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# Improving Higher Order Thinking Skills among freshmen by Teaching Science through Inquiry

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Twenty-eight freshmen majoring in biology and/or chemistry in an Arab college in Israel, were given a pre-test and a post-test in which they had to identify the control group and design a controlled experiment. During the course an intervention was used. Science was taught by inquiry while using strategies that promote higher-order thinking skills like case studies and reading scientific research articles. The study found that learning methods had a significant effect on developing HOTS among the study participants. Also, the students expressed positive attitude, both emotionally and cognitive as a result of the intervention.

*Keywords*: Higher order thinking skills (HOTS), inquiry teaching, case study, scientific articles, controlled experiment

## INTRODUCTION

For years, science teaching, including the teaching of biology, consisted of the teaching and learning of scientific facts and theories, as well as providing a foundation of 'science as inquiry' with an emphasis on teaching and learning through inquiry. However, many questions are still being asked by researchers (e.g. Zohar, 2004; Zoller, 2000) about teaching through inquiry: What are the emerging problems and in what areas? What programs should be included when modeling teaching through inquiry? Does teaching through inquiry have an impact on the student's approach to problem solving and data analysis? In this study, we address one of these questions: What are the ways of teaching and learning which can be used to promote student teachers through inquiry? The basic assumption is that this issue is emphasized in various forms in high schools but receives less emphasis in higher education, especially in colleges, where there is more frontal teaching that focuses on the transmission of massive knowledge to students. This might be due to the fact that many current teachers learned science through more traditional approaches or because teachers do not understand what inquiry is (Anderson, 2007).

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## LITERATURE REVIEW

### Higher Order Thinking Skills (HOTS) in Science Education

Traditional frontal teaching of scientific subjects is generally designed with reference to the "content" only, without explicit consideration of the cognitive demands that the subject presents to the learner. In this situation, with a teaching method based on direct lectures, students acquire knowledge, but they neither try nor are required to understand and conceptualize the subject's deeper ideas and concepts (Zoller, Dori & Lubetzky, 2002). Transition from a teaching method based on "material transfer" and imparting knowledge to one that nurtures HOTS and, in particular, develops inquiry skills, involves changes in the perception of the essence of the teaching-learning process, the teaching strategies required, and of the way the teacher functions in the classroom. Not surprisingly, teachers often find it


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***State of the literature***

- The present study is based on previous research that highlighted the importance of teaching that develops and fosters the higher order thinking skills (HOTS) of students in every age group and compares to traditional teaching.
- The present study focuses on the promotion of HOTS among students, in particular how to identify controls in scientific experiments, by way of learning science through inquiry based on teaching and learning strategies such as case studies and scientific research articles.
- The present study finds an improvement in students' ability to identify controls in experiments, to derive conclusions from controlled experiments, and to plan a controlled experiment. Students were also found to have a positive emotional view towards the contribution of teaching and learning interventions such as case studies and scientific research papers.

***Contribution of this paper to the literature***

- The present paper proposes ways to promote HOTS by learning science using the method of inquiry by means of case studies and scientific research papers.
- Teaching-learning and assessment that foster and promote HOTS require the application of different strategies than those used in traditional science teaching.
- Teaching science using the inquiry method with the help of strategies of case studies and scientific papers is an efficient method that constitutes an innovation in the way science is taught to and learned by teacher students at the college, at both the cognitive and the affective level.

difficult to made the transition from a traditional teaching-learning method that they know well to a method that develops HOTS (Zohar, 2004). However, the role of a contemporary science teacher is to give the student, on the basis of a relatively modest amount of knowledge, tools to deal with learning materials as an independent learner.

Teaching science by inquiry is a complex task that requires higher-order thinking skills (HOTS) (Zidani et al., 2003; Zohar, 2004). Toward the end of the twentieth century many researchers reported that science curricula based on learning facts and definitions from textbooks do not emphasize the application of knowledge from daily life and development of HOTS (Bransford, Brown & Cocking, 2000; NRC, 1996, 2000; Zoller, 1993). Teachers use textbooks as a source of student activities; and in most textbooks, only lower order thinking skills such as memorization of scientific facts and summarization of certain topics are required from the student (Tobin & Gallagher, 1987).

HOTS are more difficult to define, but we can identify them when they occur (Resnick, 1987). Resnick suggests some general characteristics of higher order thinking, as follows: non-algorithmic, complex and yielding multiple solutions, requires the application of multiple criteria, self-regulation, and often involves uncertainty. To teach HOTS in an effective manner, a clear and accurate understanding of these skills is needed. (Kuhn, 2005).

The main objective of science education reform around the world is to develop higher order thinking and cognitive skills at all levels (Leou, Abder, Riordan & Zoller, 2006; Resnick, 1987; Zohar & Dori, 2003; Zoller 1993, 2000). HOTS allows the learner to be a more independent and creative learner, adept at problem solving and capable of using scientific content in everyday contexts (Ben-Chaim, Ron, Zoller, 2000; Hand & Prain, 2002). HOTS can be conceptualized as a non-algorithmic, complex mode of thinking that often generates multiple solutions. Zohar and Dori (2003) include the following examples of HOTS in inquiry-oriented science education: formulating a research question, planning experiments, controlling variables, drawing inferences, making and justifying arguments, identifying hidden assumptions, and identifying reliable sources of information. These skills are focused on cognitive activities more complex than knowledge, comprehension or application on a lower level based on Bloom's taxonomy (Bloom, 1956).

Analysis of future needs, striving to produce significant learning and meaningful knowledge, require the use of HOTS. The need for such skills in the past was relatively low, but today they are indispensible. Hence, strategies for teaching-learning that claim to fit themselves into the modern age and to foster self-taught learners possessing scientific literacy and technological skills should target higher-order thinking education. It is possible to promote HOTS when teaching experimental design with a science inquiry approach.

## Teaching science by inquiry

A renewed interest in inquiry learning, with an emphasis on the acquisition of scientific literacy, is a prominent educational goal in the twenty-first century. Inquiry learning is viewed as essential for teaching scientific literacy (Zohar & Dori, 2003; Yakar & Baykara, 2014). Important to this view of teaching science are the following student outcomes: appreciating the diverse ways in which scientists conduct their work; understanding the power of observations; knowledge of and ability to ask testable questions, make hypotheses; proper use of various forms of data to identify patterns,

confirm or reject hypotheses; constructing and defending a model or argument; considering alternate explanations, and gaining an understanding of the tentativeness of science, including the human aspects of science, such as subjectivity and societal influences (Crawford, 2007). Teaching science by inquiry involves teaching students the processes and skills used by scientists to learn about the world and helping students apply the skills involved in learning science concepts. Students learn and apply these processes through conducting problem-centered investigations designed for learning specific science concepts (McBride, Bhatti, Hannan & Feinberg, 2004).

Science teachers look for ways to encourage students to understand the dynamic and changing nature of the scientific inquiry process (Khishfe & Abd-El-Khalick, 2002). Researchers and advocates of teaching science by inquiry recognize the contribution of both imparting knowledge about scientific processes and principles and the development of skills. Teaching by inquiry can be done in several ways: laboratory experiments, reading and analysis of articles, case studies from the history of science, and making observations in the field. Teaching of skills, abilities and behaviors related to inquiry are needed so that the student learns and internalizes the scientific ways of thinking objectively and critically in order to solve problems that promote the science and society (Lazarowitz, 2000).

Learning science by inquiry provides opportunities for students to experience science directly. In addition, curiosity, creativity, originality, perseverance, experience with failure and discussion are supported with this approach. Inquiry gives rise to a realistic image of science in the eyes of students as they become citizens of the future (Tamir, 1983). Thus, the teacher's role is to assist students as they process information and/or data collected in the research they conduct (Anderson, 1996). In a study among high school students who studied biology by inquiry, the researchers found that students showed a thorough understanding of the relationship between the different components of scientific research (Tamir, Stavy & Ratner, 1998). Despite the importance of this, studies about teachers' knowledge and beliefs about inquiry and their classroom practices are still few and scattered (Saad & BouJaoude, 2013).

## FORMS OF INSTRUCTION

### Case study

One possible means to develop HOTS is through the use of case studies. Also known as case narratives, these are 'stories with a message' or 'stories to educate' (Herreid, 1997, 2002). A case study is a study conducted within a story framework, which places the participants in a decision-making position regarding certain issues which are characterized by, (a) a complex problematic situation which has no simple solution and invites multiple points of view; (b) demands some specific knowledge-content to be utilized for addressing the situation; and (c) relates to ethical and value-driven issues (Ben-Zvi Assaraf & Damri, 2009).

Case studies are a tool for learning or evaluation of a descriptive/narrative nature, which deals with real situations that have an impact on the daily lives of students. In science education it is common to use case studies for three purposes: as a critical or reflective thinking tool, as a teaching tool for scientific subjects, and as a tool for evaluation and research (Beck, 2007; Koballa & Tippins, 2004). The case study method encourages learning through practice, develops skills of analytical and critical thinking and decision making while dealing with complex problems, just as in daily life (Herreid, 1994; Herreid & Schiller, 2013). It calls for complex, critical and creative thinking, and raises the level of motivation among students. The method is appropriate for application in large groups and its outcomes are a transfer of content knowledge and skills, and the ability to solve authentic problems. In research that used case studies as a teaching and assessment method, an improvement in students' achievement was observed in tasks that require higher order thinking skills (Tal, Dori & Lazarowitz, 2000). Case studies can help pre-service teachers make connections between theory and practice, and expose them to the uncertainty and complexity of science teaching (Arellano et al., 2001). They have also been found to increase students' critical thinking and problem-solving skills (Dochy et al., 2003; Yadav & Beckerman, 2009; Yadav et al., 2010), higher-order thinking skills (Bergland et al., 2006; Dori, Tal, & Tsaushu, 2003; Gallucci, 2007), and motivation to learn (Yadav et al., 2007).

### Teaching through scientific research articles

Another tool to develop scientific ways of thinking is through the use of scientific research articles. Science is communicated within the scientific community through primary literature that uses a highly technical language. Research articles are the primary reporting tools and unmediated scientific means of action. Reading scientific texts is one of the most important components of scientific literacy. The reading task should be an active process that requires the construction of new knowledge linked to prior information by creating new meanings and a deep understanding (Spence, 1995). While reading, the student deals with information and builds personal understanding without the use of external help. Reading and understanding scientific texts contribute to comprehending known scientific principles as well as to

highlighting the sources, contexts and meanings of these principles (Norris & Phillips, 2002). Therefore, developing full development of text reading skills increases the understanding of science and the scientific inquiry process and allows students to create a link between the various perceptions of the accumulated information. Learning through research articles enables student exposure to the professional scientific world.

Parkinson and Adendorff (2004) suggest that articles can make science more accessible to students, and so can play a useful role in the teaching of scientific writing as well as in the teaching of science. Learning through research articles at the university and college level has been shown to have many benefits, the main ones being exposure to the nature of scientific reasoning and communication, critical reading, practice in writing and analytical skills, improved design of the students' own research projects and enhanced confidence in their ability to reason, research and apply knowledge (Muench 2000; Yarden, Brill & Falk, 2001). Other studies have shown that high schools and universities typically engage in solving problems that do not require dealing with the reading of scientific texts (Koch, 2001; Yore, Craig & Maguire, 1998).

### Research objective and question

In addition to regular teaching, the instructor of a college biology class used two strategies of teaching, case studies and scientific research articles, to further improve students' HOTS. The three science inquiry skills focused upon were: drawing conclusions from a controlled experiment, identifying control in the experiment and designing a controlled experiment.

This study examined the initial HOTS abilities of freshman students majoring in biology and/or chemistry at the Arab College of Education, in the northern part of Israel, especially their ability to identify controls, plan an experiment, draw conclusions and measure progress in this ability by using case studies and research articles. This research objective gives rise to the following primary research question:

Does the use of case studies and scientific research articles contribute to students' ability to use higher order thinking skills as seen in their ability to:

- *identify controls;*
- *plan an experiment;*
- *draw conclusions?*

## METHODOLOGY

### The Research Tool

A pre/post questionnaire construct of three tasks aimed at drawing conclusions from the results of a controlled experiment, identifying control in an experiment, explaining and designing a controlled experiment (Appendices 1 and 2) was used. Each task included two questions. Two similar versions of the test were used, with different tasks, except task 3, which was identical in the two questionnaires, and was introduced to students at beginning of the year (pre) and at the end of the year (post) (Appendices 1and 2). Tasks 1 and 2 require the student to draw a conclusion from two different sets of experiments that are different in one variable, to identify control and justify his answer. In task 3, the student is required to build a controlled experiment on his own, to identify the control in the experiment and also to justify his answer.

A semi-structured interview was held with a selection of students, in order to obtain their reaction to the use of the case studies and research articles method

The key questions asked in the interviews were:

- *What do you think of this method of classroom teaching? Did you feel any difference between this and other teaching methods?*
- *How do you assess the various strategies used during the teaching of the course? Did you like them?*
- *How did the teaching methods used in the course help you?*

### Intervention

Students enrolled in an annual course in "Basic concepts in scientific research" which emphasized teaching science through inquiry. At the beginning of the course the lecturer/researcher provided scientific articles and case studies to augment/supplement lecture information to students. Later in the course students were asked to choose and provide case studies and scientific articles that met the course's objective. This student involvement aspect was reflected in the assessment grade of the course offered to them. The case studies (6 in number) involved several scientific issues. Each included reading a short scientific passage, followed by a number of scientific questions that require identification of the problem, use of critical thinking and identifying components of the scientific experiment such as: research question, hypothesis, dependent and independent variables and controlled variables.

Five recent suitable scientific articles were selected for use. Some were in print and others came from electronic sources. For each article provided, students were required to summarize the main ideas. Students' understanding of the process and methodology of scientific inquiry was also examined.

Students were given one hour to answer the questions in each questionnaire. The students' answers to each questionnaire (pre and post) were reviewed by two researchers/assessors, one a biology major with a Ph.D. degree in science education and the other with a Ph.D. in biology. Both researchers/assessors were

skilled and experienced, but where they clearly differed in their interpretation of an answer, it was task of interpretation was passed on to a third researcher, also with a Ph.D. in biology.

### The study population

The study population consisted of 28 freshmen majoring in biology and/or chemistry. These college students (all females) came from several Arab high schools. They specialized in biology and/or chemistry at the level of 5 units according to the Israeli educational system. Of these participants, 23 students (82%) joined the college right after finishing high school; the other five (18%) had a break of one year after graduating.

## RESULTS AND DISCUSSION

As mentioned above, this quantitative study is based on analysis and scoring students' responses to the pre and post questionnaires. The findings of this analysis are listed in Table 1.

McNemar rather than Paired-T was used because the data of the pre- and post-tests were not paired. The numbers in the table refer to the students who answered correctly in both the pre and the post, out of a total of 28 students, according to the evaluation of the assessors. The study findings show that the values of the pre-test were always low in the two questions for each task. This indicates a low starting point for students. The findings also show significant improvement in students' progress during the college year from pre to post in all tasks. The best improvement was in tasks (1) and (2) in the two questions of every task. However, despite the improvement in task (3), the difference between pre and post was low compared to tasks 1 and 2. The reason for the low improvement was that in the former task the students were required to be creative; this means that the design of an experiment with appropriate control requires an understanding of an experiment's complete setting: variables, measurement methods and constant factors. For this reason, students had difficulty in this task.

The significant improvement in tasks 1 and 2 may be related to the special learning strategies used in the course. These strategies consisted of teaching science through research by using two pedagogical tools; case studies and scientific research articles. As Yip has noted (1999), the concept of controlled experiment cannot be developed by teachers and students automatically through conventional practical work. These ideas and skills need to be taught explicitly, and constructed meaningfully through well-designed learning activities.

These findings of improvement in the achievements of students as a result of the intervention are in line with various studies. Herreid (1997) incorporated case studies in several courses for four years and found that using this method encourages learning through practice, develops analytical and critical thinking skills, and decision making while dealing with complex problems, just like in everyday life. Dori (1994) also found that integrating case studies in her teaching contributed to increased motivation and enjoyment of students and improvement of their achievements in chemistry. It is also ideal for developing the higher-order thinking skills that any teacher wishes to plant in his students (Herreid, 1994; Herrreid & Schiller, 2013). Beck (2007) also shows that pre-service teachers found the use of case studies as potentially useful in helping them learn and process course content.

In addition, teaching through research articles gives another alternative for regular/conventional teaching. It can give students opportunities to acquire thinking skills, in addition to conceptual knowledge. The results of this study are in accord with the report about a biology course based on learning through research articles which succeeded in enhancing curiosity among seventeen-year-old students and questions about how science is made and what a biologist actually does (Epstein, 1970). Our findings also support Muench's

**Table 1.** Identification and planning capability assessment for students in three control tasks between pre and post

| Task | Question | Questionnaire | Answered correctly N | Answered correctly % | Difference | McNemar test | P< |
|---|---|---|---|---|---|---|---|
| 1 | a | Pre | 15 | 53.6 | 28.5 | 8.00 | 0.005 |
| | | Post | 23 | 82.1 | | | |
| | b | Pre | 12 | 42.9 | 42.8 | 12.00 | 0.001 |
| | | Post | 24 | 85.7 | | | |
| 2 | a | Pre | 15 | 53.6 | 28.5 | 8.00 | 0.005 |
| | | Post | 23 | 82.1 | | | |
| | b | Pre | 12 | 42.9 | 28.5 | 8.00 | 0.005 |
| | | Post | 20 | 71.4 | | | |
| 3 | a | Pre | 12 | 42.9 | 17.8 | 5.00 | 0.05 |
| | | Post | 17 | 60.7 | | | |
| | b | Pre | 11 | 39.0 | 14.6 | 14.6 | 0.05 |
| | | Post | 15 | 53.6 | | | |

results concerning the unique potential of learning through research articles to guide students on scientific reasoning and communication (Muench, 2000).

In the feedback conversation with students at the end of the course and after the intervention, they mentioned the following factors as having been relevant to the applied teaching-learning approaches:

- *Develops critical thinking and scientific understanding.*
- *Improves the ability to deal with a scientific text.*
- *Develops analytic capability and improves the level of thinking and inquiry.*
- *The cases and articles were interesting and aroused the students' curiosity.*
- *The cases and articles dealt with topical issues that brought us closer to our daily world and encouraged our involvement.*
- *These methods allow students to study independently.*

Quotes from students indicate their satisfaction and positive emotional and cognitive responses. Some students claimed that some tasks were too burdensome and boring.

## CONCLUSIONS

The study's objective was to examine teaching science by inquiry using case studies and scientific research articles in order to develop the students' HOTS, especially drawing conclusion from a controlled experiment, identifying suitable controls, and planning a controlled experiment. The study found a significant effect for the this learning method on developing HOTS among the study participants. This effect was reflected in the improvement among the study group from the pre- to the post-test and may indicate some effect of the intervention.

The study results are supported by several studies in the literature on the efficiency of strategies that allow development of approaches to teaching these skills. It turned out that both tasks 1 and 2 yielded more significant improvement from the pre to the post than task 3. There was also a significant difference in the level of the experiments that students designed in this task. At the beginning of the course, in the pre questionnaire and due to their limited experience, the students suggested simple experiments, as well as simple tools and methods. In the post questionnaire at the end of the course, they proposed experiments showing full control of different variables; and offered the use of sophisticated tools and equipment.

Teaching by inquiry focuses on the process by which the student is active. The role of the researching student is to look for answers to questions by using HOTS. This method is not unique to a particular type of thinking processes or specific area. Encouraging students to develop HOTS is a goal facing educators and science curriculum developers.

Thinking skills are vital for success and effective functioning in every aspect of the individual's life in a changing society and the knowledge era. It is therefore important to foster students' acquaintance with higher-order thinking strategies and their ability to exploit them in different contexts.

Based on the findings, teaching science using inquiry by incorporating research strategies, cases and scientific research articles is an effective method and a way to change and innovate in the learning and teaching of science. Teaching and learning methods through inquiry have been for many years at the forefront of educational research in science teaching. However, the present study deals with the subject from a new perspective that focuses on adapting teaching and learning through inquiry in higher education - college students. This focus of the study corresponded to the common perception in recent years that the higher order thinking skills, in general, and teaching through inquiry, in particular, are important for all student populations. Therefore, the present study answers the rising need to characterize the ways of thinking and learning. The findings can serve as the basis for exploring teaching strategies for the entire student. The study contributes to the body of knowledge on the development of higher order thinking skills in general, and inquiry skills development in particular.

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