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ASSESSMENT OF THE LEARNING ENVIRONMENT OF INQUIRY-TYPE LABORATORIES IN HIGH SCHOOL CHEMISTRY

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ABSTRACT. An inquiry-type laboratory has been implemented into the chemistry curriculum in high schools in Israel. In this study, we investigated the idea that generally the science laboratory provides a unique learning environment that differs from the learning environment that exists in classrooms in which other instructional techniques are used. Moreover, the inquiry laboratory provides students with a learning situation in which they are involved in activities that might influence some of the variables that are influencing the learning environment of such laboratories. In this study, the Science Laboratory Environment Inventory (SLEI) was used to assess the students' perceptions of their chemistry laboratory learning environment. Statistical comparison of two groups (control and inquiry) revealed significant differences between the groups regarding their actual perceptions. Moreover, it was found that the differences between the actual and preferred laboratory learning environment were significantly smaller for the inquiry group than for the control group.

KEY WORDS: assessment, chemistry learning, inquiry, learning environment, science laboratory, science learning

1. Introduction

1.1. *The Inquiry Laboratory in Science Education*

Laboratory activities have long had a distinctive and central role in the science curriculum and science educators have suggested that many benefits accrue from engaging students in science laboratory activities (Hofstein & Lunetta, 1982; Lunetta, 1998). More specifically, when properly developed, inquiry-centred laboratories have the potential to enhance students' constructive learning, conceptual understanding, and understanding of the nature of science. Inquiry-type experiences are especially effective if conducted in the context of, and integrated with, the conceptual development of the topic taught.

The *National Science Education Standards* (National Research Council, 1996) presented a statement on teaching science as inquiry. The *Standards* define what all students should know and what kind of learning experiences they need in order to achieve scientific literacy. Moreover, they

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reaffirm the conviction that inquiry is central to the achievement of scientific literacy. The *Standards* use the term inquiry in two ways: (1) inquiry as *content understanding* (in which students have opportunities to construct concepts, patterns and meaning about an idea in order to explain what they experience) and (2) inquiry as *abilities* (Bybee, 2000). Under the heading of abilities or skills, Bybee includes identifying questions, designing and conducting scientific investigations, formulating and revising scientific explanations, recognising and analysing alternative explanations, and communicating and defending scientific arguments. It is suggested that many of these abilities are in alignment with those that characterise inquiry-type laboratories. In addition, Hofstein and Walberg (1995) reported that inquiry-type laboratories are central to learning science, because students are involved in the process of conceiving problems, formulating hypotheses, designing experiments, gathering and analysing data, and drawing conclusions about scientific problems or science phenomena. These, it is suggested, should be integrated with the other complementary activities such as the development of scientific concepts and related scientific skills and experiences. One must remember that student inquiry can range from independently conducted research on different issues to the investigation of a research question by the entire class (Lunetta, 1998).

In conclusion, there is no doubt that inquiry teaching and learning poses a challenge to both teachers and students (Kracjik, Mamlok & Hug, 2000).

1.2. *The Science Laboratory Learning Environment*

Classroom learning environments in science have been studied extensively in the last 30 years in order to determine their relationship to teaching strategies and the social interactions between teacher-students, students-students, and students-subject matter, during the process of instruction. These efforts are summarised in several published reviews, the most recent one being Fraser (1998).

Because measures of learning environments have been found to be related and sensitive to instructional methods, they can be used in order to improve instruction and pedagogy in certain scientific subjects taught in schools (Hofstein & Lazarowitz, 1986; Maor & Fraser, 1996; Walberg, 1970). Furthermore, it is suggested that information about students' perceptions of their classroom learning environment could guide curriculum developers, teachers and those responsible for their professional development, in searching for improved instructional techniques and teaching/learning methods that can contribute to positive aspects of the classroom environment. In recent years, investigating the pedagogy of science teaching in general, and the effectiveness of certain instructional techniques particularly in the context of science teaching, has become one of the key issues in our attempt to maintain new standards and attain new goals in science education (National Research Council, 1996).

We operate in an era in which the teaching of science and the formulation of curricular materials and instructional strategies should be tailored to the abilities, aptitudes, and motivational patterns of different students (Hofstein & Kempa, 1985; Hofstein & Walberg, 1995). The overall objective is to create a learning environment that allows students to interact physically and intellectually with instructional materials through hands-on experiences, and through minds-on and inquiry-oriented activities (Tobin, Capie & Bettencourt, 1988). All these are in fact a call for varying the instructional techniques that are used in the science classroom, which will improve the classroom learning environment. The science laboratory is central in our attempt to construct a learning environment in which students construct their knowledge base and their understanding of scientific concepts as well as skills related to the scientific process.

The science laboratory is a setting in which the students work cooperatively in small groups to investigate scientific phenomena, a unique mode of instruction, and a unique mode of learning environment. Hofstein and Lunetta (1982) and Lazarowitz and Tamir (1994) suggest that laboratory activities have the potential to enhance constructive social relationships as well as positive attitudes and cognitive growth. Cooperative team effort is required for many laboratory activities. The less formal atmosphere (compared to the classroom), and the opportunities for more interaction between students and teacher and between students and their peers, have the potential to promote positive social interactions and thus create a constructive and positive learning environment (Lazarowitz, 1991; Lazarowitz, Baird, Hertz-Lazarowitz & Jenkins, 1985; Tobin, 1990).

In regard to the laboratory learning environment, Lazarowitz and Tamir (1994) wrote that:

> The opportunity to work in groups may illuminate how students collaborate and assist one another. These social learning activities are vital for mastering scientific concepts and inquiry skills, since the group work imitates the teams of scientists who work in research. (p. 114)

1.3. *Past Use of the Science Laboratory Environment Inventory (SLEI)*

The Science Laboratory Environment Inventory (SLEI) was developed and validated in Australia and in other countries by Fraser, McRobbie and Giddings (1993). The original instrument includes 72 items in eight learning environment dimensions (scales): Cohesiveness, Open-Endedness, Integration, Rule Clarity, Material Environment, Teacher Supportiveness, Involvement and Organisation. We decided to use the original version because it was used and validated in the past in Israel in a comparative study regarding chemistry and biology laboratory learning environments (Hofstein, Cohen & Lazarowitz, 1996). For more details about the instrument, see Table I.

The SLEI has been used in several studies throughout the world. In particular, a comparative study of students' perceptions was conducted in six countries: UK, Nigeria, Australia, Israel, USA, and Canada (Fraser & McRobbie, 1995). Fisher, Henderson and Fraser (1997) confirmed the reliability and validity of the SLEI in an investigation of the associations between students' perceptions of the biology laboratory environment and student outcomes. When McRobbie and Fraser (1993) investigated the association between student outcomes and classroom environment in science laboratory class settings, they found that student' perceptions of the laboratory learning environment accounted for significant amounts of the variance in students' outcome beyond their abilities. In Israel, in the context of chemistry and biology learning, Hofstein et al. (1996) used a Hebrew version of the SLEI in comparing students' perceptions of actual and preferred learning environment of laboratory classes in chemistry and biology. They found significant differences between chemistry and biology laboratory environments for two scales, namely, Integration (which describes the extent to which the laboratory activities are integrated with other non-laboratory classroom activities), and Open-Endedness (which measures the extent to which the laboratory emphasises an open-ended approach to experimentation). Differences were also found between students' perceptions of the actual and preferred learning environments when Fisher, Harrison, Henderson and Hofstein (1999) conducted a comparative study using the SLEI in biology, chemistry, and physics school laboratory classes. They found that the SLEI differentiates between these three subject areas regarding students' perceptions of laboratory classes. This could be due to the nature and type of the laboratory experiences used in these scientific topics.

2. The Study

2.1. *The Chemistry Curriculum*

The present study was conducted in the context of the development, implementation, and evaluation of an inquiry laboratory used in high school

TABLE I

Descriptive Information and Reliability for the Science Laboratory Environment Inventory (SLEI)

Scale	No. of items	Description (The extent to which:)	Sample item	Alpha reliability coefficient	
				Actual	Preferred
Teacher supportiveness	9	… the teacher/instructor is helpful and shows concern for all students.	The teacher is concerned about students' safety during laboratory sessions. (+)	0.79	0.74
Involvement	9	… students participate actively and attentively in laboratory activities and discussions.	During laboratory group work, students leave it to their partners to do all the work. (–)	0.60	0.57
Student cohesiveness	9	… students know, help and are supportive of one another.	Students in this laboratory class get along well as a group. (–)	0.65	0.58
Open-endedness	8	… laboratory activities emphasise an open-ended, divergent, individualised approach to experimentation.	We know the results that we are supposed to get before we commence a laboratory activity. (–)	0.54	0.58
Integration	9	… laboratory activities are integrated with non-laboratory and theory classes.	We use the theory from our regular science class session during laboratory activities. (+)	0.80	0.81
Organisation	9	… laboratory activities are clearly defined and well organized.	There is confusion during laboratory classes. (–)	0.56	0.63
Rule clarity	8	… behaviour is governed by formal rules.	There is a recognised way of doing laboratory work. (+)	0.50	0.44
Material environment	9	… laboratory equipment and materials are adequate.	The laboratory is too crowded when we are doing experiments. (–)	0.68	0.84

chemistry in Israel. The chemistry curriculum that is followed in high schools in Israel is *Chemistry: A Challenge* (Ben-Zvi & Silberstein, 1985). This curriculum was developed on the basis of an intensive and comprehensive study of students' misconceptions and learning difficulties. In general, the experiments used in this program are designed to:

- help in explaining chemistry concepts;
- familiarise students with the properties of substances and compounds;
- help students to understand the consecutive steps used to form a specific scientific theory.

In general, most of the tasks in these experiments are clear, 'closed ended', and directly related to the concepts being taught at that time in the regular classroom (i.e. the non-inquiry laboratory learning experiences).

In an attempt to enhance the students' involvement in constructing their knowledge of chemistry concepts and ideas, inquiry-type laboratories were introduced into the teaching and learning sequence of school chemistry. This article focuses on a comparison of the laboratory learning environment with and without the inquiry component.

2.2. *Objectives of the Study*

The main goal of this study was to develop, implement, and assess the outcomes of inquiry-based laboratory experiments that were implemented in the context of high school chemistry classes in Israel. More specifically, the objectives of this study were:

- to create an innovative laboratory learning environment by introducing inquiry-type experiments;
- to develop a method for the professional development of chemistry teachers who plan to implement such laboratory experiences;
- to assess students' perceptions regarding their laboratory learning environments;
- to determine (qualitatively and quantitatively) whether the incorporation of inquiry experiments into the chemistry laboratory reduced the differences between the actual and preferred students' perceptions of the laboratory learning environment.

3. Methodology

3.1. *Stages of the Study*

The study was conducted in three consequent stages during the academic years 1997–2000.

The first stage included the development of a series of about 50 experiments to be incorporated into the regular chemistry curriculum used in Grades 10–12 in Israel. All the experiments were part of the conceptual development of the chemistry key concepts (e.g. acids-bases, oxidation-reduction, bonding, energy). The inquiry-type chemistry experiments that were developed range from those which are totally 'open' to investigation to those in which the student is asked to conduct only a partial inquiry. These could include designing and planning the experiment, interpreting the results and arriving at a scientific conclusion. In the past, Herron and Pella (see Hofstein, 1988) suggested the idea of 'degree of freedom' given in the laboratory to describe the level of inquiry for each of the experiments. (For information about the instructions given to the students regarding the execution of a typical inquiry experiment, see Table II).

The second stage was mainly devoted to the professional development of chemistry teachers and the development of valid and useable assessment tools. The assessment tools were tried out by those teachers who underwent the professional development. They tried the newly developed assessment tools, both on their peers as well as on their students in their schools. This procedure helped to improve the validity and usability of the tools (Levy Nahum, 2000).

The third stage was mainly devoted to the implementation of the program and the assessment of students' achievement and progress. Also, at this stage, we were involved in evaluating the impact of the program on

TABLE II

Components of Inquiry-Type Experiments (Criteria for Assessment) and Instructions Given to Students Regarding the Performance of Each Component

Component of inquiry-type experiment	Instructions given to students
Definition of the problem (hypothesis) and asking relevant questions	Try to define the problem and to hypothesise.
Planning of the experiment	Try to plan your experiment accurately, logically, interestingly and efficiently. Present your assumptions at each stage, act independently, and prepare an equipment list.
Performance of the experiment	Follow the safety rules (and instructions); use the proper tools and be careful with the materials.
Observation of phenomena	Observe carefully the materials and changes that occur during the experiment and write them down in your notebook.
Organising and analysing of data, interpretations, and conclusions	Use concise, exhaustive expressions; refer to unclear observations; distinguish between assumptions, explanations and conclusions and reports. Organise your findings in tables or graphs.

the teachers and students, and finally in assessing students' perceptions regarding the laboratory learning environment. This information was obtained using a combination of quantitative and qualitative methods. It was thought that using quantitative measures and interpreting the results qualitatively would provide more credible and authentic insights in our effort to probe students' perceptions of the laboratory learning environment (Tobin & Fraser, 1998).

3.2. *Sample*

The sample consisted of two groups of students, the inquiry and the control groups. The inquiry group consisted of 130 eleventh grade students and the control group consisted of 185 eleventh grade students. The two groups comprised students who opted to study chemistry beyond the tenth grade (where chemistry is compulsory). In addition we had a group of ten teachers who were involved in the inquiry program.

3.3. *Learning in the Chemistry Laboratory*

In the inquiry-type laboratories, the students work cooperatively in small groups (3–4 students each) on inquiry tasks, namely: asking relevant questions, planning an investigation, hypothesising, observing and recording phenomena (for more details about the various activities in which the students were involved, see Table II).

Lazarowitz and Tamir (1994) characterise cooperative learning in the science laboratory as peer tutoring in small investigative groups. They suggest that, in such laboratories, the learning environment is highly affected by the fact that the students are free to study at their own pace, ask questions, interact with each other and with their teachers, and seek information from various sources.

On the other hand, the traditional chemistry laboratory is very task-oriented and thus leaves the students with very few opportunities to engage in the mentioned activities. It should also be noted that the inquiry group usually spends more time in the laboratory compared with the amount of time spent by the control group.

3.4. *Professional Development of the Chemistry Teachers*

The inquiry-type laboratory experiments are very much 'student-centred' activities. Thus, the science teachers operate in a more demanding learning environment in which they can face unforeseen and unplanned situations and phenomena posed by the students. This requires that teachers are more open-minded regarding their role, and are more tolerant, encouraging and flexible (Hofstein & Walberg, 1995). In order to implement learning by inquiry in the science classroom and laboratory, it is essential that the teachers have first-hand experience with all the cognitive dimensions and practical stages that characterise such experiments. This should include asking questions, designing experiments to answer research questions, conducting the experiments, etc. It is suggested that these could only be attained by providing the teachers with comprehensive professional development courses.

Altogether, the teachers who participated in the program had an opportunity to try out about 40 experiments. These experiments were also conducted in small investigative groups similar to the way in which they would be conducted by their respective students. The professional development took place over a period of three years (teachers met once every month for about five hours). In these workshops, teachers worked with the program leaders who provided them with support and guidance regarding the implementation of the inquiry program. Thus, the professional development had a continuous and long-term flavour (an approach that has been highly recommended in recent years by, for example, Loucks-Horsley, Hewson, Love & Stiles (1998). It is suggested that such intensive and comprehensive professional development would ensure that teacher strategies in the laboratory would be aligned with the objectives of the inquiry approach.

3.5. *Measures Used to Assess the Impact of the Program*

3.5.1. *Students' Perceptions (Quantitative Data)*

In order to assess the students' perception of the chemistry laboratory learning environment, we used a Hebrew version of the Science Laboratory Environment Inventory (SLEI) (originally developed in Australia by Fraser et al., 1993, and validated in Israel by Hofstein et al., 1996). This instrument has separate actual and preferred versions. Each version consists of 70 items (two items were deleted due to reliability considerations) in eight scales. (For details about the SLEI, see Table I).

The actual and preferred versions of the 'SLEI' were administered amongst the inquiry group ($N = 130$) and amongst the control group ($N = 185$).

3.5.2. *Students' and Teachers' Perceptions (Qualitative Data)*

Information regarding the students' attitudes and perceptions of the laboratory learning environment and the inquiry approach was obtained mainly from feedback questionnaires administered by their respective teachers and also from structured interviews conducted with several students.

4. Results

4.1. *Quantitative Analysis of Students' Perceptions of the Chemistry Laboratory Learning Environment*

4.1.1. *Comparison of the Students' Actual and Preferred Perceptions of the Learning Environment*

The actual and preferred mean scores for students' perceptions of the chemistry laboratory learning environment in the two groups were compared using *t*-tests. The results are presented in Tables III and IV, respectively, for the actual and preferred forms.

A multiple discriminant analysis was used to derive weights for the eight SLEI scales in order to separate them maximally in discriminant space. For the actual form, the value of Wilks' λ associated with one discriminant function was 0.37 and the F value associated was 62.6 ($df = 8, p < 0.001$). For the preferred form, the value of Wilks' λ was 0.73 and the F value was 13.70 ($df = 8, p < 0.001$). Wilks' λ provides a multivariate test for the statistical significance of the overall differences among several group means in multivariate analysis of variance (Tatsuoka, 1971).

These findings suggest that perceptions of actual and preferred learning environment differ significantly (more pronounced in the actual form) between the inquiry and the control groups. From Table III, it is clear that the most predominant differences are for the scales of Open-Endedness,

TABLE III

Differences Between Inquiry Group and Control Group on Actual Form of SLEI

Scale	Inquiry group		Control group		*t*	*p*
	Mean	*SD*	Mean	*SD*		
Teacher supportiveness	4.26	0.57	4.22	0.53	0.64	
Involvement	3.94	0.43	3.42	0.45	9.99	0.000
Student cohesiveness	3.87	0.47	3.80	0.48	1.39	
Open-endedness	3.27	0.49	2.20	0.41	20.43	0.000
Integration	4.08	0.54	4.20	0.57	–1.99	0.047
Organisation	4.00	0.42	3.85	0.48	2.77	0.005
Rule clarity	3.69	0.48	3.62	0.60	1.08	
Material environment	3.71	0.59	3.55	0.53	2.52	0.012

The sample size was 129 students in the inquiry group and 183 students in the control group.

TABLE IV

Differences Between Inquiry Group and Control Group on Preferred Form of SLEI

Scale	Inquiry group		Control group		*t*	*p*
	Mean	*SD*	Mean	*SD*		
Teacher supportiveness	4.59	0.46	4.47	0.58	2.08	0.0385
Involvement	4.05	0.47	3.94	0.59	1.86	
Student cohesiveness	4.17	0.47	4.10	0.61	1.21	
Open-endedness	3.56	0.57	3.01	0.64	7.76	0.0001
Integration	4.01	0.65	4.33	0.65	–4.30	0.0001
Organisation	4.26	0.48	4.22	0.62	0.56	
Rule clarity	3.82	0.49	3.87	0.69	–0.66	
Material environment	4.27	0.72	4.25	0.66	0.22	

The sample size was 129 students in the inquiry group and 183 students in the control group.

Involvement, and Material Environment, for which the inquiry group students scored significantly higher than the control group.

On the other hand, the control group scored significantly higher on the scale that assesses the level of Integration of laboratory practices with classroom discussions, teachers' whole-class lectures and small-group cooperative learning.

4.1.2. *Differences Between the Actual and Preferred Laboratory Learning Environment*

It has been suggested that the discrepancy between the actual and the preferred learning environment provides an indication of the effectiveness of a certain innovation, instructional technique or new program. The values (mean preferred-mean actual) for the two groups, together with the results of a series of *t*-tests for the eight sub-scales, are presented in Table V.

From Table V, it is clear that the differences between actual and preferred learning environments in the inquiry group are significantly lower compared with the control group for Open-Endedness, Involvement, and Integration.

4.2. *Qualitative Results*

Several interviews were conducted with students and teachers who participated over a period of two years in the inquiry-type laboratories. The following are a few quotes from the audio-recording of these interviews. The SLEI scale to which each quote is relevant is indicated in brackets.

In interviews conducted with students, the following comments were made:

TABLE V

A Comparison of Actual-Preferred Discrepancies for the Inquiry Group and the Control Group

Scale	Actual-preferred discrepancy		*t*	*p*
	Inquiry group	Control group		
Teacher supportiveness	0.33	0.25	–1.44	
Involvement	0.11	0.51	6.89	0.0001
Student cohesiveness	0.30	0.31	0.04	
Open-endedness	0.28	0.81	6.91	0.0001
Integration	–0.06	0.13	3.10	0.0021
Organisation	0.26	0.37	1.94	0.0500
Rule clarity	0.13	0.24	1.78	
Material environment	0.56	0.70	2.03	0.0400

The sample size was 129 students in the inquiry group and 183 students in the control group.

- It gave me an opportunity to develop independent thinking. (Open-Endedness)
- The experiments were connected to the topics and to the concepts that were discussed in the chemistry classroom; thus it helped me to better understand what is going on. (Integration)
- I found out that the most difficult part of the inquiry exercise was the design of the experimental setting and the asking of relevant questions. However, it was challenging. (Open-Endedness)
- I enjoyed sharing ideas and cooperating with my peers in the group. (Student Cohesiveness)
- The fact that we had information about the assessment criteria helped us a lot. (Involvement)
- We got all the materials and equipment that we needed. (Material Environment)
- I enjoyed very much working with my friends on the experimental assignments. (Student Cohesiveness)
- The teacher was always around to help, support and encourage. (Teacher Supportiveness)

Interviews also were conducted with teachers. An indication of satisfaction with the program and a feeling that introducing inquiry approaches to the chemistry laboratory had a positive impact on the learning environment were also obtained from interviewing the participating teachers:

- It matches perfectly with my way of thinking regarding how I teach and how my students learn.
- I have flexibility in selecting inquiry experiments so that they will be tailored to my students' abilities and interests.
- My students enjoy what they do. I believe that these experiences improve my students' attitude towards chemistry.
- The inquiry lab provided me with a new method to assess the progress of my students.
- It helped me in varying the instruction of high school chemistry.

5. Discussion and Summary

In regard to the students' perceptions of the laboratory learning environment, the gap between the actual and preferred learning environment on various scales was significantly smaller in the inquiry group than in the control group. Also, with regard to the actual learning environment, the most predominant and statistically significant differences were observed for the Open-Endedness and the Involvement scales, with the inquiry group having much more favourable perceptions than the control group. These findings indicate a significant improvement in perceptions of the laboratory learning environment as a result of their laboratory experiences.

It was noted that regarding the preferred learning environment that only small differences between the two groups occurred. This means that the expectations are similar no matter to what type of laboratories high school chemistry students are exposed.

We observed that students perceived that they were more involved in the learning process and found the procedures more open-ended. These findings are in alignment with recent trends to enhance the involvement of students in the learning process and in constructing their knowledge of scientific concepts and processes.

Welch, Klopfer, Aikenhead and Robinson (1981) describe inquiry learning as generally associated with much involvement on the part of the students. For example students who learn by inquiry approaches are responsible for developing their own answers to questions rather than exclusively relying on the teacher and/or textbooks.

A comparison of actual-preferred differences in laboratory learning environment revealed that Integration of the laboratory experiences with other pedagogical interventions and classroom instructional techniques was associated with a significant reduction in the magnitude of the differences. In other words, the inquiry group found the actual learning environment significantly more aligned with their preferred environment compared with the control group. The results obtained from student interviews provided another source of information regarding the laboratory learning environment.

The inclusion of the results of interviews with students in this study could be regarded as a method for validating the SLEI for its sensitivity to different instructional techniques used in science. Learning science by inquiry is advocated in the literature as an effective and authentic method used by students to develop and construct a knowledge base and an understanding of scientific ideas and concepts. Moreover, it provides the science teacher with a tool for improving instruction and this should lead to an improved learning environment.

New standards in science education are being advocated that reflect the current vision of content, pedagogy, students' assessment of the classroom environment, and the support necessary to provide a high-quality education for all students. We operate in an era in which we have observed a revival of the inquiry approach in science teaching and learning.

In the Israeli case, the introduction of inquiry-type experiments into the chemistry laboratory was a 'breath of fresh air' in the way in which chemistry is being taught and learned. All this was an attempt to improve learning and the learning environment in science laboratories.

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