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Investigation of achievement and mistakes in analytical chemistry experiments

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Abstract

This research was conducted to investigate the effect of experiential learning on the achievements of prospective teachers in analytical chemistry quantitative analysis practices and to determine the mistakes made by prospective teachers in the experiments. Pre-test and post-test control group experimental research design was used. Data were collected by the analytical chemistry achievement test and laboratory form. As a result of the research, a significant increase was observed in prospective teachers' levels of academic achievement. This finding can be explained as the experiential learning classroom environment, which will construct a community of practice like the scientists' work. According to the results of the laboratory form, prospective teachers are more successful in multiple choice questions in the achievement test; however, they cannot show the same success in explaining the theoretical foundations of the experiment or detailing the calculation sections.

Keywords: Experiential learning, analytical chemistry laboratory, achievement, mistakes in experiments.

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1. Introduction

Analytical chemistry is a science that is used in all fields of science and medicine and is based on measurement. Analytical chemistry involves identifying, separating and quantifying the components that make up an example we encounter in our daily lives (Skoog, West, Holler & Crouch, 2014). Analytical chemistry and qualitative–quantitative analysis applications have an important place in chemistry education. With qualitative analysis, the student should learn how to use a sample given to him/her, carry out laboratory applications involving changes in colour and/or appearance and reach conclusions based on both theory and reactions (Berry, 2015). In analytical chemistry, gravimetric analysis and volumetric analysis are still thought to be the basis. How to obtain correct analytical data in analytical chemistry should be taught. With the analysis made in analytical chemistry, the student should learn how to use a sample given, how to determine the cations in or without each group, create laboratory applications involving changes in colour and/or appearance and arrive at conclusions based on both theory and reactions. The student should combine theory with experimental work (Guerrero, Jaramillo & Meneses, 2016). For this purpose, the analytical chemistry curriculum should consist of chemical analysis, separation chemistry and instrumental analysis. Here, analytical methods and techniques are learned with experiments (Arikawa, 2001).The student should combine theory with experimental work. Therefore, effective teaching methods should be used in teaching analytical chemistry applications. One of these methods is experiential learning. Individuals learn with different methods, usually these studies take place after their experiences (Yoon, 2000). According to Kolb, the experiential learning process is focused on the process and not the ordinary learning features (Turesky & Gallagher, 2011). In Kolb's experiential learning theory, learning is described as the process through which knowledge emerges through a series of changes of experiences. Knowledge is obtained as a result of understanding and transforming experience (Moore, Boyd & Dooley, 2010).

Experiential learning is a result of gaining skills and structuring knowledge by students, i.e., experience (Chesimet, Githua & Ng'eno, 2016). It is accepted that the student has the ability to choose and participate in experiences that will advance their development (Atherton, 2009). In this process, learning takes place as a result of the individual's choices. For example, concrete experiences and active experimentation, i.e., the individual who prefers to do something instead of watching or to think instead of feeling, combine these choices and realise an adaptive learning style. As can be understood from here, the elements of this four-step cycle combine to form some preferences. They are concrete experience, reflective observation, abstract conceptualisation and active participation. In the process of concrete experiences, the individual wants to be in situations in order to get concrete examples of this situation. For this reason, it is very important to explain the subjects by giving examples from daily life (Gencel, 2006). Reflective observation is a process in which the individual develops different perspectives in line with their learning and observations. It can be said that those who choose to learn in this way are questioning individuals who aim to think and make sense of the reasons and foundations of the situations (Kolb, 1999).In the third step, the abstract conceptualisation step, individuals need to present the theoretical information learned in a logical order. At this stage, the teacher conveys the topic summarising the subject, creating environments where students can work individually, carries out studies in the laboratory environment, computer-aided education and projects are activities that facilitate learning (Healey & Jenkins, 2000).Active participation, which constitutes the last step of the cycle, is a way of learning in which the individual learns situations through practices and is personally involved in activities. At this stage, the individual's participation in practice instead of observing, thinking or feeling is at the forefront (Hein & Budny, 2000; Kilic, 2002; Kolb, 1984). In this way, which is preferred by students who enjoy applying what they learn, it is ensured that learning is effective with group work and active learning ways. The aim of this article is to determine the effect of experiential learning on analytical chemistry achievement and opinions about experimental procedure of prospective chemistry teachers (PCT).

2. Method

In this study, pre-test and post-test control group experimental research design was used. The research was conducted in the analytical chemistry laboratory course. Therefore, PCT taking the course constitute the sample of the research. The research group comprised 30 PCT. Control and experimental groups were determined through purposive sampling. It was carried out in the experimental group with the experiential learning approach and in the control group with the traditional verification laboratory approach. The analytical chemistry achievement test and laboratory form were data collection tools.

2.1. Data Collection Tools

2.1.1. Analytical chemistry achievement test

The researcher developed an analytical chemistry achievement test. It consisted of 15 multiple choice questions related to quantitative analysis. ITEMAN Windows Version 3.50 statistics programme was used for validity and reliability studies of the achievement test. The achievement test was applied to 253 pre-service teachers who took the chemistry course. Item analysis was conducted with the data obtained. Accordingly, the researcher determined that the average difficulty value for analytical chemistry success test was 0.49, the average distinctiveness value was 0.62 and the reliability coefficient was 0.75.

2.1.2. Laboratory form

The Laboratory form was developed by the researcher. It consisted of questions prepared to identify the positive and negative aspects experienced during the application process and to reveal the effectiveness of the process. Codes were created during the evaluation phase of the form. These codes revealed the connections between the answers given. The experimental process was taken into account while creating the codes.

2.2. Procedure

Analytical chemistry quantitative analysis applications were carried out with the experiential learning approach in the experimental group, and the traditional verification laboratory approach was carried out in the control group. The experiential learning process is planned according to Kolb's (1984) learning cycle. The learning cycle consists of four steps. These steps are concrete experience, reflective observation, abstract conceptualisation and active participation. In the first step, concrete experience neutralisation titrations of quantitative analysis were carried out. In the second step, reflective observation calculations were made according to the data obtained from the experiment and PCT discussed the results obtained from the calculations. The third step is abstract conceptualisation. At this stage, problems relating to neutralisation titrations were resolved. Errors in calculations were examined one by one. The fourth step is the active experience. At this stage, the subject is learned in depth. In order to achieve this goal, many experiments are carried out and calculations are made. In the experiments, the points to be considered for monoprotic / polyprotic acid or base samples are examined. In the traditional validation laboratory approach, experiment sheets are given to PCT. In these sheets, the purpose of the experiment, theoretical knowledge of the experiment, how to do the experiment and the calculation sections of the experiment are included.

In the control group, the traditional verification laboratory approach was applied. In the traditional verification laboratory approach, experiments sheets were given to prospective teachers. Experimental sheets first start with a sentence that explains the purpose of the experiment. Then, the theoretical knowledge of the experiment is explained. Then, how to conduct the experiment and record the data obtained from the experiment is explained in detail. The conclusion section contains information on how to analyse the data and the calculation parts of the experiment. How to use the data obtained from the experiments to explain the laws and principles of chemistry are specified with formulas and explanations in the traditional validation laboratory approach.

3. Results

3.1. Findings Related to Chemistry Achievement

Data obtained from study group were analysed in terms of the difference between pre-test and post-test scores. In analysing the data, non-parametric tests were used, while the sampling numbers were below the recommended value. The differences between groups (experimental and control) before the application were examined using the Mann–Whitney U-test. The difference between pre-test and post-test scores for chemistry achievement was examined by the Wilcoxon signed-rank test. Descriptive statistics related to pre-test and post-test scores of chemistry achievement are given in Table 1.

Table 1. Descriptive statistics regarding chemistry achievement test

Groups	*N*	Pre-test		Post-test	
		Mean	SD	Mean	SD
Experimental group	15	8.40	1.99	9.87	2.09
Control group	15	7.73	1.83	8.33	2.29

According to Table 1, it can be seen that pre-test chemistry achievement score averages of the experimental group was X = 8.40 and the control group was X = 7.73. The differences between the groups' chemistry achievement before the application were investigated using the Mann–Whitney U-test. The test results show that there is no significant difference among groups (U = 94.000; $p > 0.05$).

After the experiential learning process, the differences between the experimental and control groups' pre-test and post-test chemistry achievement score averages were examined using the Wilcox on signed-rank test. The results are presented in Table 2.

Table 2. Wilcox on signed-rank test results of chemistry achievement test scores

Chemistry achievement		*N*	Mean	SD	*Z*	*p*
Experimental group	Pre-test	15	8.40	1.99	−2.501	0.012*
	Post-test	15	9.87	2.09		
Control group	Pre-test	15	7.73	1.83	−1.059	0.290
	Post-test	15	8.33	2.29		

*$p < 0.05$.

When Table 2 is examined, it can be seen that there is a statistically significant difference between pre-test and post-test chemistry achievement score averages of PCT in the experimental group ($Z = -2.501$; $p < 0.05$). In the control group, average scores among PCT are also increased, but there was no significant difference ($Z = -1.059$; $p > 0.05$). The results suggest that the experiential learning is impressive in enhancing PCT' chemistry achievement.

A comparison of the two groups' post-test scores using the Mann–Whitney U-test found that, although the experimental group had a higher average than the control group, the difference was not statistically significant (U = 78.500; $p > 0.05$).

3.2. Findings Related to the Laboratory Form

PCT filled the laboratory form after the experiential learning application in the analytical chemistry laboratory. Codes determined according to the findings obtained from the laboratory form and the PCT who gave opinions are given in Table 3.

Table 3. Codes related to the laboratory form

Codes		PCT
Code 1	Mistakes in explaining theoretical foundations	PCT4, PCT6, PCT11, PCT16, PCT20, PCT22, PCT25, PCT28, PCT30
Code 2	Mistakes in calculation of experiment	PCT2, PCT5, PCT8, PCT9, PCT12, PCT13, PCT15, PCT18, PCT19, PCT21, PCT24, PCT26, PCT27
Code 3	Mistakes in experimental procedure	PCT1, PCT3, PCT7, PCT10, PCT14, PCT17, PCT23, PCT29

When Table 3 is examined, according to the findings obtained from the laboratory form, mistakes in explaining the theoretical foundations of the neutralisation titrations experiment, mistakes in calculation the experiment and mistakes in the experimental procedure were determined.

The explanations about the determined codes are as follows: in the code of explanation of theoretical foundations, PCT pointed out that the purpose of titration is to limit only the volume, only the concentration or quantity, to determine the concentration of an acid with a known base or to find the amount of unknown substance. Some errors in the calculation of the experiment's code draw attention. They are as follows: the errors in using the data obtained from the experiment in the calculation, the errors without converting the units and the result not in the desired unit, not using the unit and the volume spent in successive titration which cannot be found. The code of the experimental procedure was highlighted by analysing the problems of how to put the analyte and titrant in the flask or burette, adding the indicator, how to check the burette's faucet, when to stop the titration, cleaning before using the burette and checking whether the burette's faucet is closed. According to the results of the laboratory form, prospective teachers are more successful in multiple choice questions in the achievement test; however, they cannot show the same success in explaining the theoretical foundations of the experiment or detailing the calculation sections.

4. Discussion and conclusion

The aim of this study is to investigate the effect of experiential learning on the chemistry achievement of PCT in quantitative analysis applications in analytical chemistry and to determine their views on the effect of the laboratory process. As a result of the research, the chemistry achievement of prospective teachers increased significantly. It is concluded that experiential learning is effective in increasing the success of analytical chemistry. The effect of experiential learning on success is supported by other research studies (Agsalog, 2019; Alkan, 2016; Dolotallas & Nagtalon, 2015; Leal-Rodriguez & Albort-Morant, 2019; Sumarmi et al., 2019; Wahyudi & Hadiyat, 2020).

The research studies on science learning and teaching have shown that the concepts forming a subject should be given by establishing a relational structure with other concepts. Therefore, the curriculum should be arranged in such a way as to increase the conceptual change between concepts (Horton, 2007). Students have difficulties in writing correct equations for the decomposition reaction, in relating what they have learnt in the course with experimental procedures (Onwu & Randall, 2006) and in understanding quantitative and qualitative analyses of analytical chemistry (Gunter & Kilinc Alpat, 2019). It is not only sufficient for students to understand chemistry concepts, symbols, terminologies and theories in learning chemistry, but they should also to represent the instructional language or material teachers use in chemistry in a meaningful way (Chiu, 2005). Teachers should provide meaningful explanations to students, and do something to change students' misconceptions and representations (Adesoji & Omilani, 2012). In analytical chemistry, students have to learn a lot of information. Students who take the analytical chemistry course are expected to know the basic concepts taught in both the classroom and laboratory experiments and gain knowledge and skills to define the items that will set an example for these concepts. Teachers give theoretical information to students in the classroom, which involves many strategies and reactions; however, in the laboratory, students sometimes have to analyse a sample of problems based on visual tests that are not very clear. Therefore, the tests are repeated several times and the working time is extended (Guerrero et al., 2016). The learning environment should be arranged in such a way that learners take responsibility (Rusmansyah, Yuanita, Ibrahim, Isnawati & Prahani, 2019) and activities towards the development of creativity in the applied courses should also increase the awareness of responsibility (Suyidno, Nur, Yuanita, Prahani & Jatmiko, 2018). These disadvantages can be removed in the learning environment by using the appropriate method. For example, laboratory practices should consist of detailed steps rather than single steps. By following these steps, the student understands the purpose of the laboratory and experiment more easily (Elzagheid, 2018).

Laboratories should no longer be the cookbook-type laboratories, followed by the data sheets. Instead, laboratories should be designed as places where real-world problems are discussed or practiced (Hicks & Bevsek, 2012). Practice and experiment are very important in analytical chemistry because the competence gained in analytical chemistry is a tool for the development of thinking and creativity (Sudrajat, Permanasari, Zainul & Buchari, 2011). According to the students, the materials to be used in analytical chemistry should be intertwined with the practices that the students experience in the laboratory. The student pays more attention to the materials associated with the experiments and uses cognitive strategies to understand them (Yulina, Permanasari, Hernani & Setiawan, 2019). A cognitive conflict arises when students get an unexpected result while experimenting in the laboratory. They discover why their previous knowledge was not good enough to explain this unexpected result and start to re-examine what they know (Najami, Hugerat, Kabya, & Hofstein 2020). Lessons such as instrumental analysis are usually given as teacher-centred. In the chemistry instrumental analysis course, different learning techniques such as problem-based learning can be used to increase students' attitudes, performances and learning effect. In this way, students' participation in lessons increases, and in turn they create information in the mind and their problem-solving skills and self-learning skills also develop (Gao, Wang, Jiang & Fu, 2018). The use of the case study method in the analytical chemistry laboratory has increased the learning of students and has increased the motivation and motivation to do research (Gunter & Kilinc Alpat, 2019). The use of diagrams based on guided inquiry method in analytical chemistry laboratory has improved students' laboratory performance and success. In the laboratory, student-centred practices play a constructive role while providing knowledge and skill development (Akkuzu & Uyulgan, 2017). In addition, associating daily life-based practices with chemistry increases the success of the students and in turn increasing the chemistry success (Altundag Kocak, 2018). Another example is experiential learning. Experiential learning is an important method for acquiring knowledge, developing skills and making learning permanent. Experiential learning and teaching in science will provide the development of students' skills (Giac, Gai & Hoi, 2017). In this research, analytical chemistry quantitative analysis applications are planned according to the experiential learning steps in order to make the learning of the students comprehensive. As a result, both the chemistry achievements of prospective teachers increased significantly and they realised what kind of mistakes they made in processes such as the experiment and calculation.

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