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Review Article

The Effects of Inquiry Demonstration on Students' Conceptual Understanding and Attitude: A Promising Approach in Analytical Chemistry Laboratory

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Abstract

A recent issue on Analytical Chemistry laboratory teaching has been on the inability to conduct individual experimentation due to large class sizes and the inadequacy of reagents and equipment in school laboratories. Questions are focused on whether learners develop understanding and attitude when they are not physically involved in physical manipulations. To contribute to this topic, this study exhausted literature involving inquiry demonstration on students' understanding and attitude. Empirical studies showed that inquiry demonstration enhances students' understanding and attitude compared to the traditional lecture. However, laboratory work has an advantage in terms of technical and manipulative skills. Throughout the years role-playing, video recordings, and virtual laboratories have been explored in Analytical Chemistry, but there had been no study with the use of inquiry demonstration in this field. This paper suggests that inquiry demonstration is a promising approach with the nature of Analytical Chemistry laboratory and to address the issue of inability to do laboratory work.
Keywords: Inquiry Demonstration; Laboratory Work; Conceptual Understanding; Attitude.
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INTRODUCTION

The chemistry teaching-learning process is continuously evolving with the development of innovative instruments. Henceforth, subdisciplines such as Analytical Chemistry must re-evaluate their approaches amid the changing student attitudes and achievements. Analytical chemistry is an indispensable part of the curriculum as it forms the foundation for future laboratory work [1]. With this, laboratory work is the focal point for Analytical Chemistry. It has been recognized that this offers an opportunity for students to develop technical and manipulative skills, practice careful observation, and develop problem-solving skills [2-7]. Students are taught to use instruments as well as understand the mechanisms through which analytical techniques function. It is therefore paramount that the learning approach is appropriate, and that the students actively engage and foster critical thinking in order to retain concepts and apply these practically. These skills are most important for technological innovation leading to economic growth.

However, in the Philippines, teaching Analytical Chemistry is still being taught traditionally. Colleges and Universities have not coped up with the advancements of this Chemistry subdiscipline. A survey of the curriculum for analytical chemistry in sixteen major Philippine universities offering an undergraduate degree in chemistry revealed that the course is still taught traditionally [8]. Furthermore, most of the non-chemistry majors with this course do not engage in laboratory work due to large class sizes, insufficient equipment, and scarcity of reagents. Without laboratory work, it suggests that students will have no conceptual knowledge and interest in science. Consequently, these students will lack the requisite qualifications for courses like medicine, engineering, agricultural science, and other science-related careers.

In light of the issue, this paper aims to determine the effects of inquiry demonstration on students' conceptual understanding and attitude. This teaching approach has the potential to address the issues raised. Furthermore, current trends on teaching Analytical Chemistry apart from practical work is included in this paper since the use of inquiry demonstrations as a teaching/learning technique has not been explored in this field.

INQUIRY DEMONSTRATION AND LABORATORY WORK

Laboratory work is used to describe the practical activities which students undertake using chemicals and equipment in a laboratory. John Dewey advocated an investigative approach and "learning by doing." Based on a review of the laboratory literature, Lazarowitz and Tamir [9] joined the long list of authors who indicated that the potential of the laboratory work as a medium for teaching science is enormous.

The demonstration, a process of showing something to another person or group, help instructors provide motivation and inspiration in classes. To identify characteristics that improve learning, chemical educators have turned to cognitive learning theories that have evolved out of the developmental research of Piaget. From this body of work, several specific recommendations have been put forward for effective preparation, delivery, and discussion of classroom demonstrations. A standard recommendation is that students not merely observe a demonstration. They must be challenged to create, invent, or discover for themselves a rational explanation for the chemistry they are witnessing [10]. Hence the birth of inquiry demonstration. It is when a demonstration is given inductively by a teacher asking several questions but seldom giving answers. An inductive demonstration has the advantage of stressing inquiry, which encourages students to analyze and make a hypothesis based on their knowledge [11-19].

Over a little more than fifty years, hundreds of research papers and doctoral dissertations investigated variables in settings associated with which laboratory teaching method is best [10]. In light of the available literature, laboratory work is favorable if activities are short and easy- not complicated as to learning involved or equipment used; caring for individual differences seems especially desirable; the results can be easily seen and interpreted, by the students working alone, after the activity has been performed; and if development of laboratory skills and resourcefulness is an objective. Compared to individual work, demonstration method have the following merits: when the learning involved in connection with the activities is complicated and confusing; the equipment used is complicated, difficult to manipulate, or expensive; the equipment used is sufficiently large to be seen at a distance; the students are likely to make mistakes, when working alone, in determining and interpreting the results after an activity has been completed; and a large amount of subject matter must be covered in a limited time.

One primary objective of teaching Analytical Chemistry is to produce skilled technicians for the industry, which makes individual laboratory work a favorable approach. But to non-chemistry majors that have this subject wherein the principal objective is to grasp analytical techniques and concepts, together with the issues on shortage of laboratories, expensive Analytical Chemistry equipment such as Atomic Absorption Spectrophotometer (AAS), High-Performance Liquid Chromatography (HPLC), Gas Chromatography (GC), and Kjehldahl apparatus, and expensive analytical-grade reagents, inquiry demonstration is desirable.

INQUIRY DEMONSTRATION ON STUDENTS' CONCEPTUAL UNDERSTANDING

Teaching for understanding should be mainly directed on what the teacher gets the students to do rather than what the teacher does. Studies by Driver *et al.*, showed the importance of active learning and reflective teaching. The theory of conceptual change suggested that instruction be improved by building students' conceptual understanding. For effective laboratory learning, students need to know not only how, but also why the experiment is worth doing, and the purpose it serves for a better understanding of a concept, relation, or process. If Piaget is correct, then the practical experience of observing and (even more critical) intervening in the world is essential for understanding.

In this study, the purpose of an inquiry demonstration is to promote understanding of content knowledge, not inquiry itself. Observing a demonstration is not enough to produce conceptual change, and background knowledge is required to make sense of new observations. When observations are integrated with other metacognitive learning experiences, they can promote the conceptual learning of science. According to NRC in 2005, an inquiry integrated into a useful teaching strategy such as demonstration support conceptual changes and understanding because observation involves the interaction of content and process.

Furthermore, the learning cycle model proposed by Atkin and Karpulus based on the Piaget's work could promote conceptual understanding. It is typically presented as exploration, invention, and discovery. In this model, exploration could be the inquiry demonstration in which students gather the information they need to learn a concept. The invention refers to the formal statement of a new concept by restructuring their prior concepts, and discovery involves applying the new concept to a new situation.

According to literature, demonstrations improves students' perceptions of the importance of the subject, which enhances the students' achievements and their understanding of concepts [20]. This is compatible with Sweeder and Jeffery's finding [21] that demonstrations if appropriately planned, have the potential to play an essential role in students understanding of chemical concepts. Demonstrations were found to promote thinking skills and to enable students to think more creatively. Thompson and Soyibo [22] found a significant difference between students exposed to demonstrations and those students who had not been exposed to demonstrations for the comprehension of concepts. The result is similar to the finding of Price and Brooks [23] that demonstrations enhance student's understanding of concepts. Meyar *et al*., [24] reported that when the teacher thinks out loud in a demonstration, students illustrate cognitive strategies and formulates questions leading to an explanation of the concepts. This can encourage perceptual understanding.

There are also studies that negate the positive effect of inquiry demonstration on conceptual understanding. In the study of Lee [25], inquiry demonstration was not sufficient to promote the conceptual understanding since his students failed to build a well-organized conceptual structure under the overarching concept. Although they successfully acquired the elements for the conceptual understanding, many of them did not achieve the ultimate goal of the instruction- conceptual understanding. Hence, this demonstrates a significant limit of inquiry laboratory as discovery learning. The results of another study indicate that inquiry-based teaching has a fragile relationship with attainment in science. Any positive effects are confined to moderate levels of inquiry combined with high levels of guidance. High levels of inquiry or unguided inquiry have no relationship with attainment at all. These results are consistent with the literature, which tends to find that inquiry is less effective than more direct forms of instruction.

INQUIRY DEMONSTRATION ON STUDENTS' ATTITUDES

In the late 1980s, there was a decline in science education researchers' interest [26, 27]. Toward the end of the century, the issue of attitude towards science became an international problem. Osborne *et al*., [28], presented students' decline in their attitudes toward science in enrollment in science-based careers. This is intensified by the results of the international comparative assessments in science education (TIMSS, since 1995 and PISA, since 2000), all of which called for rethinking the goals, content, and pedagogy of science education [29]. A characteristic feature of reports is that the pedagogical approaches of science schools are not aligned with the needs and interests of most of the students.

Bloom [30] suggested that 25% of the variance in school achievement could be attributed to how students felt toward what they are studying, their school environment, and their concept of self. Similarly, another 25% of the variance in school achievement was attributed to the quality of instruction. It is, therefore, the responsibility of educators, to advance learning approaches to improve students' attitude towards Analytical Chemistry and to prepare students to live in a highly scientific and technological society. If students are uninterested, they do not make an effort to understand the meaning of concepts that are being taught. Literature [27, 31, 32, 9, 33, 34] revealed a clear correlation between students' attitudes towards learning science and various modes of instruction in the science laboratory.

According to Omiko [1], eight (8) aspects of scientific attitudes exist, all of which can be nurtured in the science laboratory in school. These are (i) curiosity (ii) open-mindedness (iii) objectivity (iv) intellectual honesty (v) rationality (vi) willingness to suspend judgment (vii) humility and (viii) reverence for life. Also, in the review of the literature of Koballa and Glynn [26], attitudes are used interchangeably with interest, beliefs, curiosity, opinions, and other commonly used affective-related variables. The concept of attitudes towards science is composed of several components.

Ben-Zvi *et al*., [35] reported that chemistry students prefer individual laboratory work (hands-on) when contrasted teacher's demonstrations, filmed experiments, and traditional lectures. In 2004, The Attitude towards Chemistry Laboratory Questionnaire was administered in a study conducted by Kipnis & Hofstein [36] in which two groups of high-school chemistry students were compared. Students in the inquiry group have more positive attitudes towards chemistry than did those students who had experienced a regular chemistry program. It is clear that students prefer the inquiry demonstration sessions and accept their use in chemistry class. Students who participated in the study, when asked whether they prefer studying by demonstrations or by the traditional method, they replied that demonstrations were preferable. Many students thought that in addition to demonstrations, lab sessions or manual activity sessions could be useful as follow-up activities. However, they agreed that even without manual activity sessions, the demonstration lessons are superior to regular lessons. Thus, demonstrations are useful for facilitating and developing learning since they promote student interest in the lessons and provide teachers with a greater variety of pedagogical tools [37-39]. An elevated level of student attention and involvement in tasks has also been reported for demonstrations carried out in high-school chemistry courses. Meyar *et al*., [24], have shown that demonstrations encourage student involvement since they are less teacher oriented and allow students to produce questions and to become more active in the learning process. This motivates students to undertake an initial inquiry and also provides a learning opportunity because it helps create mental links between new and previous learning.

To surmise, based on research conducted for almost 50 years, it is clear that the laboratory has the potential to contribute significantly to shaping and enhancing students' attitudes towards chemistry [40, 41]. The magnitude of the attitudinal behaviors is a function of the instructional approach adopted by the curriculum developers, by the type of measure used, and by the teachers' behavior and practice in their classroom.

CURRENT APPROACHES IN ANALYTICAL CHEMISTRY LABORATORY

Today, many chemistry graduates are not employed as chemists in the industry, and their reaction to practical work is often negative. This is a result of the lack of laboratory experiences since most teachers until today use the traditional teaching approach. In a book chapter published by Settle [42], he summed up the education for analytical chemistry from the 1950s to present. He pointed out how laboratories have changed to encompass advances in instrumentation, computers, content, and pedagogy. In this environment, analytical chemistry offers a methodology that includes a unique combination of experimental design, sampling, sample preparation, knowledge of the capabilities and limitations of measurement techniques, data analysis, and presentation of results including validation procedures. Apart from the ideal individual laboratory work, role-playing, video demonstrations, and virtual laboratories are currently used approaches in analytical chemistry laboratory teaching.

Role-Playing

Even though this paper emphasized the laboratory component, the role-playing structure is firmly rooted in all facets of the analytical curriculum. “Companies” (student groups) do homework assignments, present information and interpretations, break up into workshop sessions, create, innovate, and try to reach laboratory objectives together [43]. The objective of the role-playing approach is to develop technical expertise at an individual level while developing communication and collaborative skills. Further, the group construct allows students to examine broader, more complex questions mimicking real professional problems that are assessed only with difficulty on an individual basis. Instructors and students move toward these goals with the aid of technology and in a context of realism. Students become active participants in their education as well as in the education of their peers.

Results of an alumni survey conducted by Jackson [43] indicate that role-playing in the analytical chemistry curriculum has a profound impact on graduates. Not only have students achieved under this construct, but alumni reported receiving additional benefits through participation in the course. These skills and experiences have served them well professionally and personally. Furthermore, these skills reflect the wealth of non-achievement-based outcomes associated with cooperative learning. The results show that this teaching approach has passed the proof-of-concept phase and establish a basis for continued evolutionary effort.

Video Demonstrations

Video demonstrations were developed, providing both visual demonstrations with audio explanations to reinforce each concept, and students were guided to these through compulsory prelab e-quizzes. Academic performance and an attitudinal survey evaluated the effectiveness of this program in the study conducted by Jolley *et al.*, [44]. There was no improvement in academic performance in laboratory reports; however, students reported that this approach had a positive effect on their learning. Visual representations allow students to develop a mental picture of what they do in laboratory classes, which may increase student confidence. Instructional materials which combine visual and audio components have been found to facilitate more effective learning than either approach alone.

These studies, which were developed to enrich the environment of teaching information and communication technologies, increase student motivation, and in connection with this, enhance academic achievements [46-49]. Such efforts started in the 1950s with television and continued with the use of videos in classrooms. It can be seen in the studies that there are two areas of benefit that videos provide in teaching environments. One of these relates to how videos stimulate concentration and motivation in students throughout the teaching process. The second area of benefit has to do with the power of videos in helping students conceptualize and internalize difficult and abstract topics.

Virtual Laboratories

Well-designed computer-based teaching materials, including simulations, animations, and other kinds of modeling activity, can also be very useful in helping students to operate in the domain of ideas [50]. For example, a software tool under development by the Gatsby Science Enhancement Project illustrates a way of helping students link observations of simple laboratory events to a model of energy transfers.

Several video clips and simulation programs show the process and results of school experiments that students and teachers do not need to experiment to get the results [51-55]. Thus, the focus experiments in high schools have been shifted from acquiring manipulative skills to conceptual understanding and scientific reasoning skills. The new electronic tools and resources for teaching and learning associated with the school science laboratory also offer meaningful opportunities to study learning in science. They warrant careful scholarly study by researchers in science education as we enter the twenty-first century.

The emergence of virtual laboratories in the field of analytical chemistry is one effective way to engage students in active learning. It allows students to experience and realize their potential by getting to think like they are working in the field. Students become actively engaged when they can see concepts being studied, applied to real life. The study conducted by Bortnik and his colleagues [56] found that virtual labs have the potential to enhance student research skills and practices in analytical chemistry studies.

CONCLUSION

As a whole, non-practical learning activities could not replace laboratory work to develop students' scientific knowledge. The fundamental reason is that a real event contains more information than any representation of it. All current approaches (role play, video demonstration, virtual laboratories) are selective, to a greater or lesser extent. However, the student will get more complete data on what happens by engaging in inquiry demonstration, than they could obtain from observing a representation or traditional lecture. However, they may gain more by doing laboratory work where there are kinesthetic aspects of the learning. Further, we pay more considerable attention when we carry out actions ourselves.

Philippine schools still resort to the traditional lecture method in teaching Analytical Chemistry laboratory. This is mainly due to inadequate of laboratory facilities, equipment, and materials which the literature confirms hinders the implementation of practical work. This paper provided evidence that inquiry demonstrations can enhance students' conceptual understanding as well as increase their motivation and interest to learn chemistry. Furthermore, it is favorable in Analytical Chemistry laboratories, which requires expensive equipment and reagents.

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