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Inquiry, Chemistry Understanding Levels, and Bilingual Learning

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ABSTRACT

This research followed the teaching and learning processes of the case-based computerized laboratory (CCL) module in bilingual setting — BCCL and unilingual setting — UCCL. The goal of the research was to examine the effect of the CCL module in bilingual setting (Hebrew and Arabic) on developing higher order thinking skills among high school Arab students. The research participants included about 270 12th grade honors chemistry students from thirteen high schools. Research tools included an 'unseen'— a narrative, real-life case study in pre and post questionnaires. These questionnaires served for assessing question posing and inquiry skills. Research results showed that both BCCL and UCCL students improved their question posing and inquiry skills from the pre- to the post questionnaires. In addition, the BCCL students improved their inquiry skills significantly better than their UCCL peers. The research findings have shown that exposure to second language (SL) via gradual translation of scientific learning materials is effective in promoting students` inquiry skills. In the practical domain, the research significance is exemplified in the contribution to chemistry teachers by providing them with tools for overcoming the obstacles while teaching science in second language, and may assist their students in smooth integration into higher education.

KEYWORDS: case-based computerized laboratory, question posing, inquiry, second language, bilingual learning

Resumen (Indagación, niveles de comprensión de la química y el aprendizaje bilingüe)

Esta investigación sigue el proceso de enseñanza y aprendizaje del laboratorio computarizado basado en casos (CCL por sus siglas en inglés) módulo bilingüe (BCCL) y unilingüe (UCCL). El objetivo de la investigación fue examinar el efecto del BCCL (en hebreo y árabe) sobre el desarrollo de habilidades de razonamiento de alto nivel entre estudiantes árabes del bachillerato. Los participantes de la investigación fueron 270 estudiantes de química de grado duodécimo de trece escuelas. La herramienta de la investigación incluyó unos cuestionarios pre y post sobre una narración de un caso real. Los resultados mostraron que tanto los estudiantes BCCL como los UCCL mejoraron su capacidad de hacer preguntas y sus habilidades de indagación de la aplicación previa a la posterior, aunque los BCCL mejoraron sus habilidades significativamente más que sus pares UCCL. Los hallazgos de esta investigación han demostrado que la exposición a una segunda lengua (SL) vía la traducción gradual de los materiales científicos es efectiva para promover las habilidades de indagación de los estudiantes. En el dominio práctico lo significativo de la investigación queda ejemplificado en la contribución de los profesores de química al darles las herramientas para superar obstáculos mientras enseñan ciencia en una segunda lengua y auxilian a sus estudiantes a su integración gradual hacia la educación superior.

Palabras clave: laboratorio computarizado basado en casos, planteamiento de preguntas, indagación, segunda lengua, aprendizaje bilingüe

Introduction

Towards the end of the twentieth century, many researchers reported that the curriculum in sciences is based on memorizing facts and definitions, without enough emphasis on applying knowledge in everyday settings and on higher order thinking skills (Tobin & Gallagher, 1987; Zohar & Dori, 2003). Textbooks were the main tool for learning, and most of them required low order thinking skills and studying and summarizing scientific facts.

One of the main goals of the reform in science teaching is development of higher order thinking skills in general and inquiry in particular (Resnick, 1987; Dori, 2003; Kaberman & Dori, 2009).

Since the 60s Schwab and Brandwein (1962) and Sund and Trowbridge (1967) discussed the importance of teaching

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science as *enquiry* or as we call it today — *inquiry*. In the last decade in Israel, the content and the pedagogy of the chemistry curriculum in high schools have gone through a dramatic change that included emphasis on inquiry-type laboratory activities as a central part of the matriculation examination (final examinations set by the government). These laboratory activities provided students with opportunities to develop their learning and inquiry skills (Barnea, Dori & Hofstein, 2010).

In addition, while learning the Israeli curriculum, students are required to develop their chemistry understandings levels: macroscopic, microscopic, symbolic, and process (Dori & Hameiri, 1998, 2003; Dori & Kaberman, 2012; Gabel, 1993, 1998; Johnston, 1991).

In this paper, we describe a study of learning via inquiry in computerized environments where high school students and their chemistry understanding levels will be presented. The learning environment of this study (Dori & Sasson, 2008), combined computerized and inquiry-based laboratories (Kaberman & Dori, 2009) with cased-based approach (Herried, 1994; 1997) and will be abbreviated as CCL — cased study and computerized-based Laboratory module.

Students have difficulties in understanding particulate nature of matter, structures of variety of compound, and interpretation of chemical symbols (Chandrasegaran, Treagust, & Mocerino, 2007). Most of the students find it difficult to create the required connection between the elements' and compounds' symbols, their structures and chemical processes. This difficulty stands from the abstract obstacle when students attempt to solve problems in various subjects (Dori & Barak, 2001). Chemists and chemistry teachers usually use both virtual and tangible models in attempt to create a connection between the symbols and the microscopic and macroscopic nature of matter. The study will provide a teaching, learning, and assessment approach in which the CCL learning environment can serve for either a bilingual teaching approach of Arab chemistry students (who studied chemistry in a gradual translation from Arabic to Hebrew) or a unilingual approach — Arabic only (Abed & Dori, 2007). The term 'bilingual learning' in this paper means, the use of Arab students' home language, and culture, along with Hebrew, the language in which the majority speaks. The CCL in the bilingual setting will be referred to as BCCL while the unilingual approach will be referred to as UCCL.

The two approaches were implemented and their benefit in improving students' understanding and fostering their posing question and inquiry thinking skills was investigated. Students improved their ability to ask questions and solve inquiry problems, which required transition between the four levels of understanding — macroscopic, microscopic, symbol and process. In addition, it was found that the BCCL approach that was characterized by faded scaffoldings over time, in both learning materials and language of instruction, allowed students greater responsibility over their own learning, and encouraged students who studied chemistry in a gradual translation from Arabic to Hebrew to perform better than their peers who studied in the UCCL environment.

Theoretical Background

In this paper, the research background includes a short discussion on case studies as a tool for developing higher order thinking skills such as question posing and inquiry. Following, we will describe the four levels of chemistry understanding and the need to combine means of demonstration such as computerized inquiry laboratories in chemistry teaching, to assist students in making transitions between the levels of understanding.

Following, we will describe a learning environment for minority students in Israel, whose mother tongue language is Arabic while most of the textbooks are written in Hebrew.

Computerized laboratories have developed in Israel in the last few years since the decreasing use of chemical laboratories due to safety and health risks associated with some of the experiments, as well as the experiments being of high costs and time consuming. Integrating information technology in laboratories as well as the development of appropriate curriculum enabled conduction of experimental studies in which the computer serves as a tool for collecting, processing and displaying real-time data. Throughout the experiment, students formulate inquiry questions, speculate, take part in the actual experiment, collect data retrieved by sensors which is graphically displayed on computer screens, explain the experiments' results and come to conclusions.

Inquiry concerns authentic ways in which learners can investigate the natural world, propose ideas, ask questions, and sense the spirit of conducting scientific experiments in the laboratory (Hofstein & Lunetta, 1982, 2004; Lazarowitz and Tamir, 1994).

Researchers have found that student-centered inquiry laboratories provide excellent language and content learning for students learning in second language medium (Thomas & Collier, 1995; Nieto, 2000). Participating in inquiry-based science activities may benefit students by better understanding of science concepts and developing higher order thinking skills.

According to Resnick (1987), it is difficult to define higher order thinking skills, but it is possible to identify them when they occur. Resnick claimed that higher order thinking is not algorithmic and that thinking patterns are unclear and may not be predicted in advance. Thinking patterns often result with multiple solutions, each with pros and cons, but there is no single definite solution. Higher order thinking skills include, among others, posing questions, inquiry, drawing conclusions following experiment, graphing skills, solving problems, critical thinking, reasoning, modeling, decision making and taking a stand (Bodner, Hunter, & Lamba, 1998; Dori & Herscovitz, 1999; Dori & Kaberman, 2012; Dori & Sasson, 2008; Dori & Tal, 2000; Zohar & Dori, 2003; Zohar & Nemet, 2002; Zoller, 1987).

Various approaches aimed at encouraging development of higher level thinking skills exist. This paper focuses on case studies and computerized laboratory as approaches, which enable development of a couple of these skills in a bilingual learning environment.

Lee (2004) asserted that although science inquiry is a challenge for most students, it may present additional challenges in cultures that do not encourage students to engage in the practice of science inquiry by asking questions, designing and implementing investigations, and finding answers on their own. Certain cultural values and practices may dispose students to accept teachers' authority without any critics, rather than exploring or seeking alternative solutions. Validity of knowledge may be evaluated according to the authority of the source, rather than the validity of the content. To the degree that teachers and other adults are respected as authoritative sources of knowledge, students may be reluctant to raise questions or challenge the knowledge claims or reasoning of adults if their culture considers this to be a sign of disrespect. As a result, some students may not practice questioning and inquiry at home or at school.

Case studies serve in our study, as a tool for learning and assessment (Dori, 2003; Dori & Herscovitz, 1999; Tobin, Kahle, & Fraser, 1990). This tool has descriptive story-like characteristics and deals with real-life situations, which have real consequences on the learners' everyday life. Lynch (2001) asserted that despite the best intentions to promote equity and to close achievement gaps, the science education reform movement has failed to respond adequately to the diversity of the student population. Students acquire content knowledge and develop their thinking skills when the medium of instruction is familiar. For the sake of developing content knowledge besides acquiring SL proficiency, Tucher (1999) has recommended to integrate first language into the instruction process. Acquiring the second language (SL) in an additive context, in which the first language is not lost but promoted, leads to uninterrupted cognitive development and thus increased academic achievements (Genesee, 1999).

Research settings

The CCL module is a student-centered learning environment, which incorporates hands-on activities based on authentic real-life natural phenomena introduced in a case studies which make science concepts more accessible to students with limited science experience. Besides, it supports collaborative work. Thus, provides structured opportunities for developing SL proficiency in the context of authentic communication about science knowledge.

Science phenomena become more clear and meaningful to Arab students with supplementary materials such as graphs, models, hands-on tasks, visual aids and small group activities. Studies in our research group showed that integrating small group discussions or emphasizing posing questions and inquiry instead of lecturing about chemistry, may encourage both teachers and students to discuss the meaning of the concepts involved in the chemistry subject matter and by doing so, to build and deepen the students' chemistry understanding (Avargil, Herscovitz,& Dori, 2012; Kaberman & Dori, 2009).

Integrating CCL into the Arab sector in Israel was somewhat problematic, as it requires Arab students to read and comprehend Hebrew, which for them it is a SL (Abed, 2008; Barnea, Dori, Hofstein, 2010). When dealing with the educational system in Israel, one has to distinguish between curriculum in science subject matter and school system. With respect to chemistry, the subject matter involved in this research, the same curriculum is available for both Arabs and Jews students. Same workshops are provided for professional development of chemistry teachers from both sectors. The matriculation examination that aim to evaluate the learning outcomes is identical, it takes place at the same date and time and it is evaluted on the basis of the same rubric. The solely difference is the school system, i.e Arabs are taught by Arab teachers in the medium of Arabic language in Arabic schools. This means that instruction is conducted by teachers who share the same mother tounge as well as the culture background of their students. Similarily, Jews students are taught by Jewish teachers in schools of their own.

However, since some of the chemistry learning materials for the advanced and honor chemistry students are only available in Hebrew, Arab teachers are supposed to deal with translating these learning materials into Arabic. Some of them summarize or translate the main topics to Arabic in order to help their students to better understand the subject matter. The alternative model suggested in this research was adapting SL model via gradual translation from Arabic into Hebrew. The model which was proposed for instruction included bilingual learning in the CCL environment or in short BCCL (Abed, 2008; Abed & Dori, 2007). This may be perceived as faded scaffolding. Other researches (McNeill, Lizotte, Krajcik, & Marx, 2006) suggested decreasing or 'fading' the support and scaffolds. We implemented this essential characteristic of scaffolds for preparing these Arab chemistry students to become bilingual. The assumption was that being a bilingual learner may assist students to integrate smoothly and effectively into Israeli universities where Hebrew is the language of instruction.

The SL model via gradual translation into Arabic adapted in this study used the SL for at least 10% and up to 50% during instruction time, which lasted 4-5 months.

While Arabic continued to be the language for social interaction among students, as time went by, the use of Hebrew during class sessions for interaction between the teacher and the students increased to about half of the class time. Difficult concepts and activities were fully explained by the teacher, who switched freely between the two languages. The language load at varying levels of Hebrew proficiency became increasingly more demanding as the students progressed from the first part (out of six) to the third one of the CCL module.

Key science terms in Arabic and Hebrew were written on the board, highlighted, and repeated to support communication and comprehension. The extent of using gradual trans-

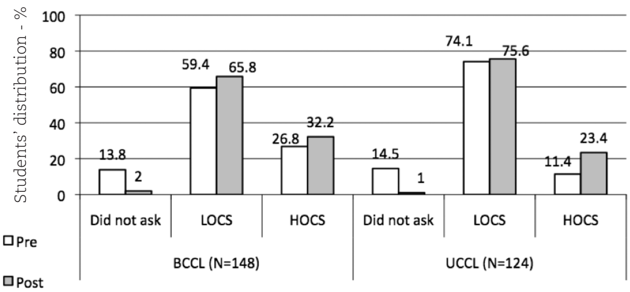

Figure 1. Distribution of questions – sorted by thinking levels: BCCL & UCCL.

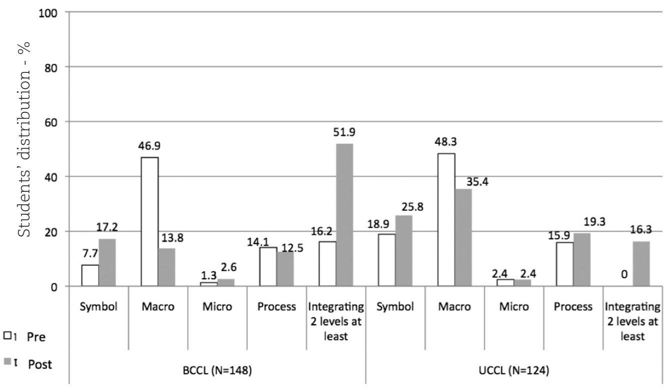

Figure 2. Distribution of questions posed and combination of levels of understanding in chemistry among BCCL & UCCL students.

lation in the teaching and learning depended on the teacher's style and pedagogical decisions.

The ultimate goal of teaching the BCCL module was to create a learning environment in which students feel secure while engaging in learning the new inquiry method along with case studies. In order to promote both students' SL and students' science inquiry practices. We take the alternative view that the integration of inquiry and language acquisition enhances both domains. As Stoddart, Pinal and Canaday (2002) reported that scientific inquiry is a valuable skill and important setting for the integration of academic content and language development for English learners. It links between investigation, language activities, and written, oral, gestural, and graphic forms of communication (Lee, 2005).

Findings

Thinking skills can vary from knowledge and understanding (lower order thinking skills-LOCS) till higher order thinking skills (HOCS) such as: applying, analyzing, and evaluating (Zoller, 1999). The score in this criteria range from 0 to 2. Figure 1 illustrates the distribution of BCCL & UCCL students' questions sorted by thinking levels.

Figure 1 shows that students posed more questions characterized by HOCS in the post questionnaire with respect to the pre questionnaire in both BCCL and UCCL groups. The percentage of questions which were related to knowledge and understanding were higher in the UCCL group in both pre and post questionnaires. While the percentage of questions which were related to HOCS were higher in the BCCL group in both pre and post questionnaires.

The range of the chemistry understanding levels varied from 0 to 3. Student scored zero when he/she posed a question, which was not chemistry-oriented. The maximum score was achieved when the question calls for a response that requires the invocation of three understanding levels of chemistry. Figure 2 illustrates the frequency and combination of levels of understanding in chemistry among BCCL & UCCL students. In the pre questionnaire, about half of the students in both BCCL and UCCL posed questions related to the macro level. Also, there was an increase in the percentage of students who posed questions related to the process level as well as relating to at least two different levels in the post questionnaire in comparison to the pre.

Examining inquiry sub-skills included: (a) generation of an inquiry question after reading the case study; (b) identification of the dependent and independent variables; (c) identification of control variables, and (d) drawing conclusions from a given graph. Figure 3 presents the BCCL and UCCL students' average scores in the various inquiry sub-skills.

Figure 3 shows an increase in average scores of all inquiry sub-skills in both BCCL and UCCL groups. The increase in the total net gain as well as in each separate sub-inquiry skill was higher in the BCCL group than their peer group. A clear improvement in UCCL group was found in control variable and drawing conclusions. While the clear improvement in BCCL group was in both defining the variables and control variables.

Figure 4 shows BCCL and UCCL students' total net gain sorted by thinking level. The total net gain scores as well as the net gain scores in both investigated skills: posing questions and inquiry of the BCCL group students were higher

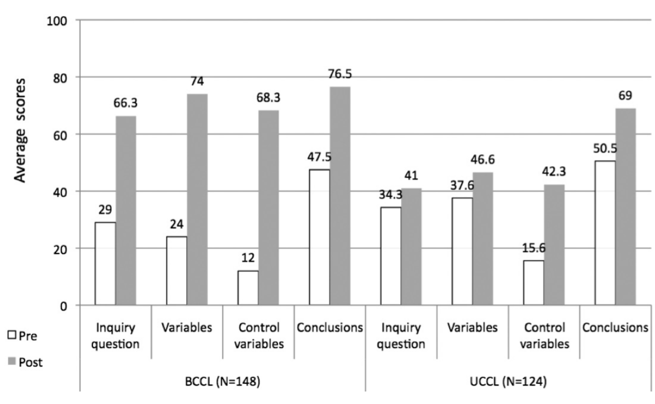

Figure 3. BCCL & UCCL students' average scores in the various inquiry sub-skills.

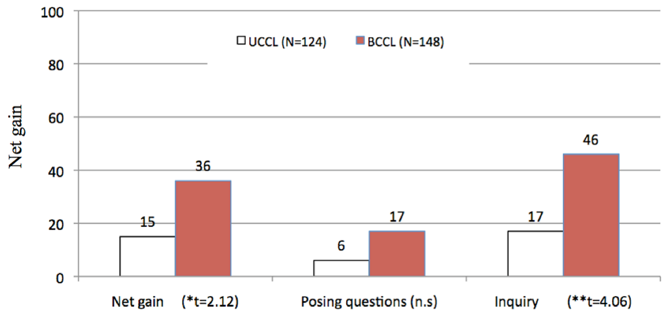

Figure 4. BCCL & UCCL students' net gain sorted by thinking skill.

than those of their comparison peers. The difference was significant solely in inquiry skill.

The CCL approach addresses the recommended instructional strategies for second language learners as described by (Lee, 2006; Lewis, Maerten-Rivera, Adamson, & Lee, 2011; Echevarria, Vogt & Short, 2004; Franco, 2005; Baker, 1997; Stoddart, Pinal & Canaday, 2002).

Discussion

It has become quite obvious to many scholars and educators that providing language and cultural support to minority students is critical to their ability to perform successfully in the science classes (Lee, 2006; Lee & Fradd, 1998).

Teaching the inquiry approach particularly opposes Arab norms and culture. In Arab sector in Israel fully guided experiments (like 'cook-book') were part of the curriculum for a long time and students were given, one by one, the simple steps to conducting an experiment. Furthermore, according to Arab culture one must respect the wisdom of elders. That means students do not often doubt the information presented by teachers. Thus, the number of questions asked in class time is limited. As a result, students did not demonstrate higher order thinking skills such as posing questions and inquiry skills. Implementing the CCL module hold three main obstacles for both Arab teachers and students: (a) teaching and learning in SL; (b) developing higher order thinking skills, especially constructing the inquiry skills which are not typical of the school culture nor for the society culture; and (c) Arab high schools are characterized by large class sizes and average high school students limited proficiency in Hebrew.

Learning environments that articulate the relation of science disciplines with students' cultural and linguistic practices enable students to capitalize on their experiences as intellectual resources for learning scientific content and finding comprehension in activities that relate science to their social, cultural, and linguistic identities (Lee, 2005).

Arab students benefit greatly from hands-on and inquiry-based science instruction since this kind of activities are less dependent on formal mastery of the language of instruction and, thus, reduce the linguistic burden.

The module focused on promoting students' science inquiry that is initially teacher directed but gradually moves towards students, initiated their own research questions. Inquiry skills included four sub skills: posing research question, defining the dependent and independent variables as well as the control variables and drawing conclusions.

In our study, the number of questions students posed in the post case-based questionnaire and their complexity were higher than in the pre questionnaire. BCCL students also improved their inquiry skills. Our results are in agreement with other researchers who claimed that when instruction through the first language is provided to language minority students in addition to balanced SL support, these students attain higher levels of academic achievement than if they had been taught in the SL only (Genesee, 1999; Lee, 2002). With the help of scaffolds, learners can complete more advanced activities and engage in more advanced thinking (Bransford, Brown & Cocking, 2000).

There is also a contribution to the minority science education community, by showing that the exposure of chemistry majors, who are minority students — Arab students in this study — to inquiry-based learning environment, they may overcome the cultural difficulties to question the authority.

In the practical domain, the research significance is exemplified in the contribution to chemistry teachers by providing them with tools for overcoming the obstacles while teaching science in second language, and may assist their students in smooth integration into higher education.

Last but not least, the integration of three elements is unique. These elements are: (a) case studies and analysis of students' questions and answers using the four chemistry understanding levels; (b) inquiry-based and computerized experiments, and (c) bilingual teaching and learning. Investigating learning processes, which occur, as students are involved in the BCCL vs. UCCL environments, may contribute to the body of knowledge related to learning science in inquiry setting and gradual exposure to second language in teaching and learning chemistry.

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