INQUIRY LEVEL OF THE UNDERGRADUATE CHEMISTRY LABORATORY MANUALS IN LEBANON

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Abstract

The effectiveness of the undergraduate chemistry laboratory has been the subject of research for several decades. However, it has proven difficult to measure the effectiveness of the chemistry laboratory curriculum without an extensive understanding of its purpose. The laboratory work is considered as an integral part of most chemistry courses. However, a significant proportion of laboratory experiments at the undergraduate level remains highly prescriptive and fails to challenge undergraduate students. This study evaluated the undergraduate chemistry laboratory manuals in a private university in Lebanon. A total of 24 experiments were randomly selected from six chemistry laboratory manuals. Data were collected using Lunetta and Tamir's Laboratory Task Analysis Instrument (1979). Results from the analysis of the LAI data indicated that almost all the experiments focused on the lowest levels of inquiry. Suggestions for modifying the "cookbook" chemistry laboratory manuals were provided to promote student inquiry.

Keywords: Chemistry Laboratory, Undergraduate Chemistry, Laboratory Manuals, Laboratory Experiments, Inquiry Level

Introduction

Laboratory work is a core component of university chemistry courses across the world. Practical work is now well established, but there are considerable variations of practical work that contributes to different science programs throughout the higher education sector.

Laboratory work is one of the main forms of teaching used in all undergraduate science courses, and most chemistry educators agree that laboratory work has an essential role in chemistry education. Also, the Chemistry laboratory is a unique mode of learning, instruction, and assessment. Chemistry laboratories have long been recognized for their importance and unique form in science education. Therefore, the design and analysis of laboratory activities have been of interest to teachers and educational policymakers (Hofstein, 2004).

All educators in the field of science education agree that the combination of new strategies, such as student-centered learning, problem-based learning, conceptual change teaching, case studies, and cooperative learning, with traditional teaching methods, can be used to improve the teaching of an experimental course. This combination will help to achieve the following: 1) Assist in the reform of the educational system; 2) Increase students' motivation; 3) Increase students' interest in learning chemistry; 4) Improve the quality of teaching; 5) Emphasize that the responsibility for learning is the learner's, not the teacher's; and 6) Develop some important abilities and skills in students such as problem-solving skills, communication skills, critical thinking abilities, creative abilities, and lifelong learning abilities (Hofstein & Lunetta, 2004). All of these skills and abilities help us to keep up with the challenges of the 21st century.

Inquiry and Laboratory Instructions

A common goal for science educators is to engage students in inquiry; however, many factors complicate the completion of such a task where the primary factor is its definition. Science educators use unique definitions and criteria for inquiry, with an overlap between them. Brown et al. (2006) describe this dilemma by stating that "What makes difficult to understand is the lack of agreement about what constitutes an inquiry based approach. The bulk of the research has taken place in pre-college classrooms examining the outcomes of various blends of inquiry-based instruction. These studies are hard to compare given the differing meanings for inquiry that have been employed". Educators, texts, and journals struggle to define inquiry in a way that can be used by both secondary school and university researchers because no universal, concrete definitions concerning the levels and terminologies of inquiry exist; therefore, they feel free to define inquiry around their methods as they see fit (Anderson, 2002). The key to understanding the mode of inquiry or inquiry level is to determine who provided the problem, procedures, and solutions. Schwab (1962) proposed a three level taxonomy for inquiry instruction. The Schwab levels were later revised into four (Herron, 1971). The Schwab-Herron classification system is illustrated in Table 1.

Table 1: *The Level of Openness in the Teaching of Inquiry (Schwab, 1962; Herron, 1971)*

	Problem	Ways and Means	Answers	Description
Level 0	Given	Given	Given	Essentially is a typical cookbook experience. This level is typical of experiences students would have if they were learning a laboratory technique or skill.
Level 1	Given	Given	Open	The procedures and questions are given to the student, but the answers/results are for the student to discover.
Level 2	Given	Open	Open	Represents a move towards more student oriented inquiry. This means that the students must generate the procedures as well as the answers.
Level 3	Open	Open	Open	Represents full inquiry. In this level, students take full responsibility for the investigation, from the beginning to the end.

In 2005, Bell et al. modeled a student-centered environments which included four different aspects of inquiry-based learning: 1) Confirmation Inquiry (Level 0) – At this first level, students are provided with the question and procedure method, and the results are known in advance; 2) Structured Inquiry (Level 1) – At this level, the question and procedure are still provided by the teacher; however, students generate an explanation supported by the evidence that they have collected; 3) Guided Inquiry (Level 2) – At this third level, the teacher provides students with only the research question, and students design the procedure method to test their question and the resulting explanations; and 4) Open or Full Inquiry (Level 3) – At this highest level of inquiry, students have the purest opportunities to act like scientists, generating questions, designing and carrying out investigations, and communicating their results.

This is not to say that all learning environments need to be open inquiry environments; however, the lesson construction, lesson goals and the specific needs of the classroom need to be addressed. A truly rich learning environment would include many if not all of these learning modes to fully maximize the opportunities for growth and development (Martin-Hansen, 2002). Using a multi-dimensional approach integrating some aspects of the four models of inquiry (Confirmation Inquiry, Structured Inquiry, Guided Inquiry, Open or Full Inquiry) would result in the best overall learning in all students and the selection of a specific level of inquiry would be determined by the lesson and the learning objectives (Bell, Smetana & Binns, 2005).

Accomplished Teaching of Inquiry in the Chemistry Laboratory Courses

The accomplished teaching of science can be defined regarding the knowledge that teachers use in their teaching (Hewson & Hewson, 1988). According to Hofstein, Nahum, and Shore (2001), during the lessons the teachers engage in the following activities: 1) Leading and tutoring students' work in small groups (cooperative learning); 2) Helping students to solve problems, to ask high-level questions, and to hypothesize regarding certain experimental phenomena; 3) Teachers must switch from the "teaching-by-telling" instructional method to listening to students' ideas and questions; 4) Assessing students continuously using a variety of alternative assessment methods; 5) Making decisions regarding the level of inquiry required for a specific activity; 6) Encouraging students to find links between the experiment and the concept taught or discussed in the chemistry classroom; and 7) Maintaining and demonstrating high safety standards (Hofstein, Nahum, & Shore, 2001). Teachers should act as facilitators who guide students' inquiry, thus enabling them to construct more scientific concepts (Hofstein & Lunetta, 2004).

Moreover, to implement learning by inquiry in the science classroom and the laboratory, it is essential that teachers have the first-hand experience with all the cognitive dimensions and practical stages that accompany such learning (Hofstein et al., 2004). Hofstein (2004) stated that teachers need: knowledge, skills, and resources that enable them to teach effectively in practical learning environments; to be able to help students interact intellectually as well as physically, involving hands-on investigation and minds-on reflection; and ways to find out what their students are thinking and learning in the science laboratory and classroom.

On the other hand, Deters (2005) found that the major barriers to implementing inquiry-based experiments in universities are clustered in 11 areas: 1) Lack of Time - Many science educators (Backus, 2005) reported that many teachers perceive that inquiry is too time-consuming, and thus they cannot cover the curriculum; 2) Teacher Beliefs - Brown, Abell, Demir & Schmidt (2006) interviewed 19 college science professors and found that the overriding constraint to implementing inquiry was their narrow view of inquiry-based instruction. They believed that inquiry-based laboratory work was a totally student-directed, unstructured, and time-consuming activity; 3) Lack of Effective Inquiry Materials - Cookbook-style laboratory activities are by far the most common among commercial chemistry curricula, and thus teachers have difficulties finding inquiry materials (Cheung, 2006a); 4) Pedagogical Problems - The pedagogical problems compiled by Costenson & Lawson (1986) include: inquiry labs require too much energy to teach, inquiry is risky because the administration may not understand what is going on and think that the teacher is doing a poor job, and inquiry textbooks lock a teacher into a particular teaching sequence, and the teacher cannot skip labs because there is too much new material in each lab; 5) Management Problems - Science teachers generally view inquiry teaching as very difficult to manage because they cannot control what is going on in the laboratory (Cheung, 2006a); 6) Large Classes - The majority of the existing literature on inquiry-based laboratory work focuses on classrooms in developed countries (Roehrig & Luft, 2004). Inquiry-based laboratory work has become an important teaching method in university education, but large numbers of students is a logistical nightmare for undergraduate science courses even though multiple sections of an inquiry lab can be arranged and teaching assistants are available (Brown et al., 2006); 7) Safety Issues - One of the key features of inquiry-based laboratory work is that students have to design their procedures, but some teachers are afraid that students might design an unsafe procedure (Deters, 2005); 8) Fear of Supporting Student Misconceptions - For inquiry-based laboratory work, there is a possibility that students just prepare a crude plan, arrive at erroneous results, or fail to draw appropriate conclusions based on the results (Deters, 2004); 9) Student Complaints - Some teachers feel that implementing inquiry-based laboratory work is very frustrating because students may complain that the inquiry process induces feelings of insecurity (Backus, 2005; Roehrig & Luft, 2004); 10) Assessment Issues - Paper-and-pencil tests are invalid for assessing student performance in the laboratory (Lazarowitz & Tamir, 1994), and most teachers are hesitant to include scientific inquiry activities in their science teaching because they are not sure how to adequately and accurately assess student performance (Lunsford & Melear, 2004); and 11) Material Demands - Sometimes the number of chemicals used is far greater than in a traditional laboratory (Gallet, 1998). Teachers think that it is expensive to equip the laboratory for inquiry (Costenson & Lawson, 1986). In summary, instructors experience a lot of barriers when implementing inquiry-based laboratory work. Common barriers include lack of time, management problems, and safety issues. Chemistry instructors are always under constant pressure to implement inquiry-based laboratory work, but large class size is one of their major concerns.

According to Cheung (2007), inquiry-based laboratory work is to be implemented in a manageable way in a large class, it must satisfy at least six criteria: 1) the laboratory work should be designed as a guided inquiry rather than an open inquiry; 2) the guided inquiry must engage students in solving real-world problems; 3) the solution to the guided inquiry should not be predictable; 4) the teacher should require a few groups of students to present their experimental plans orally so that a feasible procedure for collecting data can result from a consensus approach; 5) teacher questioning is critically important during student oral presentations; and 6) assessment criteria must be given to students in advance.

Historical Analysis of Laboratory Manuals

In the history of science education, specifically last 100 years, there was no single laboratory manual evaluated asked the students to generate the question or problem to be investigated. Nor, did the student generate a hypothesis based on the exercise question. Few of the laboratory exercises asked the students to predict the results or to design the observational or measurement procedures (Ramsey & Price, 1926). None of the exercises asked the students to design an experiment or exercise. Most of the laboratory exercises were sufficient in requiring the student to carry out qualitative and quantitative observation/measurements. Object manipulation was seen in most laboratories. Most laboratories required the student to record some data, typically observational. Most laboratories did not require data manipulation or calculation, as the nature of the laboratory was observational only. Zumberge and Rutford (1979) found that only three laboratory exercises required the student to decide on the laboratory design. In general, most laboratory exercises did not ask students to predict results or alternate data based on the learning and exercise. Nor were students asked to formulate hypotheses based on results of the investigation.

Unfortunately, a large proportion of K-12 laboratory manuals is geared toward anything by the lowest levels of Bloom's taxonomy (Hoffstein & Lunetta, 1982). The trend is even less clear in that there is a miserable lack of assessment of college laboratory manuals (Tweedy & Hoese, 2005). One study, done by Basey et al. (2000), found that laboratory manuals and instruction were seriously lacking in higher aspects of Bloom's taxonomy and were lacking in inquiry based design which means that college laboratory manuals do not involve the students in the planning, design or organization of data.

This research examined and analyzed the undergraduate chemistry laboratory manuals in one private university in Lebanon. This study aimed to evaluate and analyze the structure (inquiry level) of undergraduate chemistry laboratory manuals.

Research Methodology

In this study, the researcher used content analysis to collect data related to the chemistry laboratory manual analysis.

Sampling

This study took place at a large private university in Beirut during the spring 2014 semester which is for four months and covered a sample of six Chemistry laboratory courses. The sample was selected from six chemistry laboratory manuals, where each lab manual has ten experiments. And for this study, only four experiments were systematically selected from each laboratory manual (1st, 4th, 7th and 10th), and were evaluated and analyzed (see Table 2).

Data Collection Tools

For this study, the first researcher analyzed the undergraduate chemistry laboratory manuals in one of the universities in Beirut (Lebanon) using a modified version of the Laboratory Task Analysis Instrument (LAI) (Lunetta & Tamir, 1979) (see Appendix A). The evaluation was done by the researcher and by one of the Chemistry professors in the Natural Science Division in the assigned university, and the results were validated.

Descriptive Information for the Laboratory Task Analysis Instrument (LAI)

The modified *Laboratory Task Analysis Instrument (LAI)* analyzes and looks at laboratory activities from nine categories: activity planning and design, student performance behaviors, student analysis and interpretation of results, student application of laboratory findings, subject matter, structure (high-low cognitive level, open-ended, prescriptive), relation to text (timing), mode of participation (individual, group, whole-class), and manual orientation. The nine categories contain many questions that are designed to clarify the manipulative, social and thinking behaviors that characterize scientific investigations. Each category contains from two to ten sub-categories to further identify out the differences between laboratory manuals. The perspectives and questions are recorded in a table that the researcher can easily use to analyze and describe particular laboratory activities, modules or courses. The rubric was modeled and used by Lunnetta and Tamir (1979) and was updated by Fitzgerald and Byers (2002).

Data Gathering Procedure

Before the beginning of the Spring 2014 semester, an email was sent by the researcher to the chairperson of the Natural Sciences Department of the university that covered during this semester six Chemistry laboratory courses (see Table 2) to take permission to conduct the study, and it was approved.

Data Analysis

A modified version of the Laboratory Task Analysis Instrument (LAI) (Lunetta & Tamir, 1979) was used in this study to evaluate the inquiry level of the written laboratory manuals. The laboratory manual analysis coding is built into the LAI rubric, and no computer assistance is needed in the analysis. Six laboratory manuals from one large private university in Beirut were evaluated, and four experiments (1st, 4th, 7th and 10th) from each manual were chosen (see Table 2). These manuals were of the home-grown type; this means that the teaching faculty had compiled and modified the laboratory experiments from different books. In the analysis, a "-" sign indicated that the manual did not call for this student behavior, a "+" sign indicated that the manual called for this student behavior, and a "0" sign indicated that the manual was unclear or vague concerning this student outcome. The qualitative data from LAI were analyzed in-depth to have a clear vision related to the inquiry levels in the laboratory manuals.

Results

Following is a summary of the evaluated manuals:

Planning and Design: In no manual were the students expected to plan or design their experiments. They were not expected to formulate a question, to define the problem to be investigated, to predict experimental results based on their question, to formulate a hypothesis to be tested in their investigation, to design observation or measurement procedures, or to design experiment.

Performance: The laboratory experiments had the students make qualitative and quantitative observations (describe observations) or measurements (record results). Students were asked to manipulate apparatus and to develop techniques. Moreover, they were asked to perform numerical calculations by providing them with the equations and formulas. More than 90% of the laboratory experiments allowed the students to explain an experimental technique, and less than 10% asked them to decide on an experimental technique. None of the laboratory experiments allowed students to work from their design creatively.

Analysis and Interpretation: Most of the results of the laboratory experiments were displayed in a table. In some labs, students were asked to draw an image and in other labs, they were asked to plot graphs. Qualitative and quantitative relationships were done in all laboratory experiment, and the students were asked to explain these relationships. Students were expected to determine the accuracy of the experimental results and to define/discuss the limitations that underlie the experiment. Almost none of the experiments ask the student to formulate or propose a generalization or model. Students were expected to explain data errors or when to stop collecting data but were not asked them to formulate new questions or define problem-based upon results of an investigation.

Application: None of the experiments asked students to predict or to formulate a hypothesis based on results of an investigation. In all experiments, students were not expected to apply an experimental technique to new problems and variables.

Subject Matter: All the manuals were aligned with standards for a chemistry laboratory and provided the opportunity to learn further content (to repeat the laboratory exercises). All the material provided to the students contains accurate and clear content.

Structure: All the manuals are heavily high degree cookbook and low degree inquiry in instructional mode. Each experiment gave students step by step instructions on what to do: what to add, how much, and what to expect.

Experiment Relation to Text: None of the experiments precede text. All of them either follow the text or integrated with it. This means that all the laboratory manuals had spaces within the text/experiment to write, draw or add data collected during the laboratory period.

Participation Mode (Student Participation): In the laboratory text, it was very difficult to determine the extent of student participation. Whether the students worked individually, in small groups or pooled, results were unclear.

Manual Orientation: All of the manuals had a safety page, but no direct wording on how the laboratory manual was to be used. None of the manuals had a student or instructor orientation page (how to use manual).

That laboratory experiments are highly structured in that they provide step-by-step detailed instructions. They usually ask students to manipulate materials, make observations and measurements, record results, make qualitative and quantitative relationships, draw conclusions, make inferences and generalizations, and communicate and interpret the results. These manuals; however, did not provide opportunities for students to pose a question to be investigated, formulate a hypothesis to be tested, or predict experimental results; to design observations, measurements, and experimental procedures; to work according to their own design; or to formulate new questions or apply an experimental technique based on the investigation they performed. Also, it was found that students are not usually directed to discuss goals and strategies in pre-laboratory discussions, discuss their findings and their meanings or implications in post-laboratory discussions, discuss sources of experimental error, or comment on limitations in their measurements or on assumptions underlying the experiment. It was seldom suggested that students pool their results either when all groups have done the same procedure or when groups have investigated different parts of a common question.

According to Schwab (1962) and Herron (1971), there are four levels of inquiry (from Level 0 to Level 3). All the analyzed laboratory experiments are structured inquiry (Level 1). This means that the procedures and question are given to the student but the answer/results are for the student to discover. In this level, students investigate a teacher-presented question through a prescribed procedure. This level is commonly referred to as "cookbook labs" because they include step-by-step instructions, but at this level, experiments answer a research question. It is important to mention that the majority (83.33%) of laboratory experiments in most textbooks are written at Level 1 (Structured Inquiry level) where the Problem and Ways/Means are given, but the Answers are open (see Table 2).

Table 2: Level of Inquiry of the experiments according to Herron and Schwab

		Inquiry Level			
Courses and Experiments		**Level 0**	**Level 1**	**Level 2**	**Level 3**
General Chemistry Lab- CHM1					
Exp1	Density		√		
Exp4	Heat Capacity		√		
Exp7	Molecular Weight Determination		√		

Exp10	Identification of Household Chemicals	√			
Quantitative Analysis- CHM2					
Exp1	Molecular Determination of Hydrated Salt		√		
Exp4	Acidity of Vinegar and Stomach Antacids		√		
Exp7	Potentiometric Redox Titration		√		
Exp10	Determination of Nitrogen By Kjeldahl's Method		√		
Organic Chemistry Lab 1- CHM3					
Exp1	Melting Point Determination		√		
Exp4	Simple and Fractional Distillation		√		
Exp7	Preparation of Cyclohexene		√		
Exp10	Preparation of Isoamyl Acetate		√		
Organic Chemistry Lab 2- CHM4					
Exp1	Synthesis of Aspirin		√		
Exp4	Reactions of Aldehydes and Ketones	√			
Exp7	Reactions of Carboxylic Acids	√			
Exp10	Amino Acids and Proteins	√			
Physical Chemistry Laboratory- CHM5					
Exp1	Rate Law For Irreversible Exothermic Reaction of the Decomposition of Hydrogen Peroxide		√		
Exp4	Saponification of Ethylacetate- 2nd Order Reaction by Conductimetric measurements		√		
Exp7	Variation of Solubility Product with Temperature		√		
Exp10	Introduction to the Principle of Operation of a Fluorometer		√		
Instrumental Analysis- CHM6					
Exp1	Conductivity		√		
Exp4	Experimental Applications of the Technique of Visible UV and Fluorimetry		√		
Exp7	Polarography and Atomic Absorption Spectroscopy		√		
Exp10	NMR Technique		√		
24 Experiments		**16.67%**	**83.33%**	**0%**	**0%**

Discussion

The history of laboratory instruction fully supports inquiry learning. The inquiry based experiences enhance students' cognitive gains and improve their attitudes toward science and science curriculum. This information has been known for over 100 years, yet university laboratory settings remain characteristically "cookbook." Tweedy and Hoese (2005) stated that it is well known that all laboratory experiences by most students are typically verification exercises guided by "cookbook" type recipes and the education researchers have redefined almost all laboratory 'experiments' in high school laboratory manuals as really 'exercises.' This is problematic in that students might not know where the exercise went wrong as they were simply "following the procedure." This type of laboratory experience would certainly teach students to follow instructions only but fails to teach them to think like scientists and to solve a problem when unexpected results occur. After all, students have the ability to take greater ownership of their learning, make authentic decisions, and construct meaning for themselves at the higher levels of inquiry. Moreover, Level 1 (Structured inquiry) experiments can become a Level 2 (Guided inquiry) by simply removing the procedural directions, and this can be done gradually all over the semester. Increasing the amount of inquiry based instructional activities in both lecture and laboratory has been at the heart of most calls for curriculum reform at all levels (Lederman, 2004).

The significance of this research lies in its ability to move forward the conversation regarding the most appropriate goals and pedagogies for the undergraduate chemistry laboratory.

Faculty whose instructional goal is to move students from structured laboratory experiences to increased responsibility for decision making in the laboratory can modify their experiments in order of increasing levels of inquiry. For example, consider a laboratory where students are asked to confirm that the rate of reaction increases with temperature. Students might be given a chemical system to investigate, a data table to fill out, and post laboratory questions to answer. Using the inquiry rubric this laboratory would be a Level 0, the students are simply verifying the relationship. However, the level of inquiry could be increased by stating that the students are to investigate the relationship between temperature and reaction rate. The chemical system could still be given, but the students could be asked to develop a hypothesis, data collection and analysis procedures, and viable conclusions consistent with the data that evaluate the veracity of the hypothesis. This laboratory experiment has been transformed into Level 2. The inquiry rubric also lends itself to use in curriculum evaluation. Departments that are engaged in programmatic evaluation can use this reliable and robust rubric to characterize the current curriculum. If results from using the inquiry rubric indicate a poor fit between the declared departmental or programmatic goals and the reality of student experience, then the rubric provides a roadmap to direct meaningful data-driven change. For example, if the general chemistry laboratory curriculum is analyzed and none of the laboratories are rated as level 2 or 3, then the curriculum can be modified. Level 0 or Level 1 laboratory experiments could be replaced with Level 2 experiments that use a more open inquiry approach. Alternatively, current laboratory activities could be modified to include experiences where the students design data collection and analysis procedures and proposed viable solutions based on the data.

Bruck, Bretz, and Towns (2009) analyzed 229 undergraduate chemistry laboratories in 13 laboratory manuals in the US. This huge sample that consists of 13 chemistry laboratory manuals includes six general chemistry manuals, two GOB (general, organic, biochemistry) manuals, four organic manuals, and one biochemistry manual. Their findings indicated that nearly 90% of the experiments were highly structured (Level 0 or 1) laboratories with little opportunity for student independence. But the vast majority of experiments (83%) were classified as Level 1 structured inquiry. These findings will not contradict our findings where the majority of the evaluated experiments (83.33%) were also Level 1 structured inquiry (where the Problem/Ways and Means are given, but the Answers are open).

A close observation of the course curriculum objectives and learning outcomes in the syllabus of the six courses (CHM1, CHM2, CHM3, CHM4, CHM5, CHM6) with that of the major program objectives and outcomes stated by the Natural Sciences Department does not reveal the implementation of inquiry-based approach in the chemistry laboratory practical courses (Table 3 and Table 4). They all show a structured Level 1 inquiry (low-level inquiry) where both the problems and the procedures are given, but the students are asked to collect data, do calculations, plot graphs, and conclude. Those simple objectives of the course that bring round to practical chemistry were to familiarize students with basic practical skills, such as: learn about safety, identify, recognize, observe, taking measurements, use instruments, plot graph, collect data, do calculations, draw conclusions, describe, demonstrate, analyze, and use computer in modern instrument techniques. The word 'Inquiry' is not used in all the program and courses objectives and learning outcomes.

It does seem very important that, for practical work to be effective, the objectives should be well defined. When planning a course it is crucial to state clearly the intended objectives: what to be taught, and most importantly, what are the intended outputs of the course, in a very clear way (Lunetta, 1998). Undergraduate activities generally have two major purposes: they should give the student an opportunity to practice various inquiry skills, such as planning and devising an experimental program to solve problem, and an investigational work, which involves individualized problem solving, which is highly motivational especially if the student develops a sense of ownership for the problem (Boud et al., 1989). No single experiment in this study was identified primarily targeted to help students apply scientific reasoning, to test the hypothesis, to formulate a hypothesis and to work out problems which are another important aims for an involvement of laboratory activities in any science education. To realize outcomes that focus on scientific method requires the provision of experience in real investigations (Tafa, 2014).

Students should have experiences in seeing problems and seeking ways to solve them (when students themselves design experimental procedures), interpret data, make generalizations and build explanatory models to make sense of the findings, etc. (Hegarty-Hazel, 1990), which are non-existent in the six manuals. The concern of most of the laboratory experiments of all manuals has been identified as the achievement of basic chemistry concepts. This was revealed through a close relationship between the content of the course and the students' task in the laboratory.

Recommendations

In light of the literature review done, the recommendations are: first, each experiment should be revised by deciding who is making the decisions the instructor, text or the student. There should be activities designed for goals other than teaching students particular skills. Hence besides their role of strengthening the theoretical parts, other aims like to help students apply scientific reasoning, to test hypotheses, to formulate hypotheses and to work out problems should be included; second, procedures need to be changed by taking a Level 0 or Level 1 experiment and making a few changes to make it more like a Level 2 or Level 3 experiment. Progressive changes must be made in the experiment students do so that over the course of time they will move from doing level 0 or 1 experiment to doing experiments that seem more like level 2 or 3. By then, they are figuring things out for themselves, interpreting results, perhaps even repeating procedures. In short they will be thinking the way scientists do about what they are doing; third, the inquiry scale should be seen as a continuum, so ideally students should progress gradually from lower to higher inquiry levels over the course of a semester. Although the goal is to help students develop the skills and knowledge to conduct Level 3 open inquiries, they cannot be expected to begin there. They need practice in inquiry, building up increasingly open to complex levels. They cannot be expected to conduct high-level inquiry investigations after having participated in low-level activities throughout the semester; fourth, students must be engaged in inquiry-based learning environment, they should: (a) Be engaged in scientifically oriented questions, (b) Give priority to evidence, allowing them to develop and evaluate explanations that address scientifically oriented questions, (c) Formulate explanations from evidence to address scientifically oriented questions, (d) Evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding, and (e) Communicate and justify their proposed explanations. These five elements are essential characteristics of an inquiry-based learning environment and also describe the inquiry practices that students should strive to appropriate (NRC, 2000); fifth, well designed inquiry-type laboratory activities can provide learning opportunities that help students develop high-level learning skills. They also provide important opportunities to help students learn to investigate (ask questions), to construct scientific assertions, and to justify those assertions in a classroom community of peer investigators in contact with a more expert scientific community.

There is no doubt that such activities are time-consuming; therefore, the university systems must provide time and opportunities for instructors to interact more with their students and also to give them more time to perform and reflect on any complex inquiry and investigative tasks. Such experiences should be integrated with other chemistry learning experiences taken in other science courses in order to enable the students to make connections between what is learned in the classroom and what is learned and investigated in the laboratory; sixth, incorporating inquiry-type activities is inhibited by limitations in resources (including access to appropriate technology tools) and by lack of sufficient time for instructors to become informed and to develop and implement appropriate chemistry curricula.

Other obstructing factors include large classes, inflexible scheduling of laboratory facilities, and low budget for the department; seventh, the implementation of inquiry-type laboratories require a prolonged commitment and intensive efforts of all parties involved, including curriculum developers, researchers, instructors education programs, university administrators, science instructors, and students. Such efforts also require the financial and administrative support of the Ministry of Education; furthermore, knowledge gained from laboratory manual's evaluation will promote faculty to fully evaluate and implement what is used in the hands-on environment.

This research could lead to dramatic curricular changes within and among science departments among university campuses; and finally, it is very important to mention that one of the most crucial problems regarding the implementation of inquiry-type laboratory experiments is the issue of assessing students' achievement and progress in such a unique learning environment. As instructors, whose goal is to assess comprehensively what takes place in the laboratory, we should use appropriate assessment tools and methodologies to identify what students are learning both regarding concepts as well as procedures. The effect of such experiences on students' interest and motivation should also be assessed.

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Appendix A: General Rubric Used in Laboratory Manual Analysis (LAI)

Planning and Design	
Formulates a question or defines problem to be investigated	
Predicts experimental result	
Formulates hypothesis to be tested in this investigation	
Designs observation or measurement procedures	
Designs experiment	
Performance	
Carries out qualitative observation	
Carries out quantitative observation or measurement	
Manipulates apparatus; develops technique	
Records results, describes observation	
Performs numeric calculations	
Explains or makes a decision about experimental technique	
Works according to own design (creative)	
Analysis and Interpretation	
Transforms result into standard form (other than graph)	
Determines qualitative relationships	
Determines quantitative relationships	
Determines accuracy of experimental data	
Defines or discusses limitations and/or assumptions that underlie the experiment	
Formulates or proposes a generalization or model	
Explains a relationship	
Explains data errors or when to stop collecting data	
Formulates new questions or defines problem based upon result of investigation	
Application	
Predicts, based upon result of investigation	
Formulates hypothesis based on results of investigation	
Applies experimental technique to new problem and variable	
Subject Matter	
Material aligned with standards	
Provides opportunity to further learn content	
Contains accurate content	
Structure	
High degree cookbook	
Low degree -- inquiry	
Experiment Relation to Text	
Precedes text	
Follows text	
Integrated with text	
Participation Mode	
Students work on common task and keep individual results	
Students work on common task and pool results	
Students work on different task and pool results	
Post-lab discussion required	
Students work communicate results in various modes	
L. Manual Orientation	
Paragraphs on orientation/learning position	
Guide to student on how to use manual	
Guide to teacher on how to use manual	