the data, and

Kruskal-Wallis and Yumann-Whitney tests were used for inferential analysis. SPSS software was also used to analyze the data. **Table 1** presents the statistical description (mean and standard deviation) of misconception in the pre-test and post-test stages of the experimental and control groups.

Table 1. Descriptive indices of misconception separately for groups

Variable	Status	Group	n	Mean	SD
Misconception	Pretest	Analogy	30	7.27	1.84
		POGIL	31	7.13	2.51
		Control	30	6.30	2.56
	Posttest	Analogy	30	7.70	1.99
		POGIL	31	7.58	2.16
		Control	30	4.10	1.81

As shown, there are differences between the mean scores of misconception in the pre-test and post-test stages of analogy, POGIL, and control. To investigate these differences, the normality of the distribution of variables was first investigated. Shapiro-Wilk test was used to examine the normality of the distribution of variables in the pre-test and post-test stages. Due to the significance level ($p < 0.05$) of the Shapiro-Wilk test in some stages, the distribution of the misconception variable is not normal. Thus, parametric tests cannot be used.

Kruskal-Wallis nonparametric test was used to test the research question **(Table 2)**. Chi-square statistics for comparing the three groups of research show that there is a significant difference between the three groups in terms of the mean rank of misconception ($P < 0.001$).

Table 2. Results of Kruskal-Wallis test for misconception variable

Variable	Mean of ranks			Chi-square	df	Significance
	Analogy	POGIL	Control			
Misconception	54.45	56.11	27.10	23.43	2	0.000

The Yumann-Whitney test was used to find out in which of these groups there is this difference **(Table 3)**.

Table 3. Results of the Yumann-Whitney test for difference of groups in the area of misconception

Variable	Group i	Group j	Yumann-Whitney statistic	Z	Significance level
Misconception	Analogy	POGIL	451.50	-0.20	0.844
	POGIL	Control	165	-4.38	0.000
	Analogy	Control	183	-3.99	0.000

According to the values of Yumann-Whitney statistic, it is observed that the difference in the mean rank between the analogy and control groups ($P < 0.001$) and the difference between POGIL and control groups ($P < 0.001$) are significant. However, there is no significant difference between analogy and POGIL. According to the means, the analogy and POGIL groups showed lower misconceptions in the post-test stage than the control group. Then, the effect of teaching with the analogy model and POGIL pedagogy on teachers separately by gender was examined. Kruskal-Wallis nonparametric test was used to examine the research question **(Table 4)**. Chi-square statistics for comparing the three study groups show that there is a significant difference among the three groups in terms of the mean rank of misconception in both females ($P < 0.001$) and males ($P < 0.01$). The results of this analysis are presented in **Table 4**.

Table 4. Results of Kruskal-Wallis test for misconception variable separately by gender

Gender	Mean of ranks			Chi-square	df	Significance
	Analogy	POGIL	Control			
Female	28.77	28.03	13.40	13.01	2	0.001
Male	26.23	28.37	14.40	10.07	2	0.007

The Yumann-Whitney test was used to compare the groups **(Table 5)**. According to the values of Mann-Whitney U statistics, it is observed that the difference in the mean rank between the analogy and control groups ($P < 0.005$) and between POGIL and control groups ($P < 0.005$) is significant. However, there is no significant difference between analogy and POGIL groups. In men, the mean rank difference between analogy and control groups ($P < 0.01$) and between POGIL and control groups ($P < 0.005$) is significant, but there is no significant difference between analogy and POGIL groups.

Table 5. Results of the Yumann-Whitney test for difference between the groups in the area of misconception separately by gender

Gender	Group i	group j	Yumann-Whitney test	Z	Significance level
Female	Analogy	Control	38	-3.14	0.002
	POGIL	Control	43	-3.10	0.002
	Analogy	POGIL	115.50	-0.18	0.856
Male	Analogy	Control	53	-2.50	0.012
	POGIL	Control	43	-2.92	0.004
	Analogy	POGIL	101.50	-0.46	0.643

Then, using the Yumann-Whitney test, the differences between male and female participants in the area of effectiveness of analogy, POGIL, and control methods were investigated **(Table 6)**.

Table 6. Results of the Yumann-Whitney test for investigating the difference between male and female participants in the area of misconception separately by group

Group	Yumann-Whitney test	Z	Significance level
Analogy	100.50	-0.50	0.615
POGIL	117.50	-0.10	0.920
Control	107.50	-0.21	0.833

The significance of the z statistic ($P > 0.05$) shows that in both methods, there is no difference between male and female participants in the area of effectiveness of teaching methods. Thus, based on the above results, it can be stated that analogy and POGIL teaching methods are effective in eliminating the misconception of student chemistry concepts, but the effects of these methods on correcting the misconception of the student chemistry concepts are the same and are not different.

Results and Discussion

The results of the present study show that according to the means, the POGIL group showed lower misconception in the post-test stage than the control group. This result is in with the results of a study conducted on the positive effect of the POGIL method on the elimination of alternative concepts in electrochemistry [38]. Also, a study showed the effectiveness of the POGIL learning method in reducing the alternative perceptions of high school chemistry students compared to the traditional teaching method [39]. Studies also indicate that the POGIL method provides learners an opportunity to discuss knowledge, and teachers can help the learner to better understand the relationship among three macroscopic, submicroscopic, and symbolic levels in chemistry [40]. The results of a study conducted by Hunnicutt *et al*. showed that students worked on at least two learning cycles that they had predicted by performing POGIL activities, collecting and modeling data, and discussed on its meaning [41]. Another study showed that the teacher in symmetric action can identify the prior knowledge of the learner with the help of the POGIL learning method, which interferes with the acquisition of new knowledge [42]. In general, learners in the POGIL method evaluate the model provided in learning and pass through their unique cognition based on prior knowledge. Teachers in the POGIL method have the opportunity to informally assess students' learning when the group spokesperson provides a summary of materials [43].

Also, the results of the present study showed that according to the means, the analogy group showed less misconception in the post-test stage than the control group. This result is in line with the results of a study conducted by Brown, who stated that when learners have a misconception, analogy strategies are more effective than simply presenting materials that expand their credible intuition in creating conceptual change [44] because they evoke the inferential process in students' minds, which reduces abstractions [45]. Also, the effectiveness of teaching with an analogy model in learning the concepts of electricity was examined in a study and its results showed the better performance of learners in the experimental group [46]. The analogy model in a study on mathematics courses also showed that learners trained with the analogy model performed better in the experimental compared to the learners trained with the traditional method [47]. In general, the results of studies suggest that analogies play the role of forcing conceptual change by helping learners to overcome existing misconceptions [44]. Analogies are often used in learning settings to help the learner understand new information based on current familiar information and to help those who can relate the new information to the existing knowledge structure [48]. Since the concepts of science are inconsistent with personal and everyday experience, to overcome this problem, many educational interventions have been conducted, among which an analogy model is a powerful tool for constructing theory, changing the mental model, and understanding the concept and reasoning [49]. Also, although the descriptive results in the present study show a slight difference between the mean scores of the analogy and POGIL models, the mean post-test scores in the two analogy and POGIL groups are not significantly different and both methods have corrected student misconceptions. In explaining this result, it can be stated that both teachings with the analogy model and POGIL learning model cause conceptual change by making abstract concepts understandable.

Conclusion

In general, based on the results obtained from examining the questions of the present study, it can be stated that although the difference between the mean ranks of analogy and control groups and between mean ranks of POGIL and control groups are significant and both POGIL and analogy methods are effective in the elimination of students' misconception, but there is no significant difference between POGIL and analogy models in this regard. In other words, POGIL pedagogy and analogy techniques have equal roles in reducing learners' misconceptions. These results reveal that since analogy and POGIL approaches both have an exploratory and active basis, the teacher uses these methods in the action field by making the appropriate selection from POGIL activities and various analogies can perform their facilitating role optimally and uniquely. Also, based on the results of the present study, there is no significant relationship between the effects of POGIL and analogy methods between male and female students, and no difference is observed between them. Therefore, educators and educational activists can use both methods in chemistry classes according to the subject and the characteristics of the audience.

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