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מאת
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אפיון הוראת ולמידת חקר בתוכנית הביוטק לתלמידי תיכון המתמחים בביוטכנולוגיה

Characterizing the Teaching and Learning of Inquiry in the Bio-Tech Program for High School Biotechnology Majors

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“The trouble with school science is that it provides uninteresting answers to questions we have never asked.”

Student in Sweden (Osborne, 2006)

תודות

ראשית, ברצוני להודות לפרופ' ענת ירדן על הליווי הצמוד וההנחיה המסורה לאורך השנים. על הסבלנות הרבה והתמיכה ברגעי האתגר והקושי. על כל מה שלימדת אותי על האקדמיה והמחקר, על הדחיפה קדימה גם כשהדרך מעורפלת, על האמונה ביכולותיי.

לד"ר יעל שוורץ, חברת הוועדה המלווה ושותפה קבועה לאורך כל המחקר, שתמיד ידעה לתת את ההערות הנכונות ולשאול את השאלות המאתגרות. לפרופ' צחי פלפל, חבר הוועדה המלווה, על ההשקעה הרבה והעצות הטובות.

תודה לכל חברי הקבוצה הרבים שקיבלו אותי באהבה רבה לאורך כל השנים, עזרו בכל בעיה והיו למשפחתי השנייה. לחברי הסגל במחלקה להוראת המדעים, ובמיוחד לפרופ' דיויד פורטס ופרופ' ניר אוריון, שסייעו לי רבות. ליטי ורון, על העזרה הרבה בניתוחים הסטטיסטיים. לחברי המחלקה האחרים שתמיד היו נכונים לעזור: אורנה עמר, נתנאל עותמי, איריס מזור, אירה קרסיק, מרינה ארמיאץ, פנינה חן ועידית דקל. תודה מיוחדת לחברי המוכשרים במחלקת הגרפיקה: אבי חן, זיו אריאלי, ציפי עובדיה ומור מוריה-שיפוני. כמו כן, לכל שאר חבריי הטובים במחלקה להוראת מדעים, שתמיד היו שם לתמוך ולעודד.

לאנשי תוכנית הביוטק במכון דוידסון לחינוך מדעי, ובראשם ד"ר מיכל סטולרסקי בן-נון וירדנה דוד המקסימות, שעזרו בכל שאלה, רעיון או הצעה, ולחוקרים הצעירים ממכון ויצמן ומהפקולטה לחקלאות שהשתתפו במחקר ושיתפו איתי פעולה. כמו כן, תודה לשאר אנשי מכון דוידסון שתמיד היו שם עבורי, במיוחד ד"ר עובד קדם, ד"ר ארנה פליק וחבריי בתוכנית מדע פעיל צעיר.

למורים ואנשי משרד החינוך ששיתפו איתי פעולה לאורך כל המחקר, בראשם ד"ר אילת אברהם, מפמ"ר לימודי הביוטכנולוגיה. במיוחד ברצוני להודות למורים הנהדרים שפתחו בפני את שערי כיתותיהם ושיתפו אותי בכל: שגיא בן בסט, רחל סקאל, ענת כהן, ענת לוי, סיסי קרמרמן, תמר רוזמן ורבים אחרים.

לחברי הרבים במכון ויצמן למדע, שהפך להיות ביתי: במוזיאון בית ויצמן, במרכז המבקרים ובמועצת הסטודנטים. בזכותם היתה זו תקופה מעניינת, מיוחדת וחווייתית.

לאמיר, שתמיד נמצא בליבי, חיוכו ותבונתו מלווים אותי בכל מקום ובכל זמן.

וכמובן, מעל לכל, למשפחתי האהובה. הורי היקרים נחמה ואיגור, ואחותי מאיה. לא ניתן לתאר את כל האהבה, התמיכה והעידוד ששאבתי מכם.

Table of Contents

List of abbreviations

APL- Adapted Primary Literature

BSCS- Biological Sciences Curriculum Study

I-MAP- Inquiry-Based Teaching and Learning Mapping tool

I-R-E- Initiation-Response-Evaluation

LDL- Low Density Lipoprotein

NGSS- Next Generation Science Standards

NRC- National Research Council

NSES- National Science Education Standards

NSF- National Science Foundation

PBL- Problem-Based Learning

PCR- Polymerase Chain Reaction

PISA- Program for International Student Assessment

PON1- Paraoxonase1

SAS- Statistical Analysis System

SPSS- Statistical Package for the Social Sciences

TLOL- Teacher-Led Outreach Laboratory

UPR- Unfolded Protein Response

Abstract

Teaching and learning of inquiry lay the foundation for the development of students' scientific literacy. Students are expected to learn about the inquiry process and to develop their understanding of scientific practices by experiencing authentic inquiry in an active learning environment. This research examined the teaching and learning of inquiry in an innovative program for 11th grade biotechnology majors entitled the Bio-Tech. The study involves characterization of the Bio-Tech program while focusing on the teaching and learning of asking questions and critiquing practices, exposing gaps between the intended and the implemented Bio-Tech curricula, and exploring the participants' views towards the inquiry level and authenticity of the program. An inquiry programs assessment tool, entitled I-MAP, was developed and used for the characterization of the Bio-Tech program.

The results show that some of the Bio-Tech students' asking questions and critiquing abilities improved following their participation in the program, mostly their ability to use metalanguage of science terms in their questions and arguments, and their ability to focus their questions and critiquing arguments on the experimental process. Analysis of the communicative approach and lesson structure of two Bio-Tech lessons revealed that students' ability to formulate research questions appropriate for investigation was better developed in a student-centered, dialogic and interactive lesson than in a teacher-centered, authoritative and non-interactive lesson. Some gaps were revealed between the intended and the implemented Bio-Tech curricula, mostly in the initial stages of the program that were expected to reflect higher levels of student independence, while the enacted curriculum was more teacher-guided. Most of the Bio-Tech participants viewed the level of inquiry in the Bio-Tech program as high and authentic in the stages of formulating research questions, performing the experiments in the research institute, and writing the research portfolio. Some inquiry stages were viewed as reflecting low inquiry level, such as planning the main experiments and presenting the results, due to time and experimental tools limitations.

In line with recent calls for shifting from inquiry teaching to teaching scientific practices, the characterization of the Bio-Tech program indicate that participation in an inquiry-oriented program, such as the Bio-Tech**,** may improve students' scientific practices while experiencing high level and authentic inquiry.

תקציר

הוראת ולמידת חקר מהווים את הבסיס לפיתוח אוריינות מדעית בקרב התלמידים. על התלמידים ללמוד על תהליך החקר ולהבין את הפרקטיקות המדעיות על ידי התנסות בחקר אותנטי בסביבת למידה פעילה. במחקר זה נבדקו הוראת ולמידת חקר בתוכנית הביוטק המיועדת לתלמידי כיתות יא' במגמת הביוטכנולוגיה. האפיון של תוכנית הביוטק התמקד בהוראת ולמידת שאלת שאלות והעלאת ביקורת, חשיפת פערים ברמת החקר בין תוכנית הלימודים המתוכננת והמיושמת בביוטק, והצגת תפיסות משתתפי התוכנית לגבי רמת החקר והאותנטיות של הביוטק. כלי הערכה לתוכניות חקר פותח ויושם במהלך מחקר זה על מנת לסייע באפיון תוכנית הביוטק.

תוצאות המחקר הראו שחלק מיכולותיהם של תלמידי הביוטק השתפרו לאחר השתתפותם בתוכנית, בעיקר יכולתם להשתמש במונחי מטה-שפה מדעית בשאלות ובטיעונים שלהם ויכולתם למקד את השאלות והטיעונים שלהם בתהליך החקר. ניתוח של הגישה הקומוניקטיבית ומבנה השיעור במהלך שני שיעורי ביוטק הראה שיכולתם של התלמידים לנסח שאלות חקר המתאימות למחקר השתפרה יותר בכיתה בה המורה לימדה בגישה ממוקדת-תלמיד, דיאלוגית ואינטראקטיבית והקדישה יותר זמן לדיונים כיתתיים מאשר בכיתה בה המורה לימד בגישה ממוקדת-מורה, אוטוריטטיבית ולא-אינטראקטיבית. מספר פערים נמצאו בין תוכנית הלימודים המתוכננת והמיושמת של הביוטק. השלבים ההתחלתיים של התוכנית היו אמורים לשקף רמת עצמאות גבוהה של התלמידים, בעוד שבפועל שלבים אלו היו יותר מודרכים על ידי המורה. רוב משתתפי תוכנית הביוטק סברו שהתוכנית משקפת רמת חקר גבוהה ואותנטיות, בעיקר בשלבי בחירת שאלת החקר, ביצוע הניסוי המרכזי וכתיבת דו"ח החקר. חלק משלבי החקר נתפסו כפחות פתוחים, כמו תכנון החקר והצגת התוצאות, בגלל מגבלות זמן וכלי ניסוי אפשריים.

לאור הקריאות העכשוויות למעבר מהוראה בדרך החקר להוראת פרקטיקות מדעיות, האפיון של תוכנית הביוטק הראה כי השתתפות בתוכנית מבוססת חקר כמו הביוטק יכולה לפתח את הפרקטיקות המדעיות של התלמידים, תוך התנסות ברמת חקר גבוהה ואותנטיות.

1. Introduction

Inquiry is considered a key element in the teaching and learning of science (National Research Council [NRC], 2000). Students around the world are required to learn authentic scientific practices (National Research Council [NRC], 2012) and gain understanding of the inquiry process (Abd-El-Khalick et al., 2004; Bybee, 2000; European Commission, 2007; National Research Council [NRC], 1996). By practicing inquiry, students are expected to cultivate scientific habits of mind, practice scientific logical reasoning, develop critical thinking abilities in scientific context, and experience meaningful learning of scientific concepts and processes (Chinn & Malhotra, 2002; Harlen, 2004; Hmelo-Silver, Duncan, & Chinn, 2007). Still, suitable means to implement authentic scientific practices in classrooms are not clarified yet and many issues remain unclear regarding the learning goals and the suitable strategies for teaching scientific inquiry (Furtak, Seidel, Iverson, & Briggs, 2012; Minner, Levy, & Century, 2010). Moreover, the recently published Next Generation Science Standards (NGSS) called for a shift from teaching science by inquiry to teaching scientific practices, which requires a renewed examination of the teaching and learning of inquiry in science classrooms in general and in inquiry-oriented programs specifically (Osborne, 2014b).

In an attempt to address these challenges, this study aimed to characterize the teaching and learning of inquiry in an innovative inquiry-oriented program for high school biotechnology majors, entitled the Bio-Tech. By investigating the development of the Bio-Tech students' scientific practices, exploring the gaps between the intended and the implemented Bio-Tech curricula, and exposing the participants' views toward the program's inquiry level and authenticity, I hope to shed some light on the teaching and learning of inquiry. It is hypothesized that inovative inquiry-oriented programs, such as the Bio-Tech, may promote high school students' learning of authentic scientific practices and allow them to experience high level of inquiry and authenticity. This research may contribute to the understanding of how inquiry-oriented programs support the development of students' scientific practices, and may indicate the most appropriate means to provide students with opportunities to experience high level of inquiry in an authentic scientific environment.

2. Theoretical framework

In the first part of the theoretical framework, the educational theory of constructivist and active learning are presented. These are the theories that are relevant to this study's goal and its objectives, forming the epistemological foundation of the research. These theories lay the basis for the second part of the theoretical framework, which focuses on science teaching and learning. In this part, the theoretical framework of inquiry-based science teaching and learning is presented. It includes historical overview of inquiry in science education, and elaborates on authentic scientific inquiry, inquiry features, and inquiry levels. The next part of the theoretical framework presents the two scientific practices that were chosen to be investigated in this study: asking questions and critiquing. The final part of the theoretical framework focuses on the scientific language, which includes analysis of classroom discourse and the communicative approach, and on the intended and implemented curricula.

2.1 Constructivism and active learning

At the heart of the social constructivist theory lays the concept that knowledge is constructed from learners previous experiences and requires active meaning making (Mintzes, Wandersee, & Novak, 2005). This theory originates from the works of Piaget's knowledge schemes (Piaget, 1976), Ausubel's cognitive assimilation theory (Ausubel, 1967), and the Vygotsky's socio-cultural framework (Vygotsky, 1978). According to the construct theory, knowledge is not passively transmitted from the teacher to the students. Learner build their own knowledge from their own contextual actions and experiences (Wheatley, 1991). Mintzes et al. (2005) considered the goal of educational constructivist as building of shared meaning, obtained through social interactions between learners. They call for implementing teaching strategies which encourage students' active participation, intensive social interactions and communal reflection.

Based on the social constructivist theory, the conceptual framework of active learning instruction and student-centered teaching approach had grown in the past few decades (Gardner & Belland, 2012; Michael, 2006). Active learning is usually defined as instructional strategies that require students' engagement in the learning process in order to achieve meaningful learning. Such an approach comprised of several teaching strategies, such as collaborative learning, cooperative learning, and Problem-Based

Learning (PBL). (Armbruster, Patel, Johnson, & Weiss, 2009; Prince, 2004). Empirical studies indicate that active learning improves students' motivation and attitudes towards science, retention of knowledge, and development of thinking skills, compared to traditional teacher-centered instructional strategies (Prince, 2004). Peer interactions during cooperative active learning were shown to contribute to students' higher-order performance in biology (Linton, Farmer, & Peterson, 2014). Students' learning improved when engaged in real-world problems, activated relevant cognitive structures, practiced their problem solving skills, applied their problem solving knowledge, performed peer-collaboration, and integrated the new knowledge in communal environment (Gardner & Belland, 2012; Merrill, 2002). However, despite the vast research that had been done concerning active learning instruction and student-centered teaching, the most appropriate strategies for this instruction remain to be clarified. Inquiry-based teaching and learning, which is grounded in the constructivist and active learning theories, should provide students with opportunities to develop their knowledge and understanding. Inquiry-oriented scientific programs, such as the Bio-Tech program, where students take responsibility over the learning process, may advance their meaningful learning.

2.2 Science teaching and learning

Science teaching and learning received its modern form during the rise of industry and technology in modern civilized societies (Mintzes et al., 2005). Scientific literacy is broadly defined as the outcome goal of science education, allowing learners to gain understanding and ability to use scientific knowledge. Scientific literacy includes learning about scientific content, the nature of science, and scientific practices and abilities that are required from the 21st century citizens (DeBoer, 2000). In the following of the theoretical framework, several aspects of science teaching and learning are discussed. It includes inquiry-based science teaching and learning, scientific language and discourse, and the intended and implemented curricula.

2.2.1 Inquiry-based science teaching and learning

Inquiry-based science teaching and learning is based on the constructivist and active learning theoretical framework (Michael, 2006). Engaging students in scientific inquiry is considered one of the principle goals of science education, recommended by researchers and in various policy documents (Bybee, 2000; European Commission, 2007; National Research Council [NRC], 1996, 2000). However, a debate still exists regarding the goals, methods and strategies for incorporating inquiry into the science education classrooms (European Commission, 2007; Tamir, 2006; Windschitl, Thompson, & Braaten, 2008), and whether the teaching of inquiry be replaced with the scientific practices (National Research Council [NRC], 2012; Osborne, 2014b).

One of the commonly accepted definitions of scientific inquiry is the one published by the National Research Council (NRC) (1996): "*Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world*" (p. 23). Based on this definition, the NRC (1996) describes inquiry as the method used by scientists for exploring nature (what will be later referred to as ’authentic scientific inquiry’) and the teaching and learning of inquiry in educational environments. More traditional definitions of inquiry refer to the scientific multifaceted process of asking questions about natural phenomena, hypothesizing, designing and conducting experiments, presenting results, formulating conclusions and communicating them to others (Barrow, 2006; Bybee, 2000; Schwartz, Lederman, & Crawford, 2004).

The NRC (1996) also defined inquiry as the accepted method of the scientific community for solving problems and processes used to investigate a phenomena. According to the NRC (1996), the main goals of inquiry learning are that students learn to do scientific inquiry and to develop their understanding of scientific inquiry. The NRC (2000) describes both the abilities and understanding of scientific inquiry. The ability to do inquiry requires students to learn more than just the traditional process skills, but to combine them with scientific knowledge, reasoning and critical thinking. The NRC (2000) suggests features that best define the teaching and learning of inquiry. The five essential features for classroom inquiry are: (i) Engaging in scientifically oriented questions, (ii) Giving priority to evidence in order to develop and evaluate explanations, (iii) Formulating explanations from evidence, (iv) Connecting explanations to scientific knowledge, and (v) Communicating and justification of explanations.

Teachers’ views regarding teaching science as inquiry, based on their personal experiences, knowledge, and feelings, hold great influence on their implementation of inquiry teaching in the classroom (Keys & Bryan, 2001). Crawford (2007) found that the most influencing factor on teachers’ ability to teach inquiry and their pedagogical implementation of inquiry activities was their personal beliefs about inquiry teaching, as reflected from interviews and observations of five prospective teachers during a year-long training program. Gillies and Nichols (2015) reported that primary school teachers expressed positive views regarding teaching inquiry and cooperative learning activities that supported their students’ ownership of the inquiry process and increased their motivation and interest in science. In light of this, I set to expose the Bio-Tech program participants’ views towards inquiry, as part of the program characterization, and the possible influence of their views on the teaching and learning of the program.

The outcome of inquiry teaching and learning was examined in several recent studies. Minner et al. (2010) performed a large scale meta-analysis of 138 studies between the years 1984 to 2002, examining the impact of inquiry instruction in K-12 classes on students’ outcomes. They found that inquiry-based instruction had a clear positive effect on students’ content learning and retention, mostly when engaging students in active hand-on activities and reaching conclusions from evidence. Students’ conceptual understanding increased after being engaged in active scientific investigation where they were responsible over the experimental process (Minner et al., 2010). Furtak et al. (2012), in their meta-analysis of 37 experimental and quasi-experimental studies about inquiry-based teaching between 1996 to 2006, focused on cognitive-epistemic domains, social communication, procedural understanding and the level of teacher guidance provided to the students. It was found that inquiry-based teaching which combined the procedural, epistemic and social domains had a positive effect on students’ learning. Also, teacher-centered activities were found to be more effective on students’ learning than student-directed activities.

In a retrospective international study, McConney, Oliver, Woods-McConney, Schibeci, and Maor (2014) analyzed the Program for International Student Assessment (PISA) results of 15 years-old students from Australia, New-Zealand and Canada. They found that students who reported high level of classroom inquiry activities had below average scientific literacy scores, and above average level of interest and engagement in science. Altogether, these recent studies demonstrates that there is still much debate regarding the outcome of inquiry teaching and the most appropriate strategies for inquiry teaching, and more research is required to determine the contribution of inquiry-based science teaching and learning to students' outcomes.

Historical review of inquiry in science education

John Dewey, in the early 20th century, was one of the first researchers to formally bring inquiry to the front of the science education stage. In his view, science was taught as an accumulation of facts and knowledge and not as a method of thinking and attitude of mind (Bybee, 2000; Dewey, 1964). Dewey defined inquiry as a process in which the undefined and unknown is intentionally directed to become one clear and unified whole (Barrow, 2006). In modern society, citizens who understand the scientific method and habits of mind of scientific inquiry will be provided with powerful tools for thinking and behavior in their everyday life (Dewey, 1938).

Following the launch of the Sputnik by Russia in 1957, a new era of reform in science education had begun in the United States, prompted by the National Science Foundation (NSF), in order to support the next generation of American scientists and engineers. Inquiry teaching was considered a main feature in the new science curriculum (Barrow, 2006; Bybee, 2000). Schwab (1960) called for the incorporation of inquiry (or 'enquiry', as he wrote) in science teaching curricula and distinguished between 'stable' and 'fluid' enquiry. In stable enquiry, the goal is to fill a hole in a growing body of knowledge and not to question the body of knowledge itself. In contrast, in fluid enquiry the goal is to discover the flaws in the known principles and theories and to invent new feasible scientific conceptions. Schwab (1962) articulated that inquiry is comprised of two aspects: a method of teaching and learning science ('teaching as inquiry') and an aspect of viewing inquiry as part of the science itself ('science as inquiry'). While teaching as inquiry deals with the question of how teaching of science is accomplished, science as inquiry refers to what is being taught. Schwab argued that inquiry is perceived and taught mostly according to the first aspect and not as the second one, what can lead to an epistemological conflict among the students. Schwab also contributed to the development of the Biological Sciences Curriculum Study (BSCS) that introduced the 'invitations to inquiry' (Bybee et al., 2006). The BSCS, developed since 1969, is an important program for development and implementation of life science curricula that adopted the scientific inquiry as the main goal and served as an instruction model for biology teaching (Tamir, 1985).

During the 90’s, the NRC (1996) published the National Science Education Standards (NSES), which brought the inquiry practices back to the center of the science education stage. Several policy documents of the NRC continued to emphasize the importance of teaching science as inquiry (National Research Council [NRC], 2000, 2007). The NRC (2012) suggested that inquiry teaching should be replaced with the teaching of scientific practices, as discussed in section 2.2.2.

Authentic scientific inquiry

Authentic scientific inquiry refers to the diverse methods and habits of mind used by scientists in their ongoing pursuit of finding explanations and developing theories to explain the natural world. Like scientists, students should experience authentic inquiry to develop their understanding of the natural world around them. (Schwartz et al., 2004). Authentic scientific inquiry is a complex activity that scientists carry out in their research. It requires highly developed and specialized expertise and advanced equipment and techniques. Some studies indicate that young students lack the skills and cognitive level to perform full inquiry with all of its stages (Harlen, 2004).

Chinn and Malhotra (2002) argue that there is a conflicting difference between the inquiry tasks carried out in school and the authentic ’real-life’ scientific inquiry. "*The cognitive processes needed to succeed at many school tasks are often qualitatively different from the cognitive processes needed to engage in real scientific research. Indeed, the epistemology of many school inquiry tasks is antithetical to the epistemology of authentic science*" (p. 175). They list some of the cognitive processes needed for authentic scientific research, including generating research questions, designing studies, making observations, explaining results, developing theories, and studying research reports, and demonstrate the lack or insufficient practice of them in simple inquiry school tasks and textbook assignments. They argue that there is an opposite epistemology of inquiry in authentic inquiry and simple school inquiry tasks, especially concerning scientific reasoning. They suggest that research-based inquiry tasks developed by researchers should increase the epistemological features of authentic science, mostly concerning generating and interpreting data (Chinn & Malhotra, 2002).

Students engaging in authentic scientific inquiry should participate in three main authentic scientific practices: producing knowledge, evaluating knowledge and communicating knowledge (Jimenez-Aleixandre & Fernandez-Lopez, 2010). Students need to experience the culture of science practitioners, engage in reasoning and discursive practices and practice and understand the processes that scientists use to generate and evaluate knowledge. Sandoval (2005) argues that there is a gap between students' authentic scientific inquiry practices and their epistemological beliefs about science. According to Sandoval, inquiry is designed to help students understand the nature of science, but the actual tasks that involve inquiry in school do not change students' ideas about the nature of science. Sandoval distinguishes between 'practical epistemologies', which are the ideas that students have about their own scientific knowledge production through inquiry, and 'formal epistemology', which are the ideas and beliefs of students regarding professional and formal science. He argues that inquiry teaching must bridge practical and formal epistemologies in students' beliefs. Also, inquiry tasks should give students the opportunity to consider which data are appropriate, be responsible for connecting the data to the claims they make, and shift the responsibility of the inquiry process to the students in order to shape the correct authentic epistemology of inquiry (Sandoval, 2005). Engaging teachers in authentic research, side by side with researchers, was found to increase the teachers' inquiry understanding and conception and to support their inquiry teaching practice (McLaughlin & MacFadden, 2014). In order to characterize the authenticity of the Bio-Tech program, the program participants' views towards the authenticity of the program were exposed and analyzed.

Inquiry levels

Since the beginning of teaching and learning of science as inquiry, it was argued that student learning should be an active process (Bybee, 2000; Schwab, 1962; Tamir, 2006). According to the constructivist and active learning theory, students should experience inquiry in their own hands and mind (Wheatley, 1991). This theory developed over the years to the concept of inquiry level (Blanchard et al., 2010; Germann, Haskins, & Auls, 1996; McConney et al., 2014). Schwab (1962) described three levels of inquiry: (1) structured inquiry, where the students are given the problem and method of inquiry and they need to find the conclusions and relations between variables themselves, (2) guided inquiry, where the students are given the problem but need to come up with their own methods and explanations to the inquiry, and (3) open inquiry, the highest level where students are independent to perform all phases of inquiry (Blanchard et al., 2010; Jimenez-Aleixandre & Fernandez-Lopez, 2010; Zion & Sadeh, 2007). Herron (1971) added the (0) level, conformational inquiry, where the student is given all phases of inquiry. Germann et al. (1996) found that laboratory manuals for high school students seldom ask students to use their prior knowledge or engage in open inquiry and independently perform any of the inquiry process. They suggested that the teacher can provide the students with particular prior knowledge that can help them succeed in their inquiry, and call for a reform in the traditional ’cookbook’ laboratory activities, where students are taught to be technicians instead of scientists (Germann et al., 1996).

Open inquiry is not necessarily the ideal approach to teaching science as inquiry. Kirschner, Sweller, and Clark (2006) claimed in their controversial article that minimally guided inquiry is less effective than guided inquiry and may result in students’ incomplete and disorganized knowledge. However, Hmelo-Silver et al. (2007) argued in response that inquiry-based teaching and minimally guided inquiry that provide students with appropriate scaffolding improves students’ content knowledge, epistemic practices and learning of other skills. Bunterm et al. (2014) found that the content knowledge and scientific process skills of secondary school students who experienced high inquiry level improved compared to students who experienced a more structured inquiry. The optimal level should be appropriate to the students’ cognitive level and material demands. The involvement of the teacher in all inquiry levels is significant and a high open level does not mean that the teacher is uninvolved and not part of the students learning process (Jimenez-Aleixandre & Fernandez-Lopez, 2010).

According to the NRC (2000), full inquiry is considered an activity in which all five features of inquiry (described in section 2.3) are practiced, but there may be a variation in the level of teacher guidance provided to the students. The five essential inquiry features are placed on a continuum, reflecting the amount of learner self-direction and the amount of direction from the teacher or the learning material. This model doesn’t put the features of inquiry in a specific order. *"The more responsibility learners have for posing and responding to questions, designing investigations, and extracting and communicating their learning, the more "open" the inquiry…The more* *responsibility the teacher takes, the more guided the inquiry"* (p. 30). Blanchard et al. (2010) compared the achievements of junior and senior high school students learning a forensic laboratory unit by the traditional conformational inquiry (level 0) and a level 2 guided inquiry. They found significantly higher post-test scores of content, epistemic, and procedural knowledge of the students in the guided inquiry, provided that their teacher had a strong positive attitude towards inquiry teaching. This shows the importance of having inquiry-oriented teachers with strong inquiry pedagogical content knowledge.

Taken together, although the field of the teaching and learning of scientific inquiry had been thoroughly explored in the past, there are still many questions that remain to be clarified. There is a need to further investigate the most appropriate strategies of teaching students how to perform scientific inquiry and to evaluate the inquiry level of inquiry-oriented programs, such as the Bio-Tech, and their effect on students' learning.

2.2.2 Scientific practices

The Next Generation Science Standards (NGSS) introduces a three-dimensional model for science learning: (i) Scientific and engineering practices, (ii) Crosscutting concepts, and (iii) Disciplinary core ideas. The three dimensions are integrated in performance expectations, which assess K-12 students' knowledge in use. These are the core concepts that are required from the 21st century students (Krajcik, Codere, Dahsah, Bayer, & Mun, 2014; NGSS, 2013).

The recent NGSS document call for a shift from teaching science by inquiry to teaching scientific practices (Bybee, 2014; National Research Council [NRC], 2012; NGSS, 2013; Osborne, 2014a). There is a fundamental difference between the goals of scientific inquiry, as they are portrayed in the work of scientists and their continuant endeavor to discover new knowledge ('doing of science'), and the goal of learning science, which sets to build students' understanding of existing scientific ideas and knowledge (Osborne, 2014a, 2014b). This cognitive and epistemic difference was also discussed by Chinn and Malhotra (2002) in their comparison between authentic scientific inquiry and classroom inquiry activities. Another reason for replacing the term 'inquiry' lies in the lack of accepted definition and understanding of what teaching by inquiry means, ranging from hands-on activities to cookbook laboratory exercises (Osborne, 2014a). As claimed by Osborne (2014b): *"a basic problem with the emphasis on teaching science through inquiry is that it represents a confusion of the goal of science—to discover new knowledge about the material world—with the goal of* ***learning*** *science—to build an understanding of the existing ideas that contemporary culture has built about the natural and living world that surround us…Thus, the flaw in the argument for inquiry-based teaching of science has been a conflation of the* ***doing*** *of science with the learning of science*" (p.178, emphasis in original text). The idea behind teaching science as a set of practices entails the concept of developing students' communicative engagement in reasoning, argumentation, critiquing and modeling, alongside with their gaining appreciation of the scientific process. Focusing on scientific practices is expected to develop students' understanding of scientific epistemology, procedural knowledge, and scientific literacy (National Research Council [NRC], 2012; Osborne, 2014b).

Scientific practices are defined not only as skills but also as specific knowledge to perform each practice that scientists and students employ to investigate and build models and theories about the natural world. These are the diverse ways and methods that can be used to describe phenomena in the world around us (NGSS, 2013). Much emphasize is directed to the social and cognitive aspects of the scientific process: the communication, argumentation and model generating abilities, which rely on social skills and critiquing others. The practices are designed to facilitate students' scientific habit of mind, as well as enhancing their engagement in scientific inquiry (Stage, Asturias, Cheuk, Daro, & Hampton, 2013). The eight essential practices of science and engineering, according to the National Research Council [NRC] (2012) are: (i) asking questions, (ii) developing and using models, (iii) planning and carrying out investigations, (iv) analyzing and interpreting data, (v) using mathematical and computational thinking, (vi) constructing explanations, (vii) engaging in argument from evidence, and (viii) obtaining, evaluating and communicating information.

This study focuses on the teaching and learning two of these scientific practices: asking questions and critiquing, in the context of the Bio-Tech program. Critiquing is not one of the eight scientific practices presented above, but viewed as central to the teaching and learning of all the other practices, as mentioned by Osborne (2014b): "*One of the arguments for the turn to practices is that it places the higher order skills of critique and evaluation at the center of teaching and learning science*" (p. 183).

Asking questions

One of the key authentic scientific practices is the ability to pose questions that are relevant to the scientific content, that are testable and that can contribute to the scientific knowledge of a concept, a model or a theory (Chin, 2002; Chin & Osborne, 2008; Yip, 2004; Zion & Sadeh, 2007). Students' questions are usually derived from their interest and curiosity, and promoting students' questions could be a powerful tool for increasing their motivation in science classes (Baram-Tsabari, Sethi, Bry, & Yarden, 2006). The goals of teaching asking questions, from the students learning perspective, are to direct their knowledge construction, foster communication, help self-evaluating their understanding and increase their motivation and curiosity (Chin & Osborne, 2008). Asking questions can also serve for diagnosing students' understanding and supporting their high-order thinking. Some teachers do not encourage students to ask questions. They probably see the students' questions as distractive, time-consuming or out of reach from the teacher's sphere of knowledge and comfort. This is most prominent among teachers who perceive their role as dispensers of knowledge (Chin, 2002).

Asking questions is one of the scientific features mentioned in the NRC (2000). Student's questions should drive the inquiry process in all its stages. In order to answer scientific questions, the questions should be appropriate to the student's cognitive developmental level and the procedures should be accessible and manageable to the student. It is an important scientific habit of mind, driven from curiosity, studying of model or theory or the need to find a solution to a problem (National Research Council [NRC], 2012). Students should be able distinguish between scientific and non-scientific questions, formulate and refine empirical classroom questions and use questions while communicating. Students' questions during classroom discourse are usually of the informative type (Chin, 2002). This study aims to explore the development of students' ability to ask questions following their participation in an inquiry-oriented program.

One of the tools to classify questions is according to Bloom's taxonomy of the thinking level required to answer them (Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956). Bloom's taxonomy includes six levels of reasoning skills: knowledge, comprehension, application, analysis, synthesis and evaluation. Dillon (1984) classified research questions based on the following categories: rhetorical, properties, comparisons, and causal relationship. The categories depend on the level of knowledge that may be conceived by researching these questions. Rhetorical questions do not require any new knowledge. Questions of higher level require new knowledge in a hierarchal order. Properties questions are usually comprised of only one variable. Comparison questions ask to compare and distinguish between two variables, while causal relationship questions concern the relations and causal effects of two variables, and may involve different conditions. Brill and Yarden (2003) reported that learning science using Adapted Primary Literature (APL) prompted high school students' ability to ask higher order questions, indicating that the students' higher-order thinking skills developed.

Students' research questions

Research questions, also termed researchable questions (Chin & Kayalvizhi, 2002; Cuccio-Schirripa & Steiner, 2000), investigable questions (Chin, 2002), or operational questions (Allison & Shrigley, 1986), are questions which require hands-on, manipulative, operational activities and lead to a process of collecting data in order to answer them (Chin, 2002; Hartford & Good, 1982). Research questions should be meaningful, interesting and challenging for the students, providing them with opportunities to demonstrate their knowledge, skills and abilities, and also to encourage them to exercise their critical and creative thinking (Chin & Kayalvizhi, 2002). For practical, operational, and cognitive reasons, research questions should not be too complicated (Chin, 2002). Students' research questions should be manageable for investigation under the time and material limitations. The inquiry process that is required for answering research questions should not be too expensive, complicated or dangerous to perform (Chin & Kayalvizhi, 2002). Furthermore, research questions should lead to genuine exploration and discovery of knowledge that was previously unknown to the students (Cuccio-Schirripa & Steiner, 2000).

Students are expected to formulate their own research questions while participating in scientific inquiry (Cuccio-Schirripa & Steiner, 2000). These questions should help students to progress to the next stages of the inquiry process (Chin, 2002), and develop their procedural and conceptual knowledge (Chin & Brown, 2002). Students are expected to formulate their own research questions during their school science learning (National Research Council [NRC], 2007). In addition, students should be able distinguish between research questions and other types of questions, and to refine their empirical questions that lead to open investigations (National Research Council [NRC], 2000).

Harris, Phillips, and Penuel (2012) investigated 5th grade teachers' instructional moves and teaching strategies while teaching students to formulate research questions. They found that although the teachers displayed a student-centered and dialogic approach, they experienced challenges in developing their students' ideas into investigable questions. Lombard and Schneider (2013) found that high school biology majors' ability to write research questions appropriate for investigation improved while maintaining their ownership of the inquiry process. Some of the students' ability to write appropriate research questions was achieved by employing structured teacher guidance while engaging students in peer discussions (Lombard & Schneider, 2013).

Explicit teaching of asking research questions in middle and high school was found to improve the level of students' questions (Allison & Shrigley, 1986; Cuccio-Schirripa & Steiner, 2000; Hartford & Good, 1982; Roth & Roychoudhury, 1993). Hasson & Yarden (2012) suggested that providing teachers with explicit knowledge of laboratory techniques can improve their ability to ask research questions and to promote their ability to teach students to ask research questions. Chin and Kayalvizhi (2002) found that primary school students experienced difficulties in formulating research questions that lead to open and practical investigations. Presenting students with examples of research questions can assist them in generating their own questions (Chin, 2002). Based on this theoretical framework, there is a need to characterize the teaching of asking research questions in inquiry-oriented programs, such as the Bio-Tech, and to explore means to promote the learning of asking research questions in science classrooms.

Critiquing

The ability to critique, as defined by Ennis (1987), is "*reasonable reflective thinking that is focused on deciding what to believe or do*" (p. 10), and is crucial for productive participation in scientific discourse. Students should be able to identify possible weaknesses and flaws in scientific claims, articulate the merits and limitations of peer views and read media reports in a critical manner (National

Research Council [NRC], 2012). Berland and Reiser (2011) considered critiquing to be a key goal of sense-making and persuasion in scientific argumentation. The ability to critique makes up an important part of scientific inquiry and consists of several skills and abilities, such as testing hypotheses, designing experiments and drawing conclusions from results (Ford, 2012). Students rarely have opportunities to be engaged in critiquing and in scientific argumentation (Sampson & Clark, 2011). Even though the teaching and learning of critiquing is well accepted by the science education community, much debate still remains on how this practice should be taught. More activities are needed to develop these abilities in the classroom, mainly by restructuring current science lessons (Berland & Reiser, 2011; Osborne, 2010).

The practice of critiquing is closely related to the practice of argumentation, since both of them are necessary for producing and evaluating new scientific knowledge (Berland & Reiser, 2011; Osborne, 2010). As claimed by Osborne (2010): "*Critique is not, therefore, some peripheral feature of science, but rather it is core to its practice, and without argument and evaluation, the construction of reliable knowledge would be impossible*" (p. 464). Both critiquing and argumentation are connected to other scientific skills and abilities such as reasoning, logical thinking, language skills, communication and justification. An argument is defined as an assertion or conclusion with justification, reasons and supports (Osborne, Erduran, & Simon, 2004). According to Toulmin's model of argumentation (Driver, Newton, & Osborne, 2000; McNeill & Krajcik, 2007), a good argument is constructed of three main features: claim (the conclusion), data (the evidence to support the claim) and warrant (the reasoning or justification that connects the data to the claim). Beside these main features, an argument can include a backing (premises of the warrant), qualifiers (the limitations of the claim) and rebuttals (the counter-argument), which are considered to represent students high order thinking (Osborne, 2010).

Ford (2012) claimed that critiquing is essential for learning scientific knowledge and for the development of argumentation abilities. To construct new scientific knowledge, students must be able to search for errors in their own or their peers claims. In Ford's study, students practiced critiquing during classroom laboratory unit by practicing a 'dual-role' condition, where they plan and carry out a relatively open inquiry experiment in physics and asked to critique the suggestions of other students. To evaluate the students' critiquing ability, they were asked to critique a conclusion of an unknown student regarding an issue presented in a popular science article. Students who participated in the ’dual-role’ activity were more inquisitive, demonstrated more sustained attention and avoided premature closure than the control students in the standard laboratory unit. It is suggested that students that are engaged in argumentation develop high level of critiquing and oppositional voice abilities (Ford, 2012). This theoretical framework and methodological approach served as the basis of my research, as I incorporated the similar methods as Ford (2012) to examine the development of the Bio-Tech program students’ critiquing practice following their participation in an inquiry-oriented program.

2.2.3 Scientific language and discourse

Language and communication play a pivotal role in the social constructivist theory and in inquiry-based science teaching, where learners are actively engaged in shared meaning making. The appropriate usage and mastery of the scientific language is a crucial part of gaining scientific literacy, as it is the means of doing science, developing science understanding, communicating about inquiry, and participating in the argumentative scientific discourse (Lemke, 1990; Yore, Bisanz, & Hand, 2003). Group discussions provide the students with opportunities to share and discuss different views and to stimulate deep and meaningful learning (Wheatley, 1991). The main goal of teaching science is to teach students to use the scientific language in order to help them construct and interpret the meaning of scientific knowledge. This should allow students to practice scientific reasoning, argumentation, critiquing and communication (Osborne, 2002). As written by Yore et al. (2003): "*Language is an integral part of science and science literacy –language is a means to doing science and to constructing science understandings; language is also an end in that it is used to communicate about inquiries, procedures, and science understandings to other people so that they can make informed decisions and take informed actions.*" (p. 691).

There is a gap between the language of school science and the language of science, both in texture and structure. For scientists, the language is part of their scientific research, allowing them to communicate and justify their ideas. School textbooks fail to present the appropriate scientific language, since knowledge is presented as non-argumentative truth statements in the form of exposition, which is the description of a theory or a problem (Phillips & Norris, 2009). Students are expected to develop their ability to interpret the meaning of scientific statements in several aspects: the degree of certainty of the statements, the scientific status of the statements and the role of the statements in the chain of reasoning (Norris, Phillips, & Korpan, 2003). Therefore, there is a need to bridge these gaps between the school science language and the scientific language. Students should be given more opportunities to engage in science language and communication in the classroom (Pimentel & McNeill, 2013). Examining the development of students' scientific language during participation in inquiry-oriented programs may shed further light on this issue.

The metalanguage of science is the language that enables to talk about science. It is a language about science that is used to analyze and describe the generation of scientific knowledge (Norris & Phillips, 1994). The metalanguage refers not only to technical terms but also to specialized terms used to communicate about the learned knowledge with peers. Metalanguage is needed to support students in deconstructing and critiquing scientific knowledge as it is presented in scientific text (Shanahan, 2010). In my research, I examined the Bio-Tech students' usage of metalanguage of science terms in the questions and arguments they wrote, as an indicator for the development of their scientific language.

Classroom discourse and the communicative approach

Examining classroom discourse is a powerful tool for evaluating the development of students' scientific understandings and abilities (Osborne, 2010; Pimentel & McNeill, 2013). Most of the discourse that is carried out in classrooms is teacher-centered and authoritative, as it is difficult for teachers to shift from the traditional teacher-centered instruction to more student-centered discursive teaching strategies (Jimenez-Aleixandre, Bugallo Rodriguez, & Duschl, 2000; Lemke, 1990).

One of the methods to investigate classroom discourse is the communicative approach. The communicative approach analytical framework was developed by Mortimer and Scott (2003) in order to examine and classify types of classroom discourse. The communicative approach focuses on the teacher-students interactions that serve to develop students' ideas and understanding in the classroom. The framework is based on the socio-cultural principles, according to which individual learning and understanding is influenced by the social interactions context (Scott, 1998; Vygotsky, 1978) and the language role during classroom talk (Lemke, 1990).

Central to the communicative approach are the dialogic / authoritative and interactive / non-interactive dimensions. The authoritative / dialogic dimension determines whether the teacher acts as a transmitter of knowledge embodied in one scientific meaning or adopts a dialogic instruction that encourages exploration of different views and ideas in order to develop shared meaning of new knowledge (Scott, 1998). In an authoritative discourse, the discussion is ‘closed’ to other voices, has fixed intent and controlled outcome. In a dialogic discourse, the teacher encourages the students to express their ideas and debate their points of views. The discussion is ‘open’ and may include several different views. The intent of the dialogic discourse is of generative nature and the outcome is unknown. Scott, Mortimer, and Agular (2006) suggested that there is a necessary tension during classroom discourse between the authoritative and dialogic dimensions. The teachers may shift between the approaches, according to their teaching purposes and goals (Scott et al., 2006). Mortimer and Scott (2003) mention that there are different levels of engaging with students’ ideas in the dialogic discourse, which they referred to as ’interanimation level’. On the one hand, students’ points of views could just be listed and not discussed or evaluated by the teacher or by other students (low level of interanimation). On the other hand, the teacher may encourage the students to compare, contrast and probe their points of views (high level of interanimation). In order to achieve meaningful learning, students are expected to engage in dialogic discourse with high level of interanimation (Scott et al., 2006). The interactive / non-interactive dimension determines the students’ involvement level during the discourse. In interactive discourse, many students participate in the discussion, while in non-interactive discourse the number of students participating in the discussion is limited to a single student or to very few students.

The communicative approach examines the patterns of interactions during classroom discourse. They are represented by the triadic dialogue, comprised of the Initiation-Response-Evaluation (I-R-E) structure (Mehan, 1979). According to this pattern, each dialogic sequence usually starts with teacher initiation (mostly in the form of a question), followed by a response from a student (an answer to the question) and closes with a teacher evaluation of the response. This short and closed chain triadic sequence dominates most teacher-centered classroom discourse and is highly common in high school classrooms (Lemke, 1990; Scott et al., 2006). Mortimer and

Scott (2003) suggested that interactive discourse is characterized by long and open non-triadic patters, in which the teacher refrains from immediate evaluation of the student’s response and instead may prompt the student to further elaborate on his idea or encourage other students to critique their ideas.

The discursive moves used by the teacher during the lesson are pivotal in navigating the classroom discussion and promoting meaningful discourse (Pimentel & McNeill, 2013) and for providing collaborative feedback (Gan Joo Seng & Hill, 2014). Among the various teacher moves, teachers’ questions play an important role in students’ learning, as they scaffold students’ thinking and understanding and encourages students to be more involved in the classroom discourse (Chin, 2007; Kawalkar & Vijapurkar, 2011). One classification of teacher questions is as open or closed questions. Open questions, in which the teacher probes for students’ ideas without expecting a specific known answer, promote dialogic discourse and increase students’ involvement in the discussion. In contrast, closed questions, requires the students to recall factual knowledge and leads to authoritative discourse that does not promote students’ meaningful learning (Chin, 2007). This research focuses on the classroom discourse during whole class discussions in lessons designed for teaching students to formulate their research questions. Examining the communicative approaches and teacher’s moves allowed me to analyze the possible connections between the teacher’s instructional strategies and the students’ learning of asking research questions and critiquing in the context of the Bio-Tech program.

2.2.4 Intended and implemented curricula

Curriculum is the plan of learning an educational content. This includes the developers’ ideological perception, the teachers’ perceived and enacted teaching and students’ experiences (Goodlad, Klein, & Tye, 1979). Central to the scientific teaching and learning and to the development of students’ scientific literacy is the implementation of the scientific curricula. Goodlad et al. (1979) described two of the curricular substantive domains: the intended and the implemented curricula.

The *Intended curriculum* includes the *Ideological curriculum*, which refers to the curriculum that emerges from idealistic planning processes of the program developers and policy makers, and the *formal curriculum* that includes written documents (curriculum guides, official syllabi, adopted texts, units of study etc.) that gain official approval of the authorities and policy makers. The *Implemented curriculum* includes the *perceived curriculum*, which is perceived in the minds of those involved in the teaching process and other involved groups, such as the students' parents, and the *operational curriculum,* which refers to the enacted activities that are taught to the students. The distinctions between the domains are not always clear and it is difficult to gain a full and precise understanding of all the curricular domains (Porter & Smithson, 2001).

Gaps and tensions between the intended and implemented curricula have been widely investigated (Anderson & Helms, 2001). Many factors influence the implementation of the intended curriculum in the classrooms, among them are the teachers' attitudes and intentions that may support or interfere with the curriculum developers' goals (Porter & Smithson, 2001). Patchen and Smithenry (2013) found that student-centered inquiry designed curriculum supported students' collaborative work, communication during inquiry investigation, and achieving disciplinary goals. In my study, a comparison between the intended and implemented inquiry curricula of the Bio-Tech program was performed. This serves as a platform to expose possible gaps between the curricular inquiry levels, elucidate explanations for these gaps, and indicate means and strategies for bridging between them.

3. Research goals, objectives, and questions

The main goal of this study is to characterize the teaching and learning of inquiry in the context an innovative educational program for 11th grade biotechnology majors, the Bio-Tech program. To achieve this goal, the research focuses on the following three specific objectives:

(i) To characterize the teaching and learning of the asking questions and critiquing scientific practices in the Bio-Tech program.

(ii) To identify possible gaps between the intended and the implemented curricula of the Bio-Tech program.

(iii) To explore the Bio-Tech program participants' views regarding the program's inquiry level and authenticity.

The following research questions address the first objective of characterizing the teaching and learning of asking questions and critiquing practices:

1. How does the participation in the Bio-Tech program influence students' ability to ask questions?

2. What are the characteristics of teaching and learning of asking research questions in the Bio-Tech program?

3. What are the Bio-Tech participants' views regarding asking research questions in the program?

4. How does the participation in the Bio-Tech program influence the development of students' ability to critique?

The following research question addresses the second objective of identifying possible gaps between the intended and implemented curricula:

5. What are the differences between the inquiry processes in the intended and in the implemented Bio-Tech program curricula?

The following research questions address the third objective of exploring the inquiry-oriented program participants' views regarding the program's inquiry level and authentic research:

6. What are the Bio-Tech participants' views regarding the program's inquiry level?

7. What are the Bio-Tech participants' views regarding the program's authenticity?

4. Research context

The Bio-Tech program is an optional part (1 credit out of a total of 5 credits) of the Israeli matriculation examinations for biotechnology majors carried out during the 11th grade (Israeli Ministry of Education, 2005, 2008). In the Bio-Tech program, students are required to perform an inquiry project following a visit to a biotechnology laboratory in an industrial or an academic facility. The Davidson Institute of Science Education and the Department of Science Teaching at the Weizmann Institute of Science started to support the Bio-Tech program during 2009, and this year (2015) will be the sixth year that the Bio-Tech program will be offered to 11th grade biotechnology majors, with over 20 classes participating in the program every year. The Bio-Tech program design originates from the Teacher-Led Outreach Laboratory (TLOL) approach (Stolarsky Ben-Nun & Yarden, 2009).

The Bio-Tech program, carried out at the Davidson Institute of Science Education (hereon referred to as the 'Bio-Tech program'), is an innovative high school program in several aspects. The inquiry-oriented approach allows students to practice high level of inquiry. A co-teaching approach is implemented, where teaching is performed by the class teacher, a young scientist instructor from one of the research groups at the Weizmann Institute of Science or from the Faculty of Agriculture at the Hebrew University of Jerusalem, and a science educator working at the Davidson Institute. The topic of inquiry is learned using the Adapted Primary Literature (APL) approach (Yarden, 2009; Yarden, Brill, & Falk, 2001), which allows the students an opportunity to learn up-to-date scientific concepts, and experience firsthand encounter with authentic science (Brill & Yarden, 2003).

The Bio-Tech program begins with a teacher professional development program (3-6 days long) that focuses on the inquiry process and the concepts of the Bio-Tech program. The teachers carry out the inquiry process as learners similarly to their students and by this they can evaluate and adjust the program to their students' level, needs, and abilities. Following the teacher training, at the beginning of the school year, school classroom lessons are devoted to the study of the APL article which presents the students with the background content knowledge as well as the tools, methods, and procedures used in their designated research group lab. About two months after the beginning of the year, the class arrives to the research institute for a preliminary experiment. During the visit, the students meet the young scientist instructor from their designated research group and visit his / her lab in the research institute. The students learn about the research institute's structure, departments, and main fields of research. They also take part in small-scale preliminary experiments that introduce the methods and content of the research topic. Following the preliminary visit to the research institute, the students are divided to groups of two or three and begin to plan their investigation under the guidance of their teacher with assistant of the young scientist instructor and the science educator. The planned experiments are restricted to the methods and tools available at the research institute labs. Once all the students have their experiments planned and approved, the class arrives again to the research institute labs for additional two days to perform the main investigation. Data is collected by the students and they begin analyzing their results. Back in the school, the students continue to interpret the data, write the research portfolio and prepare for the final oral exam (timeline described in Fig. 1).

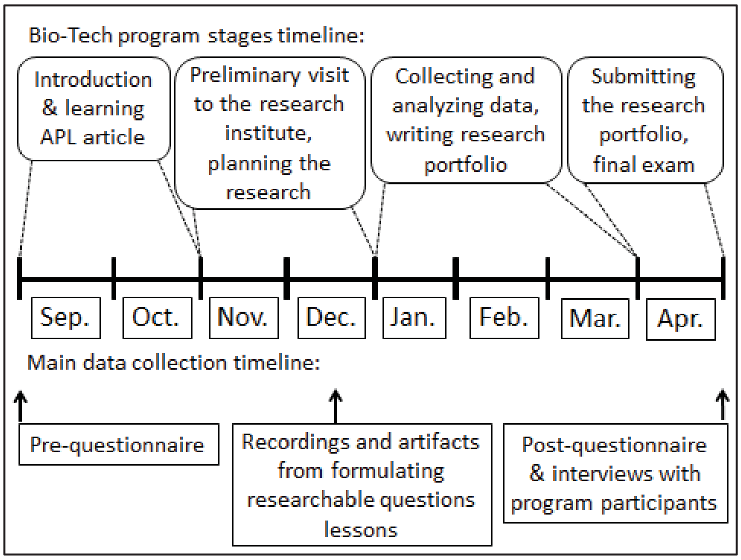


Fig. 1: The Bio-Tech estimated yearly timeline and main data collection events

The biological systems investigated in the Bio-Tech program range from the molecular level, including genes, proteins and organelles, to the cellular level including bacteria, fungi, yeast and tissue culture cells. The experimental techniques used in the Bio-Tech program range from simple observational methods, such as bacterial colony growth on plates, color alternations in growth medium and microscope observations, to highly advanced tools and equipment that are usually not available in schools, such as spectrophotometer, Polymerase Chain Reaction (PCR) and fluorescent microscope. The protocols are especially designed and adapted to fit the students' cognitive abilities and the time limits of the program.

5. Methodology

This research aimed on characterizing the teaching and learning of inquiry in the Bio-Tech program. In order to achieve this goal, several methodological approaches were used. This was an applied experimental research that involved mixed methods, integrating both quantitative and qualitative approaches. The research included characterization of the 11th grade Bio-Tech program. The approach was deductive "top-down": the inquiry program and curricula analysis were based on the accepted models of student-centered active learning (Gardner & Belland, 2012; Michael, 2006), scientific language (Lemke, 1990), inquiry-based science teaching (Bybee, 2000; National Research Council [NRC], 1996), and authentic scientific practices (Chinn & Malhotra, 2002; National Research Council [NRC], 2012)

The quantitative part of this study was aimed at identifying and evaluating the changes in students' acquisition of authentic scientific practices by analyzing their pre- and post-questionnaires. The qualitative part of this study was aimed at characterizing the inquiry process that was experienced in the inquiry-oriented program and exploring the Bio-Tech participants' views regarding the program's inquiry level and authenticity. Analysis included triangulation of several tools, including observations and recordings of specific lessons, interviews with the program participants, and artifacts from classroom activities. Analysis also included characterization and visualization of the inquiry features using the I-MAP tool.

5.1 Research population

The research population participating in this research is a non-random, convenient and by quota sample. It includes the following:

1. Eleventh grade senior high school students majoring in biotechnology (n=15 classes) were chosen to participate in the pre- and post-questionnaires assessment during the 2011/12 and 2012/13 academic years. Classes were chosen by convenient selection and represent medium and high socio-economic background schools from various regions in Israel. Eight of the classes participated in the Bio-Tech program; the other classes learned a unit about fermentation instead and did not participate in any inquiry-oriented program during their biotechnology studies. A total of 115 Bio-Tech students and 80 non Bio-Tech students filled-out both of the questionnaires.

2. Bio-Tech students (n=57), teachers (n=6), young scientist instructors (n=7), and program developers (n=3) were chosen for semi-structured interviews by convenient selection. The chosen teachers were experienced biotechnology teachers who taught the Bio-Tech program for at least one year. The young scientist instructors, all of them are M.Sc. or PhD students from either the Weizmann Institute of Science or the Faculty of Agriculture at the Hebrew University of Jerusalem, completed at least one year of teaching the Bio-Tech program. The program developers were the main Bio-Tech designers and science educators running the program, including the chief supervisor of biotechnology studies in the Israeli Ministry of Education. All of the developers were part of the original development team of the Bio-Tech program.

3. Bio-Tech teachers (n=2) and their classes (n=2) were chosen for in-depth analysis of the formulating research questions teaching process by convenient selection during the 2012/13 academic year. The teachers, Sam and Rebecca (Pseudo names), were experienced biotechnology and biology teachers. The two teachers were chosen for this research since they were both experienced biotechnology teachers with many years of experience in teaching different inquiry programs (Table 1). Sam also participated in the I-MAP tool analysis of the implemented curricula.

Table 1: Teachers, schools and class characteristics which were subjected to the in-depth analysis

Teacher's pseudo-names	Scientific background	Teaching experience	Experience in the Bio-Tech	School location	# of students in class	Bio-Tech topic
Sam	M.Sc. in life sciences	13 years	3 years	Rural	27	Unfolded Protein Response (UPR) in yeast (Cox & Walter, 1996)
Rebecca	B.Sc. in life sciences	26 years	2 years	Urban	19	Bacterial expression of PON1 enzyme (Aharoni et al., 2003)

4. Bio-Tech teachers (n=10) participated in the I-MAP tool workshop during a professional development session focusing on the Bio-Tech program at the Davidson Institute at the end of the 2012/13 academic year. The analysis included the teachers' resulting I-MAP stars and the whole group discussion that was carried out during the workshop.

5.2 Data sources

5.2.1 Students' Pre- and Post-questionnaires

The questionnaires used in this research were based on previously published studies, in which students' argumentation and critiquing abilities were evaluated following reading a popular scientific article (Ford, 2012; Ratcliffe, 1999). Students were given the same popular scientific article used in the previously mentioned studies ('Alarm sounds over toxic teething rings', *The New Scientist*, July 14, 1997, translated to Hebrew), which discusses a scientific research about release of Phthalates toxins from babies' teething rings, and includes a description of an experimental process. This article was previously validated and found appropriate for examining high school students' cognitive level (Ford, 2012; Ratcliffe, 1999).

Following reading the article, students were asked to answer 9 open pen-and-paper questions. In the first five questions, the students were asked to explain the research described in the article (the research question, hypothesis, method, results and conclusions). These questions were designed to explore students' understanding of the scientific inquiry process. Analysis of these questions is not presented in this study. In the sixth question, students were asked to write at least two new scientific questions that come up in their mind after reading the article and to suggest experiments to answer these questions. In the last three questions of the questionnaires, the students were given a statement of an unknown student who stated a deliberately arguable conclusion regarding the research described in the article. The argument was presented as claimed by an unknown student in order to prevent personal bias in students' answers, since they may tend to be less critical towards a student they may know. The students were asked if they agree or disagree with the claim, and asked to articulate arguments to justify their claims. Analyzing the students' answers allowed me to explore their ability to critique arguable claims and to evaluate their argumentation abilities (Appendix 1).

The pre-questionnaire was administrated at the beginning of the school year, before the classes of the Bio-Tech program engaged in the program and before they started learning the APL article. The post-questionnaire was administrated in proximity to the final Bio-Tech exam at the end of the school year. In the 2011/12 academic year, eight biotechnology classes filled-out the pre- and post- questionnaires (4 Bio-Tech classes and 4 not participating in the Bio-Tech). In the 2012/13 academic year, 4 Bio-Tech classes and 3 non Bio-Tech classes filled-out the questionnaires. The questionnaires were initially tested in two Bio-Tech pilot classes during the first year of this study (2010/11), evaluated by science education researchers, and revised. The questionnaires were then validated by several expert science education researchers and revised to fit the Israeli students' level and the research goals. Changes were made in the questionnaires following the science education researchers' reviews. The final version of the questionnaire (Appendix 1) was accepted for its reliability by two science education researchers.

5.2.2 Observations, recordings, and artifacts of the lessons

The teaching and learning of formulating research questions in the examined Bio-Tech classes that participated in this study was facilitated by a lesson that included explanations and examples of appropriate research questions. Several of these lessons included a peer-critique activity that was specifically designed for the Bio-Tech program, and the teachers who volunteered to use this activity were prepared and trained to use it in their classrooms. This activity gave the students an opportunity to formulate their own research questions, to evaluate their peers' research questions and to receive critique of their own research questions from their peers. Prior to the formulating research questions lesson, students were given a questionnaire in which they were asked to write at least three research questions that they would like to explore. The pre-lesson questionnaire was filled-out by individual students, while the peer-critique activity was performed by the designated research groups.

The peer-critique activity was based on a written sheet that each group received. At first, students were asked to write three research questions that they want to investigate in the Bio-Tech program. Then, they chose one of the questions and formulated it as a research question, according to what they learned in the previous lesson part. Subsequently, each group exchanged their written sheet with another group. The Bio-Tech students were asked to critique the other group's chosen question, based on the research question characteristics they had learned. They were also asked to re-write the research question if needed so it will be appropriate for the Bio-Tech program. Finally, the original group received their sheet back, wrote their responses to the other students' critique and formulated their final suggested research questions (Appendix 2).

This interactive peer-critique activity offered the students an opportunity to formulate their own research questions and to evaluate their own and their peers' questions. The activity was performed in 5 Bio-Tech classes during the 2011/12 and 2012/13 academic school years. Collected data included students' written sheets and audio-recordings of the lessons. Students' written questions during the peer-critique activity were collected, analyzed and compared to the students' questions in the pre-lesson questionnaire and to their final research questions investigated in the Bio-Tech program.

5.2.3 Interviews with Bio-Tech program participants

Students from three Bio-Tech classes were chosen for semi-structured interviews at the end of the 2011/12 and 2012/13 academic years (n=57). The individual students' interviews took place immediately following their final oral Bio-Tech exam at the end of the school year. In their interviews, the students were asked to describe the Bio-Tech program process, to evaluate the level of their independence in performing their investigations and the level of their teacher's involvement, to explain how they chose their research questions, and to address the main advantages and disadvantages of the Bio-Tech program (Appendix 3).

Semi-structured interviews with the teachers, young scientist instructors, and developers were performed in order to explore their attitudes towards the scientific practices and the inquiry process. In addition, their goals and their teaching strategies of the Bio-Tech were explored, focusing on the practices of asking questions and critiquing. The interviews took place at the end of the 2011/12 and 2012/13 academic school years (Appendix 4).

5.2.4 Class observations

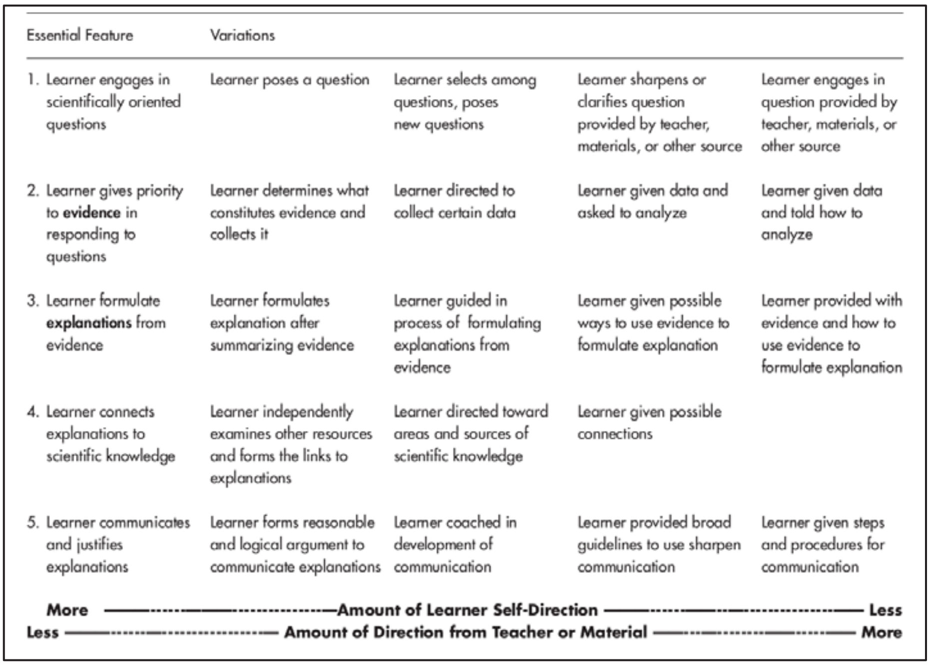
Several classroom and laboratory lessons were observed and audio-recorded, both at the research institute and in schools. The main goal was to examine the inquiry process and the teaching and learning of scientific practices. Observation sheets were filled-out for each observation (Appendix 5). Classification of the inquiry level in each Bio-Tech stage was based on the observations and recordings of specific lessons. Two researchers validated the inquiry level classification.

5.2.5 Israeli Ministry of Education Bio-Tech policy papers

Documents regarding the Israeli biotechnology curriculum (Israeli Ministry of Education, 2005), and the Bio-Tech program curriculum (Israeli Ministry of Education, 2008) were subjected to analysis in order to determine the intended Bio-Tech curriculum and the developers' goals. These documents were analyzed top-down by the researcher in search of specific references to the inquiry level in each stage.

5.2.6 The inquiry forum's I-MAP tool

The I-MAP (Inquiry-based Teaching and Learning Mapping) tool was developed as a multi-disciplinary instrument for characterizing and assessing inquiry-oriented programs, thus hopefully allowing identification of programs in which "best inquiry practices" are performed. It was developed by a forum of researchers, entitled the 'inquiry forum', which was assembled at the end of 2010 at the Department of Science Teaching at the Weizmann Institute of Science. Although other instruments for evaluating inquiry teaching and learning are available, such as DiISC (Baker, 2008), PSI-T and PSI-S (Campbell, Abd-Hamid, & Chapman, 2010) and EQUIP (Marshall, Smart, & Horton, 2010), none of them is simple-to-use, multidisciplinary and graphically illustrative as the I-MAP. The I-MAP tool is based on the NRC (2000) five essential inquiry features, describing the level of student independence in performing the inquiry and the level of guidance provided by the teacher or by the supporting materials (Table 2).



Essential Feature	Variations			
1. Learner engages in scientifically oriented questions	Learner poses a question	Learner selects among questions, poses new questions	Learner sharpens or clarifies question provided by teacher, materials, or other source	Learner engages in question provided by teacher, materials, or other source
2. Learner gives priority to **evidence** in responding to questions	Learner determines what constitutes evidence and collects it	Learner directed to collect certain data	Learner given data and asked to analyze	Learner given data and told how to analyze
3. Learner formulate **explanations** from evidence	Learner formulates explanation after summarizing evidence	Learner guided in process of formulating explanations from evidence	Learner given possible ways to use evidence to formulate explanation	Learner provided with evidence and how to use evidence to formulate explanation
4. Learner connects explanations to scientific knowledge	Learner independently examines other resources and forms the links to explanations	Learner directed toward areas and sources of scientific knowledge	Learner given possible connections	
5. Learner communicates and justifies explanations	Learner forms reasonable and logical argument to communicate explanations	Learner coached in development of communication	Learner provided broad guidelines to use sharpen communication	Learner given steps and procedures for communication

More ——————————**Amount of Learner Self-Direction**—————————— **Less**

Less ——————————**Amount of Direction from Teacher or Material**—————————— **More**

Table 2: Essential features of classroom inquiry (taken from NRC, 2000; p. 29)

The I-MAP tool was designed as a visual representation of the following core inquiry features: (i) engage in a phenomenon, (ii) formulate question, (iii) hypothesize, (iv) plan investigation, (v) collect data, (vi) analyze and represent data, (vii) explain and justify, (viii) link resources to explanations, and (ix) present artifacts. In each feature, the level of the teacher or the learning material involvement is to be determined (low, medium or high, Table 3). Each feature is also classified into three levels of inquiry. In level 1, the learner is completely guided and given all the information and support to perform the inquiry task. In level 2, the learner is partially directed or given possible ways to perform the task. In level 3, the highest level of inquiry, the learner independently performs the task (Table 4).

During the I-MAP tool activity, participants were asked to fill-out the I-MAP features table. Subsequently, they were asked to fill-out the inquiry star, a visual map that represents the participants' chosen inquiry level and teacher involvement of the nine inquiry features and the sequence that the features were carried out during the examined program. This map was presented to the other participants and designed to enable interactive discussion between the participants. The development of the I-MAP tool by the inquiry forum members required several iteration cycles until the final version was reached and agreed upon by all the members. Initial versions of the tool included additional features that were found to be too general for the characterization of the inquiry process, such as critiquing, communication, and justifications. These features were taken out of the final I-MAP version. The I-MAP tool was tested by different disciplinary groups at the Department of Science Teaching at the Weizmann Institute of Science (life sciences, chemistry and physics) in a variety of teaching and learning environments. Several other adjustments to the I-MAP tool were performed following the testing of the tool and analysis of the results by the different forum participants. These adjustments were focused on the visual design of the tool. The final version of the I-MAP tool is presented in Appendix 6.

Table 3: I-MAP levels of teacher support

Level of support	Description
Low	No active involvement, student independent work
Medium	Teacher responses to students requests for directions or directs students
High	Teacher discusses and directs students explicitly

Table 4: I-MAP inquiry features according to the student's independence level in performing inquiry

Feature	Level 1- Dependent	Level 2- Intermediate	Level 3- Independent
1. Engage in a phenomenon	Learner engages in a phenomenon provided by the teacher	Learner selects a phenomenon to be investigated among possibilities provided by the teacher	Learner chooses the phenomenon to be investigated
2. Formulate question	Learner engages in question provided by teacher, materials, or other source	Learner guided to formulate questions	Learner independently poses a question
3. Hypothesize	Learner engages in hypothesis provided by teacher, materials, or other source	Learner guided to formulate hypothesis	Learner formulates a hypothesis and/ or generates alternative hypotheses
4. Plan investigation	Learner engages in a plan for investigation provided by teacher, materials, or other source	Learner guided to plan a part of investigation or to take into account what variables will be controlled, manipulated, and measured	Learner determines what constitutes evidence and plans investigation (procedures and tools)
5. Collect data	Learner engages in data provided by teacher, materials, or other source	Learner directed to collect certain data	Learner independently collects data
6. Analyze and represent data	Learner engages in data analyzed by teacher, materials, or other source	Learner directed to analyze and represents data	Learner independently analyzes and represents data
7. Explain and justify	Learner engages in explanation based on evidence provided by teacher, materials, or other source	Learner guided in process of formulating explanations from evidence	Learner formulates explanations after summarizing evidence
8. Link resources to explanations	Learner engages in given scientific resources	Learner directed toward areas and sources of scientific knowledge, and connects to explanation	Learner independently examines other resources and forms the links to explanations
9. Present artifacts	Learner is guided how to present the artifacts	Learner chooses between several methods to present the artifacts	Learner independently chooses and prepares the artifacts

In order to characterize the inquiry features of the intended and the implemented curricula of the Bio-Tech program, the students' inquiry level and the level of teacher involvement were determined for each of the nine inquiry features by analyzing several data sources. The data sources of the intended curriculum included the Israeli Ministry of Education documents (Israeli Ministry of Education, 2005, 2008) and interviews with the Bio-Tech program developers. Data sources of the implemented curriculum included recordings and observations of one Bio-Tech class and interviews with the students and teacher during the 2010/11 academic year.

In order to examine the Bio-Tech teachers' views regarding the inquiry level of the program, the I-MAP tool was used in a workshop for Bio-Tech teachers, which took place at the end of the 2012/13 school year. During the workshop, the I-MAP tool was introduced to the group, and the participants were asked to fill-out a table with the nine inquiry features, ranking the student inquiry level and the teacher involvement level in each feature for typical Bio-Tech students. Subsequently, participants were asked to fill-out the I-MAP inquiry star, present it to the group during the whole group discussion, and discuss their ideas and understanding with the group. This workshop was audio and video recorded. Some parts of the discussions were transcribed and taken for analysis.

5.3 Data analysis

5.3.1 Analysis of students' pre- and post-questionnaires

Questionnaires from a total of 112 Bio-Tech students and 78 Control students who filled-out both the pre- and post-questionnaires were collected and taken for analysis. Analysis was blindly performed to students' written questions and to their critiquing arguments which were written in response to an unknown student's claim following reading a popular scientific article (questions 6 and 8 in questionnaires, Appendix 1). Students' written answers were inserted into an excel file and coded according to the categories detailed in the following sections.

5.3.1.1 Students’ written questions

In order to evaluate possible changes in students’ abilities to ask questions, students’ written questions in response to question no. 6 in the pre- and post-questionnaires were analyzed and categorized. Students’ questions were classified into several categories relevant for this research. A total pool of 743 written questions were collected and analyzed. The data were statistically analyzed using Statistical Analysis System (SAS) and Statistical Package for the Social Sciences (SPSS) programs for both descriptive statistics and comparing frequencies. Statistically significant differences between means were determined using non parametric one sample binominal goodness of fit χ^2 for comparing frequencies test, t-test, and Wilcoxon signed-rank test (Wilcoxon, 1945). Effect size was calculated for standardized differences between two means using Cohen's D (Cohen, 1988).

Response to media reports

Initial classification of students’ questions was performed using the categories of required information for interpreting media reports (Ratcliffe, 1999), based on Korpan’s taxonomy for classifying questions and knowledge about scientific research (Korpan, Bisanz, Bisanz, & Henderson, 1997). This analysis aimed to expose students’ abilities to evaluate and interpret evidence from media reports about scientific research. In her study, Ratcliffe (1999) classified students’ written responses following reading the same article that was used in my questionnaires. This article and similar questionnaires were also used by Ford (2012) in order to evaluate students’ critiquing abilities.

Ratcliffe (1999) classified students’ comments into the following categories: (i) research, regarding the research design and methods, (ii) research subject, concerning the subject of toxins in teething rings, (iii) research context, focusing on general issues like teething rings, baby’s toys, etc., (iv) research effect, regarding the outcomes of the performed research, (v) personal, concerning the responsibility of the researchers, (vi) media, relating to the connection of the article to other media, (vii) personal experiences, and (ix) economics, regarding the economic and financial implications of the research. The last four categories were found to be irrelevant to this study since only a few of the students’ questions were classified into these categories. Questions from these categories were classified as ’other’ (Table 5).

Table 5: Classification of students' questions according to categories of response to media reports following Ratcliffe (1999)

Categories	Description of questions	Examples
Research	Regarding the conduct of the research (i.e., theory of mechanism, evidence evaluation, alternative experiments, etc.)	*"Is there another method to examine the toxins release?"* *"How do the toxins cause cancer?"*
Subject	Regarding the main subject of the research (i.e., toxins in teething rings)	*"Could these teething rings be produced without the toxins?"*
Context	Regarding other issues related to the main subject of the research (i.e., teething rings or babies toys)	*"Do other toys also release Phthalates toxins?"*
Effect	Regarding the main outcome of the research (i.e., the release of toxins from teething rings)	*"Why is there such a difference between the amounts of toxins released from each teething ring?"*
Other	Regarding other issues, such as personal responsibility, personal experiences, other media or economics	*"Why do the manufactures put the toxins inside the teething rings in the first place, if they know they are dangerous for the babies?"*

Questions regarding the experimental process

In order to examine possible changes in students' ability to focus their questions on the experimental process, their written questions were classified as questions that focus on the experimental process that was described in the article. This type of questions could also be defined as methodological or experimental questions (Baram-Tsabari & Yarden, 2005). Examples of these questions are given in Table 6.

Research questions

Students' questions were defined as research questions provided they include the following criteria: answering the question requires hands-on investigation and data collection, it includes variables that are specific, manipulative and measurable, and that the answer to the question is unknown to the students (Cuccio-Schirripa & Steiner, 2000). Examples of these questions are given in Table 6.

Table 6: Classification of students' questions regarding the experimental process and research questions

Categories		Examples
Regarding the experimental process	Research question	
-	-	*"Are there other baby products that may hurt babies?"*
-	+	*"Is there a connection between the amount of toxins [in the teething rings] and the softness of the toy?"*
+	-	*"Are the results of the experiment accurate?"*
+	+	*"Did the time duration that the rings were shaken effect the amount of secreted toxins?"*

Metalanguage of science terms

Scientific metalanguage is the language about science that is used to analyze and describe the generation of scientific knowledge (Norris & Phillips, 1994). In this thesis I used the term 'metalanguage of science' instead of the term 'scientific metalanguage'. Following the suggestion of the approval committee, it was suggested that the term 'metalanguage of science' was more appropriate, since the term 'scientific metalanguage' implies that the metalanguage itself is the center of examination and not the scientific aspects. In order to examine possible changes in students' ability to use metalanguage of science terms, the number of such terms was calculated in students' written answers. The metalanguage of science terms were those terms used for communication by the scientific community in order to describe the scientific process which are not content specific (Norris & Phillips, 1994). Each answer was scored for the total number of such terms found in it (Table 7).

Table 7: Metalanguage of science terms in students' questions

Question	# of metalanguage of science terms
"Can another substance soften the plastic and not be toxic?"	0
"Is one <u>experiment</u> enough to make such <u>conclusions</u>?"	2
"Which <u>experiment</u> can be performed in order to <u>examine</u> if teething rings secret more toxins in different <u>conditions</u>?"	3

* Metalanguage of science terms in each question are <u>underlined.</u>

Order of required information

Students' questions were also analyzed and classified according to the order of required information (Dillon, 1984), ranging from Properties questions, that ask about and include only one variable, through Comparison questions that ask for a comparison between at least two variables, to Causal relationship questions that ask about possible causal relationships between at least two variables. Examples of students' questions are presented in Table 8.

Table 8: Classification of students' questions classified according to categories of required information (Dillon, 1984)

Categories of required information	Examples
Properties	"*If it is known that the phthalates are toxic, why did they still use them in the teething rings?*"
Comparison	"*Do phthalates have the same effect on babies and adults?*"
Causal relationship	*"Does human saliva effect the release of phthalates from the teething rings?"*

5.3.1.2 Students' critiquing arguments

In order to evaluate possible changes in students' ability to critique, their written arguments in response to an arguable claim were analyzed and categorized. The arguable claim was presented in question no. 8 of the pre- and post-questionnaires: "*A student that read the article claimed that the article* ***proves*** *that teething rings hurt babies. Do you agree or dispute this claim? Explain*" (Appendix 1, emphasis in the original text). This question was previously used by Ford (2012) in order to expose students' critiquing ability and tendency to disagree with an unknown peer claim in similar questionnaires for students following reading the same article. To categorize students' arguments, in-depth analysis of their answers was performed. First, all answers were scored for the average number of metalanguage of science terms (as described in the previous section). Then, each answer was classified as agreeing or disagreeing with the arguable claim and the arguments they used were analyzed and categorized. Students' answers were statistically analyzed using one-way ANOVA and t-tests. Percentage of students in agreement with the arguable claim was calculated from the total number of students in each group.

All the answers of students who disagreed with the arguable claim were taken for further analysis. These arguments were classified as arguments regarding the experimental process (as described in the previous section). For example, one student wrote: "*I disagree with the student, because the article doesn't prove that the rings are dangerous. The article states that only 3 out of 11 teething rings are dangerous. Also, only one experiment was performed, and maybe if a similar experiment would have been performed the results would be different*." Another student wrote: "*The conditions under which the experiment was performed do not match the conditions under which babies use the teething rings*". Both of these answers were classified with regards to the experimental process, since they are focused on the reliability of the experiment and the experimental conditions.

Students' answers were also scored for the average number of arguments used in each student's answer. For example, in the two examples given above, the first example was scored 2, since it mentions two different critiquing arguments (only 3 out of 11 rings were dangerous, the need to repeat the experiment). The second example comprised of only one argument (the experiment conditions).

5.3.2 Analysis of artifacts of the formulating research questions lessons

Students' written questions in the pre-lesson questionnaire and during the peer-critique activity were classified as research or non-research questions, based on Cuccio-Schirripa and Steiner (2000) definition of research questions: questions that require hands-on data collection including variables that are specific, manipulative, and measurable and that the answer to the question is unknown to the students. Students' questions were statistically analyzed for comparing frequencies using non-parametric one sample χ^2 and binominal goodness of fit tests. Effect size was calculated for standardized differences between two means using Cohen's D (Cohen, 1988). The students' questions prior to the lesson were compared to the research questions that they wrote during the peer-critique activity and to the final research questions that were investigated by them during the Bio-Tech program.

5.3.3 Analysis of classroom discourse

Audio-recordings of the formulating research questions lessons were fully transcribed and divided to episodes and utterances. The episodes were divided according to the content that was discussed in each part of the lesson. Each utterance included one speech turn. Some speech turns were divided into several utterances according to their content. Each utterance was coded and classified according to the communicative approach (Mortimer & Scott, 2003). Based on Mehan (1979) and Lemke (1990), utterances were coded as a question or remark that started a new dialogic chain (Initiation), response to the initiation (Response), prompting feedback that required the students to further elaborate on their ideas (Prompt), or evaluation to the students' responses that terminated the dialogic chain (Evaluation).

Frequencies of dialogic sequences (truncated chains, I-R-E closed chains, and long open chains) were calculated for each lesson. The teachers' instructional moves were coded into the following categories: open or closed questions, probing, Toss-back, re-voicing, and elaboration (Pimentel & McNeill, 2013). Long teacher speech acts were defined as utterances with more than 100 consecutive words. The communicative approach dimensions and teacher's instructional moves are summarized in Table 9. Descriptions and examples of teacher's moves are presented in Table 10.

Table 9: Communicative approach dimensions and teacher's moves, following Mortimer and Scott (2003) and Lehesvuori, Viiri, Rasku-Puttonen, Moate, and Helaakoski (2013)

Dimension	**Interactive** *many participants*	**Non-interactive** *mostly teacher talk*
Dialogic *presenting different ideas*	Long open sequences open teacher questions, probing, toss-back, re-voicing	Review
Authoritative *presenting one scientific idea*	Closed I-R-E sequences closed teacher questions, elaborating	Lecture

Table 10: Coding of teacher's moves, following Pimentel and McNeill (2013)

Teacher's move	Description	Example
Open question	Questions that aim to expose students' ideas, no specific answer is required	Teacher: "*Now, tell me, what you think are the characteristics of a good research questions?*"
Closed question	Questions that aim to recall student's knowledge, specific answer is required	Teacher: "*In one treatment I provide the treatment to see its effect. What would be the other treatment?*" Student: "*Control*"
Probing	Asking the student to elaborate or explain his / her ideas	Student: "*Risk*" Teacher: "*Risk, there may be danger. Can you give me an example related to PON1 when it comes to risk?*"
Toss-back	Asking other students to comment on another student's idea	Teacher: "*You should formulate research questions that you can investigate*" Student: "*Why should we not be able to investigate*?" Teacher: "*Does anyone have an idea why we can't investigate a question?*"
Re-voicing	Repeating a student's response in different words	Student: "*Because it is hurting animals.*" Teacher: "*OK, on the one hand this [the question] should avoid hurting animals.*"
Elaboration	Providing an elaborated expansion following a student's short response	Student: "*Toxic gas*" Teacher: "*Toxic gas may be a problem. Maybe we shouldn't ask questions that are related to toxic gas, to use it specifically*"

5.3.4 Analysis of interviews with Bio-Tech program participants

Interviews with the program participants were transcribed and analyzed top-down according to Chi (1997). Data were used to expose the Bio-Tech participants' views towards the inquiry level and the authenticity of the program. In addition, the teachers' views regarding the methods of teaching inquiry-oriented programs were examined. Participants' views towards the inquiry level of the Bio-Tech program were classified according to the different inquiry stages mentioned by the participants. The classification of the Bio-Tech participants' views regarding the authenticity of the program were classified according to the cognitive processes categories, described by Chinn and Malhotra (2002): generating research questions, designing studies, making observations, explaining results, developing theories, and studying research reports. Other categories, which emerged from analyzing the interviews and did not fit into the given categories, were added to the classification as 'other aspects'.

5.3.5 Analysis of the I-MAP tool

The intended curriculum was described using the I-MAP tool by analyzing the Ministry of Education Bio-Tech documents (Israeli Ministry of Education, 2005, 2008), These documents were searched for specific references regarding the inquiry level and teachers' involvement in each of the program's inquiry features. In addition, the Bio-Tech developers' views regarding the program's intended inquiry level for each inquiry feature were analyzed. The implemented curriculum was determined by analyzing the teaching and learning of one Bio-Tech teacher, Sam (pseudo-name) and his class (see Table 1). Data included observations and recordings of specific lessons and activities during the school year, interviews with the teachers and the students, and the teachers' filled-out I-MAP stars.

In order to determine the Bio-Tech teachers' views regarding the program's inquiry level, the I-MAP stars were collected following the teachers' workshop and taken for analysis. The average mean scores of the Bio-Tech teachers' views regarding students' independence level were calculated. Low level of student independence was scored as 1, medium level as 2 and high inquiry level as 3. The teachers' involvement level was not calculated due to misunderstanding by some of the teachers regarding this aspect, since some of them considered the young scientist instructors as the teachers in the some of the inquiry stages and some didn't.

5.4 Validation

5.4.1 The pre- and post-questionnaires and the peer-critique activity artifacts

Validation of the students' written answers in the pre- and post-questionnaires and in the peer-critique activity was performed by four science education researchers experienced in teaching high school science classes. The validation was performed to a sample of about 10% of the data. More than 80% agreement was achieved between the raters regarding the classification of students' questions and critiquing claims according to the categories presented above. Debatable terms were further discussed until full agreement was achieved.

5.4.2 The communicative approach during classroom discourse

Validation of the communicative approach demonstrated in the examined formulating research questions lessons was performed by six science education researchers who are experts in language and discourse analysis. The raters were presented with the communicative approach of Mortimer and Scott (2003), and asked to analyze samples of the transcribed whole class discussion for I-R-E sequences, teacher's moves and teacher's communicative approach. More than 85% agreement was achieved between the raters. Debatable items were further discussed until full agreement was achieved.

5.4.3 The I-MAP tool analysis

Validation of the I-MAP tool analysis was performed by several cycles of iteration by the inquiry forum members, until the final version of the I-MAP tool was accepted and approved by all members. In each cycle of iteration, the tool was tested by the inquiry forum members in different inquiry-oriented activities and programs. The I-MAP tool was found to be appropriate for the characterization of the Bio-Tech program, after several adjustments of the tool were performed.

6. Summary of research objectives, questions, methods and publications

Research objectives	Research questions	Research tools & methods	Publications
(i) To characterize the teaching and learning of the asking questions and critiquing scientific practices in the Bio-Tech program.	1. How does the participation in the Bio-Tech program influence students' ability to ask questions?	A. Students' pre- and post-questionnaires. B. Interviews with Bio-Tech participants.	Bielik & Yarden, 2015 (in review).
	2. What are the characteristics of teaching and learning of asking research questions in the Bio-Tech program?	A. Classroom lessons recordings and observations. B. Students' written sheets from peer-critique activity. C. Interviews with Bio-Tech participants.	Paper in preparation.
	3. What are the Bio-Tech participants' views regarding asking research questions in the program?	A. Interviews with Bio-Tech students.	Paper in preparation.
	4. How does the participation in the Bio-Tech program influence the development of students' ability to critique?	A. Students' pre- and post-questionnaires. B. Students' written sheets from peer-critique activity. C. Interviews with Bio-Tech participants.	Bielik & Yarden, 2013 (Appendix 7)
(ii) To identify possible gaps between the intended and the implemented curricula of the Bio-Tech program.	5. What are the differences between the inquiry processes in the intended and in the implemented Bio-Tech program curricula?	A. Classroom lessons recordings and observations. B. I-MAP activity artifacts, observations and recordings. C. Interviews with Bio-Tech participants. D. Bio-Tech Policy papers.	Paper in preparation.
(iii) To explore the Bio-Tech program participants' views regarding the program's inquiry level and authentic research.	6. What are the Bio-Tech participants' views regarding the program's inquiry level?	A. Classroom lessons recordings and observations. B. I-MAP activity artifacts, observations and recordings. C. Interviews with participants.	Paper in preparation.
	7. What are the Bio-Tech participants' views regarding the program's authenticity?	A. Classroom lessons recordings and observations. B. Interviews with participants.	Paper in preparation.

7. Results

7.1 How does the participation in the Bio-Tech program influence students' ability to ask questions?

In order to characterize the development of Bio-Tech students' ability to ask questions following their participation in the program, analysis of their written questions in the pre- and post-questionnaires was performed, and compared to the questions written by the Control group students. A pool of 743 questions, from the Bio-Tech and Control groups' students who filled-out both the pre- and post-questionnaires, was taken for analysis. Initial analysis was based on the categories of response to media reports. Further classification of students' questions focused on the following categories: (i) students' questions regarding the experimental process, (ii) students' ability to use metalanguage of science terms, (iii) students' ability to formulate research questions, and (iv) order of required information in students' questions.

7.1.1 Categories of students' responses to media reports

The initial classification of students' questions was based on Ratcliffe (1999) categories of responses to media reports (see section 5.3.1.1). No meaningful differences were found between the Bio-Tech and the Control groups students' responses to media reports by the end of the school year. The percentage of students' questions in the research category increased in both the Bio-Tech and Control groups (35.7% in the pre-questionnaire and 49.8% in the post-questionnaire in the Bio-Tech group, 38.2% in the pre-questionnaire and 50.7% in the post-questionnaire in the Control group). A decrease in the percentage of questions from all three other categories (subject, context, and effect) was found among the Bio-Tech and Control groups (Fig. 2). This result indicates that a similar shift occurred in the Bio-Tech and Control group students' tendency to ask more questions about the research presented to them in media reports by the end of the school year.

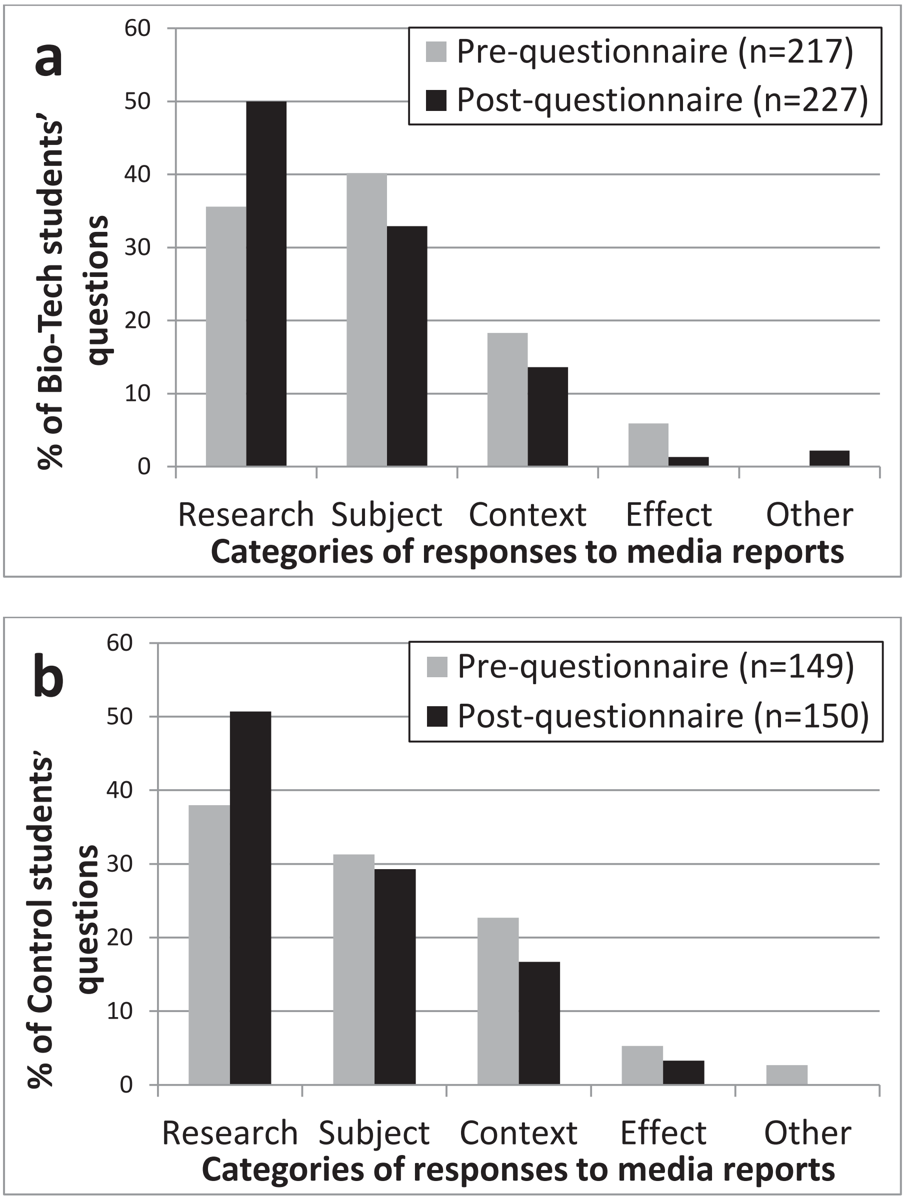


Fig. 2: Students' questions classified according to the categories of responses to media reports, following Ratcliffe (1999)
(a) Bio-Tech students, (b) Control students**,** n=number of questions.

Most of the students' questions in the research category in both groups focused on the theory of mechanism (more than 80% and more than 70% of the questions from the research category in the Bio-Tech group students' and in the Control group students' pre- and post-questionnaires, pre- and post-questionnaires, respectively). These questions included questions regarding the toxins' health dangers (e.g., "*How does the toxin cause cancer? What is the long term effect of the toxins on the health of the baby? Do the toxins released from the teething rings threat the baby's life?*"), and questions regarding the mechanism of toxins release from the teething ring (e.g., "*Why does the chewing of the teething rings release more toxins? Can the duration of* *the toxins' mixing in the saliva effect the amount of released toxins? What is the substance in the saliva that causes the toxins release?*"). This result indicates that most of the examined 11th grade biotechnology students' attention and interest was focused on the issues of health and toxin release mechanism after reading the article.

The classification of students' questions based on their responses to a media report by the end of the school year did not reveal any meaningful differences between the Bio-Tech and Control group students. This classification was found to be insufficient to answer the research objective of exposing differences between the Bio-Tech and Control group students' asking questions practice. Further analysis of students' questions was required in order to gain a better understanding of students' development of the asking questions practice.

7.1.2 Students' ability to ask questions regarding the experimental process

In order to identify possible changes in students' ability to focus their questions on the experimental process presented to them (see section 5.3.1.1), students' questions were classified with regard to the experimental process described in the article. Statistical analysis was performed using non parametric one sample binominal goodness of fit χ^2 test. While a significant increase in the percentage of students' questions regarding the experimental process was found among the Bio-Tech students (χ^2=2.11, df=442, p=0.007), a non-significant decrease was found among the Control students by the end of the school year (χ^2=0.886, df=297, p=0.146) (Fig. 3).

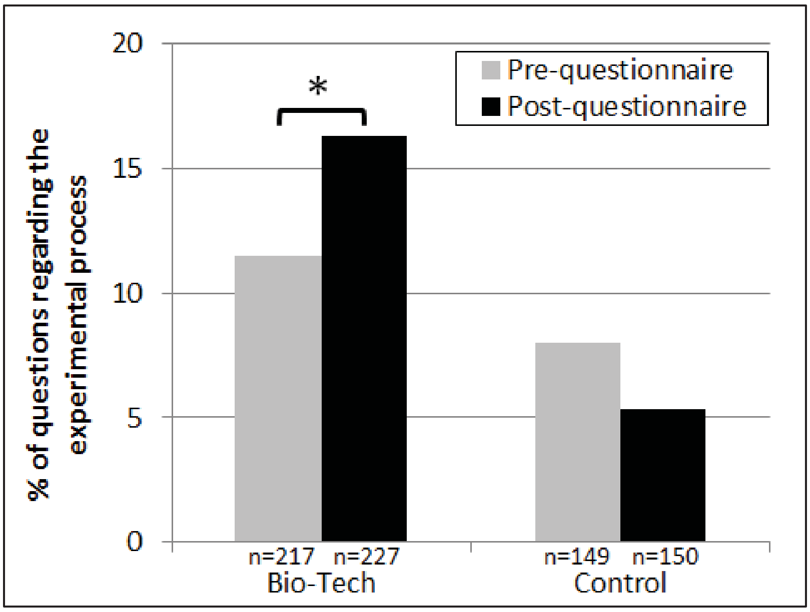


Fig. 3: Percentage of students' questions regarding the experimental process
* p<0.01, n=number of students' questions.

Most of the Bio-Tech students' questions regarding the experimental process focused on the tools and methods described in the article in both the pre- and post-questionnaires. For example, one of the Bio-Tech students (C1S17) did not ask any questions regarding the scientific process described in the article in her pre-questionnaire, but asked four questions regarding the tools and methods used in the described experiment in the post-questionnaire ("*What is the artificial saliva comprised of? Why are there no shakers that resemble the baby's chewing more accurately? What method was used to measure the amount of released Phthalates? Why were 11 types of teething rings chosen for the experiment?*"). Another Bio-Tech student (C4S26) did not ask any questions regarding the experimental process in the pre-questionnaire, and asked two questions regarding this issue in the post-questionnaire, focusing on the tools and methods ("*Are the research conditions, like the shaking level and experiment time, appropriate for this kind of examination? Is one experiment enough to reach general conclusions?*"). These results indicate that the Bio-Tech students' ability to ask questions regarding the experimental process presented to them developed following their participation the Bio-Tech program.

7.1.3 Students' ability to use metalanguage of science terms

In order to expose possible changes in students' ability to use metalanguage of science terms, the number of terms which were considered scientifically oriented (e.g., effect, cause, examine, investigate, result, experiment, conclusion, method, etc.) in their questions were calculated (see section 5.3.1.1). Each question was scored for its number of scientific terms, and the average number of metalanguage of science terms in students' questions from that group was calculated. T-test comparison analysis was performed in order to identify possible differences between the groups.

A significant increase in the average number of metalanguage of science terms used by the Bio-Tech students in the pre- and post-questionnaires was observed (average of 0.36 and 0.56, respectively, t=-3.03, df=442, p=0.003), while a non-significant increase in the average number of metalanguage of science terms used by the Control group students was found (average of 0.3 and 0.42. respectively, t=-1.77, df=297, p=0.077). A significant difference (t=2.05, df=375, p=0.041) was also identified between the Bio-Tech and Control group students' post-questionnaires in their average number of metalanguage of science terms (Fig. 4).

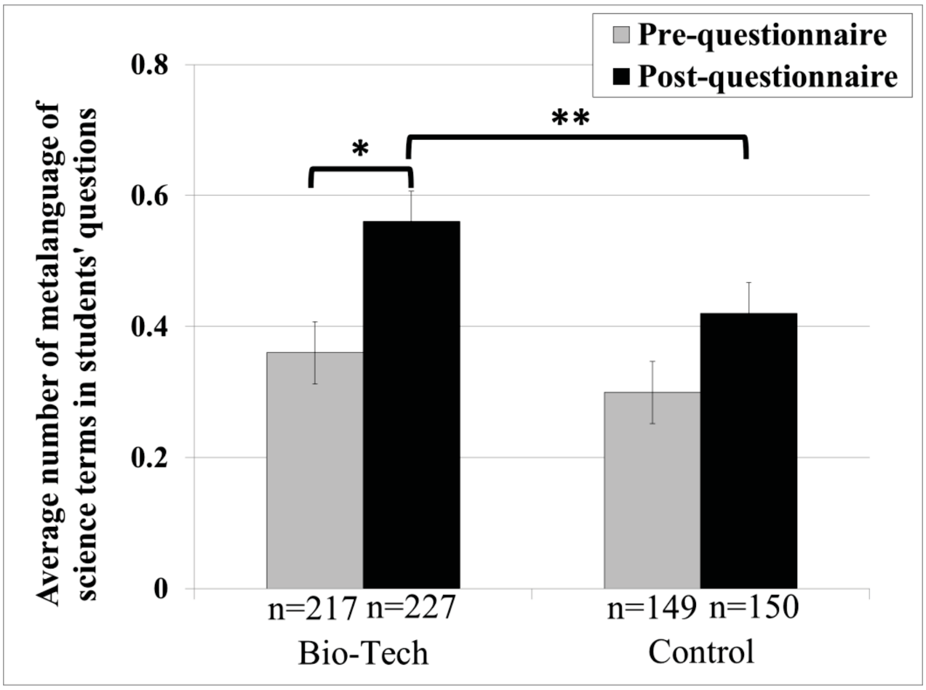


Fig. 4: Average number of metalanguage of science terms in students' questions
* p<0.005, ** p<0.05, n=number of students' questions, error bars=standard error.

For example, one of the Bio-Tech students (C1S23) didn't use any metalanguage of science terms in the questions he wrote in the pre-questionnaire ("*Are the high amounts of Phthalates that were found dangerous for babies? Are there no other substances in toys that may danger our health?*"). In his post-questionnaire, the student wrote a question using five metalanguage of science terms: "*Did the <u>experiment</u> duration <u>effect</u> the <u>results</u>, which means, what would be the difference in the <u>results</u> if the <u>experiment</u> would last five or two hours?*".

Some differences were found between the different metalanguage of science terms used by the students in the pre- and post-questionnaires. An increase in the usage of the term 'effect' was found among both the Bio-Tech group students (from 25% to 61%) and the Control group (from 29% to 50%) students' questions. A decrease in the usage of the term 'cause' was found in both the Bio-Tech group (from 28% to 9%) and in the Control group (from 40% to 27%) students' questions. A decrease in the usage of the term 'test' was found among the Bio-Tech group (from 12.5% to 0), while an increase in the usage of this word was found among the Control group students' questions (from 0 to 7%). This indicates that the changes in usage of different metalanguage of science terms by the students in their questions were relatively similar among the Bio-Tech and Control group students (Table 11).

Table 11: The main metalanguage of science terms used in students' questions

Metalanguage of science term	Bio-Tech		Control	
	Pre	Post	Pre	Post
Effect	25%	61%	29%	50%
Cause	28%	9%	40%	27%
Research	12.5%	8%	0	0
Test	12.5%	0	0	7%
Experiment	0	0	0	7%

7.1.4 Students' ability to formulate research questions

In order to examine the possible development of the students' ability to ask research questions during their participation in the Bio-Tech program, their written questions in the pre- and post-questionnaires were categorized as research or non-research questions (see section 5.3.1.1). Research questions were defined as questions that require hands-on investigation and data collection, include variables that are specific, manipulative and measurable, and that the answer to the question is unknown to the students (Cuccio-Schirripa & Steiner, 2000). Statistical analysis was performed using non parametric one sample binominal goodness of fit χ^2 test. A significant increase was found in the pre- and post-questionnaires of the Bio-Tech (χ^2=18.11, df=442, $p<0.001$) and the Control group (χ^2=13.12, df=297, p=0.002) students' questions (Fig. 5). The effect size between the pre- and post-questionnaires in both groups was significantly high (Cohen's d Bio-Tech=0.419, Control= 0.413).

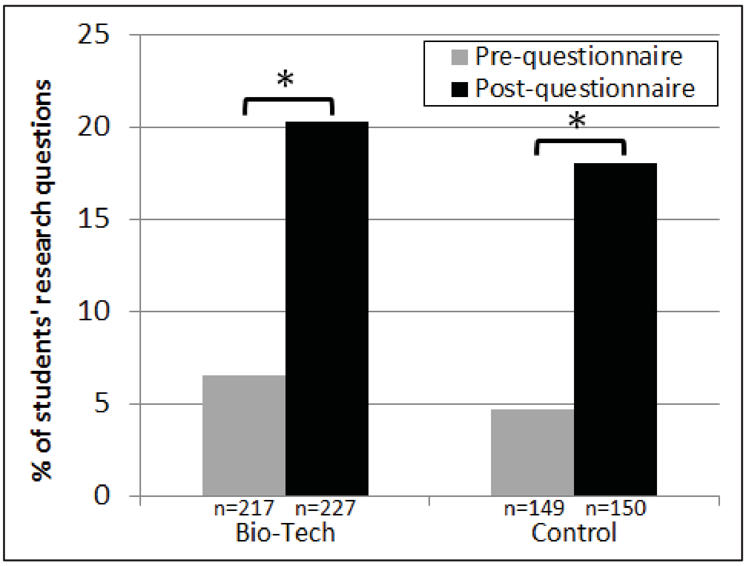


Fig. 5: Percentage of students' research questions
* $p<0.001$, n=number of students' questions.

Since no differences were founds between the percentage of research questions asked by the students of both groups, it seems that their ability to ask research questions developed in the course of other learning opportunities besides the Bio-Tech program. Such opportunities were mentioned by Rebecca, one of the Bio-Tech teachers. In her interview, she mentioned that the biotechnology students have numerous opportunities to practice this ability in other scientific learning environments such as laboratory experiments and other projects ("*They [the students] receive this knowledge [of asking research questions] not only in the Bio-Tech. We try to provide them with inquiry learning also in the school laboratory experiments, the computer laboratory or the bioinformatics project. This means that they learn the inquiry approach in many other places…We start in the 10th grade. They study this in biology, so this is not the first time they encounter formulating research questions*").

7.1.5 The order of required information in students' questions

Students' questions were classified according to Dillon's (1984) order of required information (see section 5.3.1.1). Analysis was performed using Wilcoxon signed-rank test. A statistically significant difference was found between the Pre- and Post-questionnaires among the Bio-Tech ($\chi^2=20.45$, df=2, $p<0.001$) and the Control ($\chi^2=16.51$, df=2, $p=0.0003$) students' questions. Examining the changes in percentages of students' questions in the different categories indicated similar shifts in both the Bio-Tech and Control groups: a decrease in the percentage of questions from the properties category (Bio-Tech χ^2 pre=0.26, post=0.28, Control χ^2 pre=0.16, post=0.16), a decrease in the percentage of questions from the comparison category (Bio-Tech χ^2 pre=3.55, post=3.75, Control χ^2 pre=2.55, post=2.56), and an increase in the percentage of questions from the causal relationship category (Bio-Tech χ^2 pre=6.48, post=6.14, Control χ^2 pre=5.52, post=5.56) (Table 12).

Table 12: Questions' order of required information, following Dillon (1984)

	Bio-Tech		**Control**	
Category	Pre-questionnaire (n=217)	Post-questionnaire (n=227)	Pre-questionnaire (n=149)	Post-questionnaire (n=150)
Properties	44.5%	39.9%	47.3%	42.9%
Comparisons	35.6%	21.9%	38%	23.5%
Causal relationships	19.9%	38.2%	14.7%	33.6%

For example, the questions of one Bio-Tech student (C3S16) changed from properties questions in the pre-questionnaire to causal relationship questions in the post-questionnaire. In the pre-questionnaire this student wrote: "*Which toys are safe to use by babies? Are there other risks from biting the toys?*" (Properties order questions). In the post-questionnaire that student wrote- "*What is the connection between the amount of Phthalates and the softness of the toy? What is the effect of the Phthalates on the liver?*" (Causal relationships order questions).

This result indicates that students' ability to ask questions of higher order of required information improved throughout the school year by all 11th grade biotechnology students who participated in the research, regardless of their participation in the Bio-Tech program.

Summary

Altogether, these results demonstrate that the participation in the Bio-Tech program enabled some of the students to develop their asking questions abilities, as seen by the improvement in the Bio-Tech students' abilities to focus their questions on the experimental process presented to them and in the increase in the average number of metalanguage of science terms used in their questions. However, no differences were identified between the Bio-Tech and Control group students' ability to ask research questions, their tendency to ask questions of higher order of required information, or in the type of their responses to the media reports in their questions. This suggests that 11th grade biotechnology students have other learning opportunities to develop these abilities, which are independent of their participation in the Bio-Tech program.

7.2 What are the characteristics of teaching and learning of asking research questions in the Bio-Tech program?

In order to examine the possible development of students' ability to ask research questions, an in-depth examination of specific lessons designed for teaching the Bio-Tech students to formulate research questions appropriate for investigation was performed. These lessons were assumed to be central to the students learning of formulating research questions in the Bio-Tech program. It is not suggested that this is the only factor that contributes to the development of the Bio-Tech students' asking research questions ability, yet it is believed that it is a meaningful part of the program that influences the students' learning of this practice. The contribution of the lessons' structure and communicative approach during whole class discussions to the development of students' ability to formulate research questions were investigated.

The Bio-Tech lessons of Sam and Rebecca (pseudo names) were chosen for examination. These lessons included a peer-critique activity that was designed for engaging students in collaborative discussions and critiquing. Students' written research questions in the pre-lesson questionnaire were compared to their written questions during the peer-critique activity and to their Bio-Tech research questions that were investigated in the main experiment that was carried out by the students at the research institute.

In Sam's class, 12 groups formulated their research questions during the lesson. None of the final research questions that were investigated by Sam's students in the Bio-Tech program were based on the students' formulated questions during the lesson. In his interview, Sam mentioned that the majority of the research questions were given to the students prior to the main experiment at the research institute. He claimed that he tried to match the research questions to those suggested by the students during the lesson, but that the majority of their questions were not appropriate or not possible to be investigated in the research institute.

In Rebecca's class, 9 groups wrote their suggested research questions during the lesson. Out of the 5 research questions that were investigated by Rebecca's students in the Bio-Tech program (most questions had been investigated by two groups, exploring different variants of the bacterial strains), 4 originated from the students' research questions formulated during the lesson. The questions that were taken for investigations focused on the effect of the growth medium on PON1 enzyme expression level, the effect of PON1 competitive inhibitor levels on PON1 activity, the effect of the protein purification method on PON1 activity level, and the effect of PON1 expression on the protein activity level. Since the majority of Rebecca's students' research questions written during the lesson were subsequently used for the inquiry conducted by the students in the Bio-Tech program, it is assumed that Rebecca's lesson was fundamental to students' acquisition of this practice.

7.2.1 Bio-Tech students' ability to ask research questions

In an attempt to explore the possible development of students' ability to formulate research questions during the lesson, their questions in the pre-lesson questionnaire were compared to their written questions during the peer-critique activity. The questions were categorized as research, based on the previously described definition of Cuccio-Schirripa and Steiner (2000), as described in section 5.3.1.1. Statistical analysis was performed using non parametric one sample binominal goodness of fit χ^2 test. The percentage of research questions written by Rebecca's students significantly increased in the pre-lesson questionnaire and during the peer-critique activity (38.5% and 89.3%, respectively, χ^2=17.5, df=65, p<0.001). The percentage of research questions written by Sam's students remained low in the pre-lesson questionnaire and during the peer-critique activity (3.7% and 5.4%, respectively, χ^2=0.151, df=90, p=0.455). The effect size in Rebecca's class was high (Cohen's d= 1.03), compared to the low effect size in Sam's class (Cohen's d=0.08). This indicates that Rebecca's lesson improved her students' ability to ask research questions (Fig. 6).

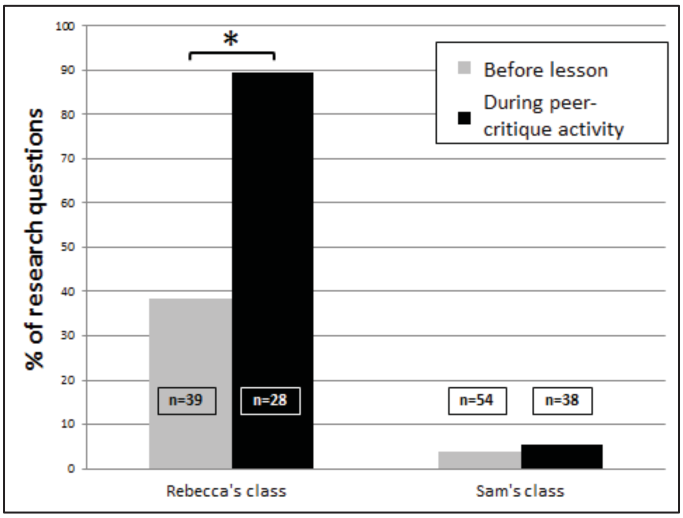


Fig. 6: Percentage of students' research questions
*- p<0.001, n= number of questions.

In both classes a significant increase in students' ability to ask research questions upon completion of the Bio-Tech program was observed (data not shown). This indicates that the learning of asking research questions may take place in other situations beside the specifically examined lessons. The initial percentage of research questions in Rebecca's class was higher than in Sam's class. This could be explained by the fact that Rebecca's students experienced inquiry in other environments besides the Bio-Tech program, as mentioned by Rebecca in her interview (see section 7.1.4).

7.2.2 The peer-critique activity

The peer-critique activity that was carried out during the lesson was designed to allow the Bio-Tech students to experience and practice formulating research questions while performing peer-critiquing. Students were asked to write their suggestions for research questions and hand it to another group of students in order to be reviewed. Then, the reviewed questions were handed back to the original group, and the students were asked to formulate their final research question based on the critique they received. By doing so, the students had an opportunity not only to critique others' research questions and to receive critique on their own suggested questions. The following analysis of the peer-critique activity focuses only on Rebecca's class, since her lesson was found to be more meaningful for her students' learning of asking research questions than Sam's lesson, as seen in the significant increase in Rebecca's students' ability to ask research questions during the lesson (see section 7.2.1).

In Rebecca's class, 9 groups wrote their final suggested research questions during the lesson. 5 groups wrote that the chosen question was appropriate for the Bio-Tech program, mentioning in their justifications that the question is relevant to the Bio-Tech topic, is operational, and that the answer is unknown to the students. The other 4 groups, which did not accept the other groups' suggested question as appropriate to the Bio-Tech program, mentioned some points of critique to their peers' questions. The main points of critique mentioned by the students were: (i) the question was not phrased correctly, (ii) the required experiment was not applicable to the Bio-Tech program, (iii) the question did not include a clear and specific independent variable, and (iv) the question did not contribute to the scientific knowledge. The following examples demonstrate the criticism that the groups mentioned.

In the following section, three examples of critiquing are presented and analyzed, taken from Rebecca’s students’ written sheets during the peer-critique activity. The first example is of students who suggested the following initial research question: "*The effect of LDL on dismantling of neural toxic gas*". The critique of the other students focused on the specification and clarity of the question, as written: "*Your question is not specific, not relevant, and not clear*". These students wrote a corrected question included both rephrasing of the question and adding specification of the dismantling enzyme: "*What is the effect of LDL on dismantling of neural toxic gas by PON1 enzyme*?". This question was accepted by the original students, demonstrating that they were able to receive and accept the critique. The critique was based on the research question characteristics that were discussed in the lesson prior to the peer-critique activity, which included issues such as the correct phrasing of the question, choosing variables that are measurable, and formulating questions that can be investigated. This indicates that the students were able to understand and apply the previously learned knowledge about formulating research questions.

The second example demonstrates a research question that was not applicable to the Bio-Tech program and did not contribute to the gaining of scientific knowledge. The students’ initial question was: "*What is the difference between the effect of the PON1 enzyme that is naturally produced in the [human] body and the engineered enzyme on dismantling neural gas*?". The critiquing students mentioned that the question is relevant to the Bio-Tech program since it deals with PON1 enzyme, but it is can’t be investigated in the Bio-Tech program for both experimental limitations and knowledge gaining reason, and therefore it should be replaced ("*The research question includes clinical experiments that are not moral and not appropriate for the Bio-Tech program. Also, in this research there will be no difference between the natural gene and the engineered gene since the gene sequence is similar. This question will not contribute to our knowledge*").

The third example presents a research question that did not include a specific independent variable. The initial students’ question was: "*How do the different antibiotics in the growth medium effect the growth of the bacteria that contain the PON1 gene?*". The critiquing students mentioned that the question topic was relevant to the Bio-Tech program, but suggested that the independent variable was not specific ("[*the question] is not focused enough when you say* ’*different antibiotics*’. *There is a* *variety of antibiotics and you don't have the time or the means to examine all of them*"). The critiquing students suggested the following question: "*What is the difference between the effect of Tetracycline and Kanamycin antibiotics in the growth medium on the growth of the bacteria that contain the PON1 gene?*". These examples indicate that the students were able to critique their peers' questions and to suggest more appropriate research questions during the peer-critique activity.

Both teachers pointed out that the peer critique activity was meaningful and supported their students' understanding (Rebecca: "*This activity is a very good idea. The students are thinking and they can critique the work of someone else. I think the students are gaining a lot [from the peer-critique activity]*"). However, none of the teachers used the peer-critique activity in the following year during the Bio-Tech program because of time limitations. This suggests that the peer-critique activity was suitable for the Bio-Tech program students, but teachers need more support and encouragement to use peer-critique activities in their teaching.

7.2.2 Structure of the formulating research questions lessons

In an attempt to explain the differences that were found between Sam's and Rebecca's students' ability to formulate research questions following the formulating research questions lesson, comparisons between their lessons' structures and communicative approaches were performed.

Sam's lesson was 64 minutes long. He devoted the first part of the lesson to a teacher-lead whole class discussion (30% of the lesson duration) that was followed by the peer-critique activity (70% of the lesson duration). In the first part of the lesson, Sam focused on the characteristics of research questions and formulating a hypothesis that will lead to an experiment that may enable to answer the question. Sam used a few examples of research questions which were unrelated to the Bio-Tech program in order to explain to his students how to formulate an appropriate research question and a hypothesis, and did not appear to have a well-organized lesson continuum, demonstrated by the frequent changes in the discussed issues. In his interview, Sam addressed the time limitation of the examined lesson, mentioning it was a restricting factor in his teaching ("*If I had more time I would have talked with them [the students] and maybe ask other questions in different subjects").*

Rebecca's lesson was 100 minutes long. It included a whole class discussion that focused on the requirements of a research question appropriate to the Bio-Tech program (40% of the lesson duration), the peer-critique activity (38% of the lesson duration) and another whole class discussion dedicated to analyze some of the students' chosen research questions (22% of the lesson duration). The first part of Rebecca's lesson included a discussion about the characteristics and components of research questions appropriate for the Bio-Tech program, in which students were asked to propose possible research questions. In the lesson part that followed the peer-critique activity, two groups presented their chosen research questions and the other students critiqued them in a whole class discussion. Summary of the two lessons' structure and teaching strategies are presented in Fig. 7.

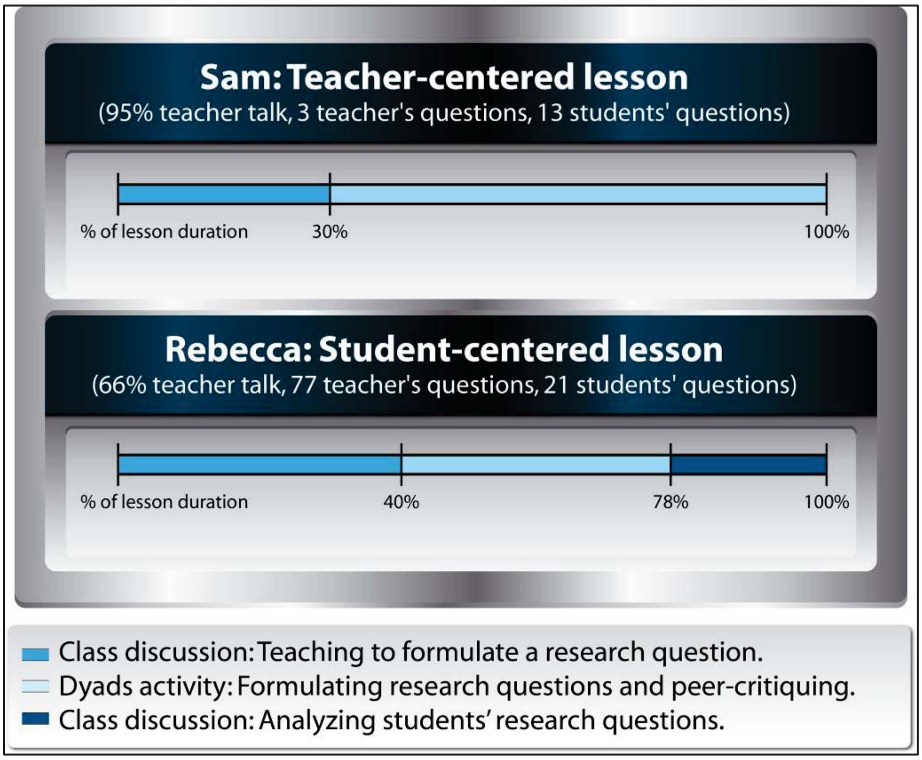


Fig. 7: Lessons structure and teaching strategies during the lessons

7.2.3 Classroom discourse and communicative approach during the lessons

This part of the results presents a discourse analysis of the whole class discussions that were performed in the beginning of the examined lessons, following the communicative approach framework described by Mortimer and Scott (2003). The goal of this analysis is to identify differences between the two teachers' teaching strategies, which might shed light on the gaps that were found between the two classes' students ability to formulate research questions.

Sam’s lesson

In the first part of the lesson, Sam focused on the characteristics of research questions and the importance of formulating hypotheses that can lead to experiments that may answer the research questions. Sam used several examples unrelated to the Bio-Tech subject in order to explain how to formulate appropriate research questions and hypotheses. Sam also emphasized the nature of science and the scientific method in several cases, as can be seen in this teacher speech act taken from the whole class discussion: "*Based on the scientific method, the first thing I want to do is to ask myself the question, define the question"*.

Sam’s communicative approach was mostly authoritative and non-interactive. His authoritative approach was pronounced in the fact he was presenting to the students only his views regarding the characteristics of research questions and hypotheses, not allowing the students to voice their own ideas. Sam’s lesson included only a few teacher questions for the students (2 closed questions with a specific answer, one open question), several long teacher speech acts (more than 100 consecutive words), and low involvement of students during the lesson. All of the above demonstrated Sam’s non-interactive approach.

Most of the discourse during the class discussion was done by the teacher (95% teacher talk). In the long speech acts that occurred during the lesson, Sam did not ask questions and did not to engage the students in the discussion. His voice was the only voice heard. Sam occasionally asked the students to confirm their understanding using a rhetorical question (e.g., "*OK?...right?*"). Sam’s teaching moves during the examined whole class discussion included mostly long teacher speech acts and a few questions. The students asked 13 questions during the first part of the lesson, most of them were requests for clarification of the taught topic. These questions were answered by long teacher answers, as exemplified in Episode 1.

Episode 1: Sam's answer to a student's question (9:05 in recording)

Turn	Speaker	Utterance
1	Student	*I have a question. In our research we will write a hypothesis that is opposite to our original hypothesis?*
2	Sam	*No, not necessarily. What is more important for me is that you will write a hypothesis which makes a stand. To write the hypothesis correctly, OK? This treatment will effect, or will not effect, on what we see. OK? And eventually to address this in the discussion. In the discussion you go back and address the hypothesis, right? The primary [hypothesis]. If this was my hypothesis, now I've verified it, the experiment verified the hypothesis or disputed it. OK?*

In the few interactions initiated by Sam's questions, the canonical I-R-E (Initiation-Response-Evaluation) closed chains triadic pattern of interactions was demonstrated. This can be seen in Episode 2.

Episode 2: Closed chain interaction in Sam's lesson (5:48 in recording)

Turn	Speaker	Utterance	Pattern of interaction
1	Sam	*If I think that something is effecting, I usually use two treatments, right? In one treatment I provide the treatment to see that it effects. What would be the other treatment?*	Initiation
2	Student	*Control.*	Response
3	Sam	*That is correct; the other treatment would be the control, to compare.*	Evaluation

In his interview, Sam acknowledged this teacher-centered approach during the examined lesson. He claimed that his teaching approach changes between the formal classroom lessons and the laboratory lessons. In the formal classroom lessons, he is in control of the discussion and tries to use the limited amount of time he has to cover as much content as possible. On the other hand, during the laboratory lessons, he allows the students to be more independent, promotes more open discussions and encourages his students' involvement. According to Sam, the students know they will have the opportunity to further discuss and elaborate their ideas in the laboratory lessons ("*When I teach them, they have me for two hours in the classroom and two hours in the computer laboratory. The dichotomy is fundamental, it is black and white. I give them all the content in the formal lessons and I don't open my mouth in the other lessons. It is the opposite. There [in the laboratory lessons] they ask me questions, work in groups, I walk around and explain. There is no formal teaching there…part of the reason for this is the time limitations. We have a lot of materials to cover.*").

Rebecca's lesson

Rebecca dedicated two parts of the lesson to whole class discussions, focusing on the characteristics and components of research questions appropriate to the Bio-Tech program. In the first part of the lesson, she asked the students to propose possible research questions. She focused on the correct wording of research questions and the characteristics and components of research questions appropriate to the Bio-Tech program. Each episode during the whole class discussion began with an open teacher question, inviting the students to share their ideas. Rebecca repeatedly connected the discussion to the Bio-Tech topic, when discussing the possible research questions, the available tools and methods, and using the specific Bio-Tech subject-matter terms.

Rebecca's communicative approach was mostly dialogic and interactive. The dialogic approach was demonstrated by the teacher's moves, encouraging the students to voice their opinions and prompting them to elaborate on their ideas (e.g., "*What are the characteristics of a good research question?*"). Rebecca's interactive approach was observed in her interactions with the students. She asked 77 questions during examined whole class discussion, 56 of them were open questions that encouraged the students to expand on their thoughts and give their own opinion, and 21 closed questions requiring specific answers. The interactions between the Rebecca and her students were frequent during the class discussion, and the students were highly involved in the discussions (66% teacher talk). Rebecca used interactive talk moves, such as re-voicing of students' answers, writing the students' suggestions on the board, and asking students to elaborate on their answers. Some of the students' ideas developed to a dialogic discourse between the students and teacher. It should be mentioned that Rebecca rejected students' answers in three occasions during the examined discussion, as exemplified in Episode 3.

Episode 3: Rejection of student's answer in Rebecca's lesson (20:07 in recording)

Turn	Speaker	Utterance
1	Rebecca	*You are examining the effect of the independent variable. What do you need to know about the wording [of the question]?*
2	Student	*The conditions?*
3	Rebecca	*No, I want to know about the dependent variable, how I measure it, What is the preferred method of measuring it.*

Altogether, this demonstrates that Rebecca's approach in the examined lesson was mostly dialogic and interactive. In her interview, the teacher confirmed her dialogic and interactive approach. She viewed this approach as critical for supporting students' understanding and for productive and meaningful discourse ("*In my approach I allow the students to open the discussion, bring up whatever you think is reasonable in the criteria we've defined…my students know that there are always many questions they can ask, I ask a lot*").

Rebecca's moves during the examined lesson included student-centered moves such as prompting questions, re-voicing her students' ideas without evaluating, and tossing-back some of the students' questions to the other students. The students asked 21 questions during the analyzed lesson part, most of them were requests for clarification about the taught subject or requests for further elaboration and explanations from the teacher. The teacher's responses to these questions were sometimes direct answers, but in some cases she also replied by asking the students to elaborate or expand on their question, as exemplified in Episode 4.

Episode 4: Rebecca's request for elaboration in response to a student's question (13:53 in recording)

Turn	Speaker	Utterance
1	Student	*Does the concentration, the amount of light that something is exposed to, can this effect it [the enzyme production]?*
2	Rebecca	*The question is if this is relevant. Do you think the light is relevant? Convince me that it is relevant to examine the light.*

In the examined discussion, Rebecca demonstrated the triadic I-R-E pattern 5 times, while demonstrating longer sustained interactions 21 times (e.g., I-R-P-R-P-R-E). By doing so, Rebecca maintained longer chains of interactions with the students. In Episode 5, an open chain of interactions is demonstrated. Starting with the teacher's request for an example of a question that can't be investigated (Initiation, turn 1), and a response from a student (Response 1, turn 2), followed by a teacher move of re-voicing the student and asking a probing question in the form of a request for an example (Prompt, turn 3). Only after the student's second response (Response 2, turn 4), the teacher provided her feedback to his suggestion (Evaluate, turn 5).

Episode 5: Open chain interactions in Rebecca's lesson (7:35 in recording)

Turn	Speaker	Utterance	Teacher's move	Pattern of interaction
1	Rebecca	*Now, you may be asking why it [the research question] can't be investigated. Give me one idea.*	Open question	Initiation
2	Student	*Risk.*		Response 1
3	Rebecca	*Risk. It could be risky. Give me an example of a risk related to PON1 enzyme.*	Re-voice, elaborate	Prompt
4	Student	*Toxic gas.*		Response 2
5	Rebecca	*Toxic gas may be a problem. Maybe we shouldn't ask questions that are related to toxic gas.*	Re-voice	Evaluation

In her interview, Rebecca confirmed her student-centered teaching strategy and emphasized the importance of students' involvement during the lesson. She allowed the students to think and explore their ideas during the lessons, even if they sometimes sidetracked from the main lesson plan ("*My students know that they can always ask many questions. I ask them a lot and I always try to bring something new based on what they already know and advance with that…during the lesson I address different people. I try to respond when someone says something in class. They [the students] have the knowledge, you can expose it, try to share it and create something*").

Summary

Altogether, these results show that students' ability to ask research questions may be developed during classroom lessons devoted to teaching the students to ask research questions that include a peer-critique activity. Rebecca's teaching was mostly student-centered, dialogic and interactive. Her students' ability to formulate research questions significantly improved following the lesson, and most of the questions that they formulated during the peer-critique activity were eventually investigated in the Bio-Tech program. This demonstrates the contribution of Rebecca's lesson and her communicative approach during the whole class discussions to the development of her students' asking research questions practice**.** On the other hand, Sam's teaching was mostly teacher-centered, authoritative, and non-interactive. Sam's students' ability to formulate research questions did not improve following the lesson and none of the students' questions that were formulated during the peer-critique activity were later investigated in the Bio-Tech program.

7.3 What are the Bio-Tech participants’ views regarding asking research questions in the program?

In order to explore the Bio-Tech participants’ views about asking research questions in the program, 57 students and 6 teachers were interviewed. The Bio-Tech students were interviewed immediately following their final oral Bio-Tech exam at the end of the school year and asked why and how they chose their Bio-Tech research questions. Most of the students (48 students, 84%) mentioned that they independently chose their research questions to be investigated in the Bio-Tech program. This does not prove that the actual percentage of independently chosen research questions was as viewed by the students. However, this indicates that most of the Bio-Tech students had positive views regarding their independence in choosing their research question.

Students’ views regarding asking research questions were classified to four main categories that emerged from analyzing the students’ transcribed answers, based on their content: positive aspects, negative aspects, affective aspects, and other aspects. Each category comprised of several aspects that were affiliated with the category. It was mentioned by 22 students that they chose their research question because it was interesting (e.g., "*You choose something that interests you, and not something that is interesting for the scientist or the teacher*"). I was mentioned by 12 other students that they chose their research question because it was original, new, and wasn’t explored by other students (e.g., "*We thought what [research question] would be possible, what would be different…something that haven’t been done before, something that no one in class had investigated*"). Some students claimed that the most limiting factor while choosing their research questions was the research institute (mentioned by 4 students), mostly for lack of appropriate experimental tools and methods (Table 13).

Table 13: Students' views regarding the reasons for choosing their Bio-Tech research question

Categories	**Aspects**
Positive aspects	<u>New/ original (12)</u>
	Develop the scientific knowledge, thinking, and understanding (6)
	Easy to explore (4)
	Researchable (3)
	Produce good results (2)
	Gain experience in research (1)
	Not too simple (1)
	Lead to more questions (1)
Negative aspects	Research institute limitations (4)
	Not appropriate for class experiment (2)
	Not appropriate for the Bio-Tech program (2)
	Meaningless (2)
	Different organizational level (1)
	Difficult to explore (1)
	Nothing to ask about (1)
	Not suitable to the scientific background (1)
	Can't be tested (1)
	Not effective (1)
Affective aspects	<u>Interesting (22)</u>
	Nice (8)
	Independence (4)
	Fun (3)
	Proud (1)
	Feeling connected to the question (1)
Other aspects	What they came up with (2)
	Didn't know what was interesting (1)

Number of students=57. Most frequently mentioned aspects are underlined.
The number of students that mentioned that aspect appears in brackets.

The Bio-Tech teachers mentioned in their interviews that their goal was to allow as much independence to the students in choosing their own research questions. However, in most cases the students needed additional support from the teacher or were even given the research questions. Two teachers claimed that the students were completely independent in choosing and formulating their research questions (Teacher 4: "*I didn't help them [the students] in formulating their research questions…there were cases when I said that this is not a question, I erased it and told them to try again, until they reached 'normal' questions*"). Two other teacher said that they tried to allow students to independently formulate their research questions, but at the end they needed to limit them and provide them with alternative questions (Teacher 3: "*They [the students] wanted their independence but eventually we gave them a lot of them…We went with the more ordinary questions of the children, they got the expected results and it was much easier for them*". Teacher 5: "*I allow them [the students] to run wild with their questions in the beginning, but at the end I give them the questions that were agreed upon with the research institute. This is not ideal, because of the complexity [of the Bio-Tech program]*"). Another teacher mentioned that the students were more guided in formulating their research questions since they were not capable of doing this on their own.

Summary

Most of the students in the examined classes viewed the Bio-Tech program as allowing them to independently formulate and explore their own research questions. This allowed the students to hold positive views regarding asking research questions in the program, mostly mentioning that it was interesting and allowed them to explore something new and original. However, some of the students were also aware of the program's limitations regarding asking their own research questions, mostly concerning the research institute's limitations. The Bio-Tech teachers aim to provide the students with independence in choosing their own research questions, but in most cases they needed to guide the students to choose research questions that are appropriate to the Bio-Tech program and limit the students' independence level.

7.4 How does the participation in the Bio-Tech program influence the development of students’ ability to critique?

In this part of the study, the influence of participation in the Bio-Tech program on the students’ ability to critique was explored. In order to evaluate possible changes in students’ critiquing abilities, their argumentative responses to an arguable claim before and after participating in the Bio-Tech program were examined and compared to the arguments of other 11th grade students not participating in the inquiry-oriented program. The analysis focused on the following aspects: (i) metalanguage of science terms used by the students in their arguments, (ii) students’ agreement with an arguable claim, (iii) students’ arguments regarding the described experimental process, and (iv) the number of arguments used by the students. Preliminary results from this part of the research were published (Bielik & Yarden, 2013; Appendix 7).

No explicit references regarding teaching about critiquing were found in the formal educational documents and guidelines of the Bio-Tech program (Israeli Ministry of Education, 2005, 2008). The Bio-Tech teachers claimed that no specific instruction of critiquing was made during the teaching of the program. They expected their students to be able to raise arguments and critique, and did not focus on these practices in their teaching. The Bio-Tech developers did not mention teaching the students to critique as one of the program’s goals or focus of the teachers’ training.

7.4.1 Students’ ability to use metalanguage of science terms in their arguments

In order to expose possible changes in students’ ability to use metalanguage of science terms in their arguments, the average number of metalanguage of science terms used by students was calculated using t-test for comparing significant mean differences. Results revealed that the average number of terms used by the Control group students decreased by the end of the school year (average of 1.05 and 0.93, respectively, t=-0.777, df=222 p=0.438), while the average number of terms used by the Bio-Tech students following their participation in the program increased (average of 1.14 and 1.32, respectively, t=0.574, df=154 p=0.567). No statistically significant differences were found between the groups, probably due to the relatively small number of students who filled-out the pre- and post-questionnaires. This indicates that the Bio-Tech students’ ability to use metalanguage of science terms in their critiquing arguments improved following their participation in the program (Fig. 8).

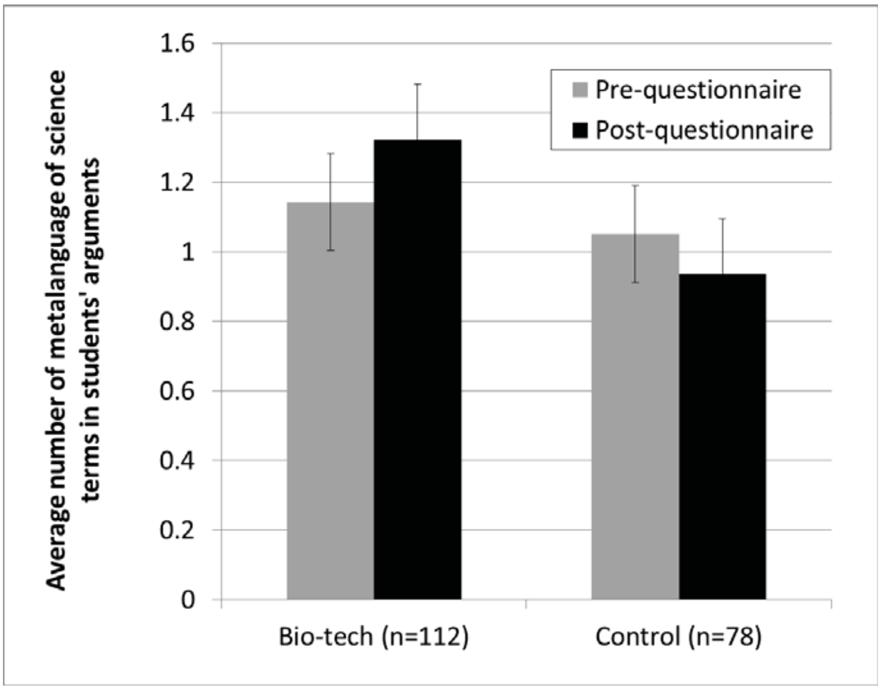


Fig. 8: Average number of metalanguage of science terms in students' arguments
n=number of students' arguments, error bars=standard error.

7.4.2 Students' agreement with an arguable claim

Another indicator for the possible development of students' critiquing ability is their tendency to disagree with arguable claims presented to them. Statistical analysis was performed using one-way ANOVA test. An increase in the percentage of arguments regarding the experimental process described in the article was found among the Bio-Tech students' group (from 33%% in the pre-questionnaire to 43% in the post-questionnaire) and among the Control students' group (from 33% in the pre-questionnaire to 39% in the post-questionnaire). No statistically significant difference was found between the groups (F [3, 379]=1.2 [p=0.31]), probably due to the small number of analyzed arguments. This demonstrates that the students' tendency to dispute arguable claims decreased by the end of the school year (Fig. 9).

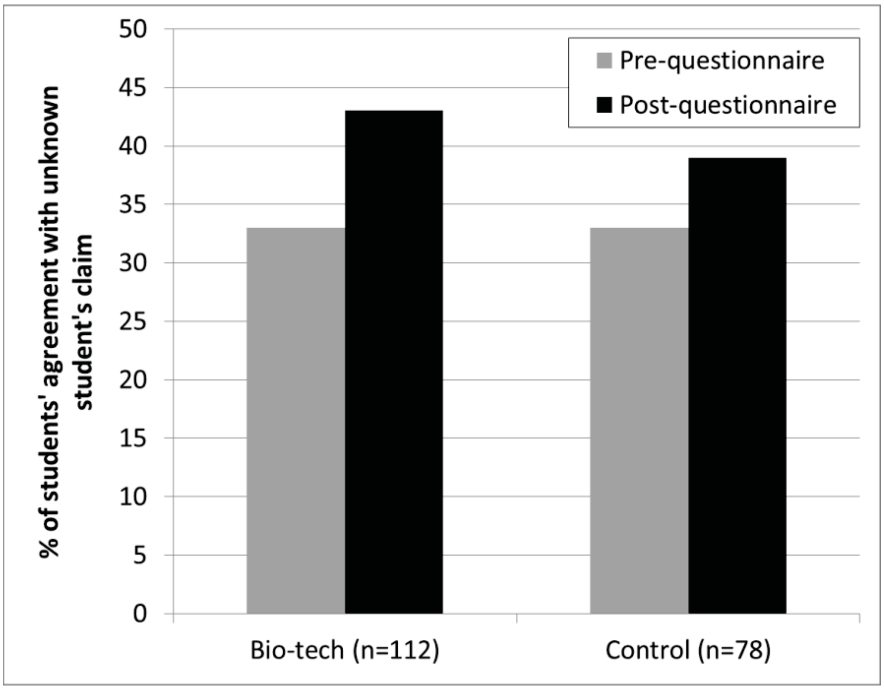


Fig. 9: Students’ agreement with an arguable claim
n=number of students’ arguments.

An example of students’ arguments shift from disagreement to agreement with an arguable claim can be seen in the following example. This Bio-Tech student disagreed with the arguable claim in the pre-questionnaire and his answer included arguments related to the chain of inferences (*"I disagree with the student, since this article didn’t prove that all of the teething rings are dangerous for babies. It proved that there are specific kinds of teething rings that release phthalates and are dangerous for use, but that there are other teething rings which are not considered dangerous"*). In the post-questionnaire, the student changed his opinion. He agreed with the claim and used arguments related to the experimental process described in the article (*"I agree with the student since after establishing the hypothesis, the researchers performed the experiment in order to prove their hypothesis and with the experiment they proved that teething rings are dangerous for babies because of the phthalates that are released from them").*

This result indicates that students in both the Bio-Tech and Control groups tended to be more in agreement with an arguable claim by the end of the school year and that the participation in the Bio-Tech program did not increase the students’ tendency to disagree with an arguable claim. The next two sections of the results will focus on the argumentative claims written by the students who disagreed with the arguable claim.

7.4.3 Students' arguments regarding the experimental process

To further explore students' arguments, an examination of the content of the arguments used by the students who disagreed with the arguable claim was carried out. Statistical analysis was performed using one-way ANOVA test. An increase in the percentage of arguments regarding the experimental process described in the article was found in the Bio-Tech students' group (from 13.5% in the pre-questionnaire to 15% in the post-questionnaire), while a decrease was found among the Control students' group (from 16.7% in the pre-questionnaire to 10.2% in the post-questionnaire). No statistically significant difference was found between the groups (F [3, 220]=0.385 [p=0.764]), probably due to the small number of analyzed arguments. This indicates that the Bio-Tech students' tendency to use arguments regarding the experimental process increased following their participation in the program (Fig. 10).

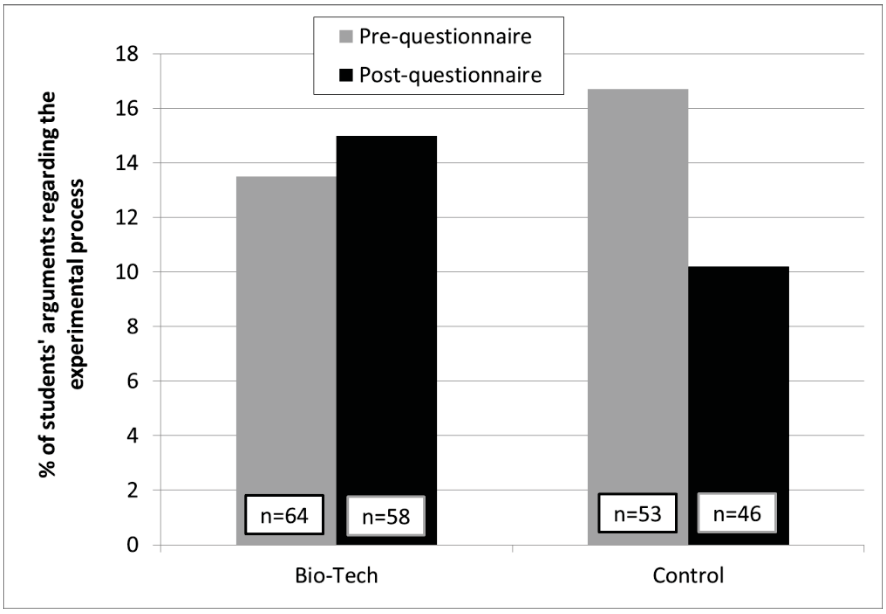


Fig. 10: Percentage of students' arguments regarding the experimental process
n=number of students who disagreed with an arguable claim.

An example of the Bio-Tech students' tendency to use arguments regarding the experimental process described in the article is presented below. The following Bio-Tech student wrote an argument concerning babies' health issues in the pre-questionnaire ("*I don't agree with the student. It was not experimentally examined or written in the article if phthalates are dangerous for babies or how they effect them. Maybe babies have immunity to phthalates? They didn't examine the health of the* *baby who uses the teething rings compared to a baby who does not, therefore you can't know if the teething rings are dangerous*"). In the post-questionnaire the student still disagreed with the arguable claim but used arguments regarding the described experimental process ("*They need to repeat the experiment to validate the results, examine all kinds of rings and only then determine which rings are dangerous").*

7.4.4 The number of arguments used by the students

Examining the number of arguments in the answers of students' who disagreed with the arguable claim, using t-test statistical analysis, revealed that the average number of arguments decreased in the Bio-Tech students' group (1.37 and 1.26, respectively, t=1.402, df=120, p=0.163) and in the Control students' group (1.36 and 1.28, respectively, t=0.734, df=97, p=0.465). No statistically significant differences were found between the groups (Fig. 11).

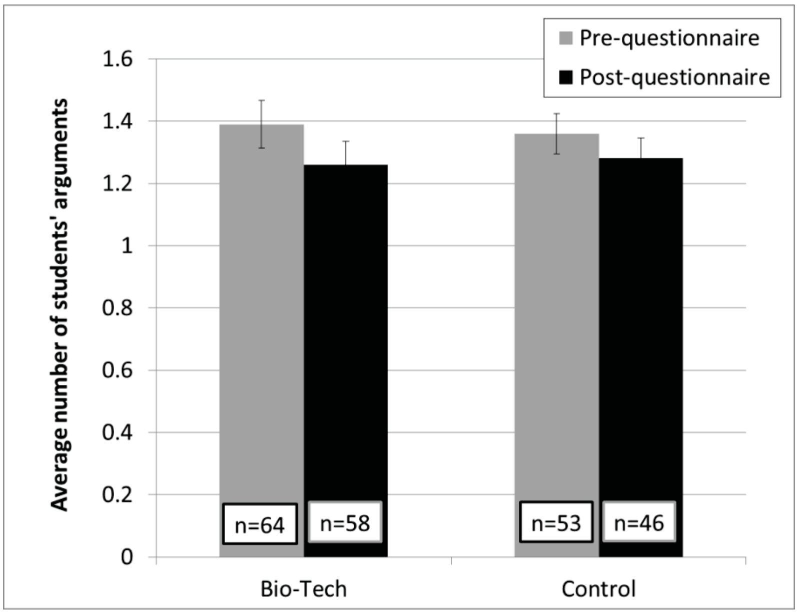


Fig. 11: Average number of arguments used by the students
n=number of students who disagreed with arguable claim, error bars=standard error.

An example for the decrease in the average number of arguments in students' answers is presented below. This student from the Control group disagreed with the arguable claim in the pre-questionnaire, using two arguments regarding the chain of inferences ("*I disagree with the student, since the experiment in the article was performed on only 11 types of teething rings and this is not enough to determine and generalize that all teething rings are dangerous* [first argument]. *There may be other companies that are not using this substance* [second argument]"). In the post-questionnaire, this student agreed with the arguable claim and used only one argument in her answer ("*I agree. The article shows an experiment that proves that the teething rings are dangerous*").

Summary

These results revealed that some of the Bio-Tech students’ critiquing abilities improved following their participation in the program, mostly their ability to use metalanguage of science terms in their arguments and their tendency to focus their arguments on the experimental process. However, the Bio-Tech students’ tendency to disagree with an arguable claim did not increase following their participation in the Bio-Tech program, nor did their ability to use more arguments in their answers. This indicates that developing the Bio-Tech students’ critiquing practice requires more explicit teaching of this practice.

7.5 What are the differences between the inquiry processes in the intended and in the implemented Bio-Tech program curricula?

In order to examine the possible gaps between the intended and the implemented Bio-Tech curricula, an analysis of the Bio-Tech program's intended curriculum and the implemented curriculum was performed. This examination allowed an in-depth characterization of the Bio-Tech program's inquiry level. The I-MAP tool was used in order to evaluate the Bio-Tech program curricula in two dimensions: (i) the intended curriculum, as depicted by the intensions, aims and goals of the Bio-Tech program developers, consisting of a set of classroom materials and the suggested teaching strategies and theoretical perspectives, and (ii) the implemented curriculum, consisted of the strategies, practices and activities enacted by one Bio-Tech teacher (Sam, details in Table 1) during the 2010/11 academic year in his classroom.

The two resulting I-MAP inquiry stars enabled to compare between the intended and the implemented Bio-Tech curricula and inquiry level. As can be seen in Fig. 12, the inquiry and teacher involvement levels in the intended and implemented curricula were identical in the features of engage in phenomena, collect data, explain and justify, and present an article. The features of formulate questions, hypothesize, plan investigation, and analyze and represent data, were found to reflect higher level of inquiry and / or lower level of teacher involvement in the intended curriculum than in the implemented curriculum. The feature of link resources to explanations was found to reflect lower level of teacher involvement in the implemented curriculum that in the intended curriculum.

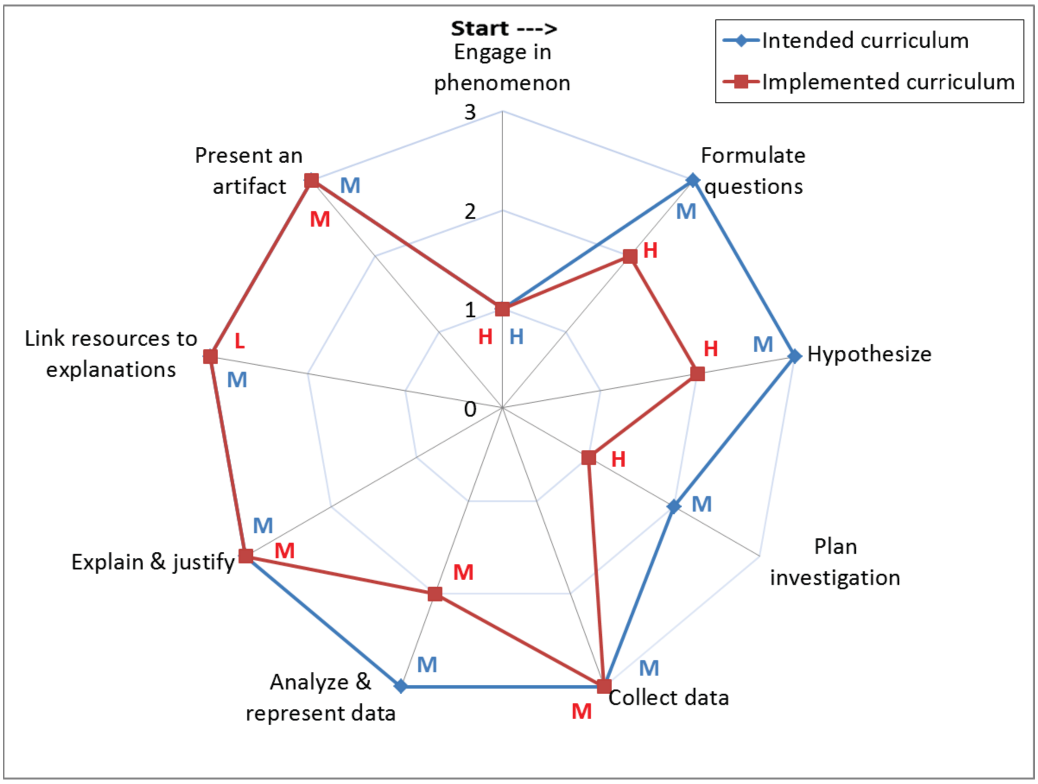


Fig. 12: Bio-Tech intended and implemented curricula
Students' level of independence: 1-dependent, 2-intermediate, 3-independent; teacher's level of involvement: H-high, M-medium, L-low.

The overall goal of the Bio-Tech program developers was to allow students to experience high level of inquiry and low to medium level of teacher involvement, as perceived by one of the Bio-Tech developers (EA): "*A teacher with high confidence will direct the students and not teach them using the classical approach, allowing them the freedom of real exploration. Independent inquiry will be performed in these cases*". In the following section, the detailed analysis of each inquiry feature is presented, based on the intended and implemented Bio-Tech curricula as reflected in the class observations, Israeli Ministry of Education policy papers (Israeli Ministry of Education, 2005, 2008), and interviews with the program participants.

Engage in a phenomenon

During their participation in the Bio-Tech program, the students were exposed to a phenomenon chosen by the teacher in the form of the Adapted Primary Literature (APL) article and other resources that provided the students with the required knowledge and core concepts of the topic. In both the intended and implemented curricula, the students' engagement in the given phenomenon was of low inquiry level (dependent) and reflected high teacher involvement (Fig 12).

Formulate questions

Formulating the research question is mainly manifested in the Bio-Tech curriculum (Israeli Ministry of Education, 2008): "*The student will know and understand his self-generated research question…explain the connection between his research question and the experiment that he performed…explain and understand the tools and methods he used and the data analysis and conclusions reached from it*" (p. 7). According to the intended curriculum, the Bio-Tech program students are expected to formulate their own research questions. This was also mentioned by one of the Bio-Tech developers (EA): "*It is very important that the students will raise the questions on their own. This is the main thing. The teacher needs to navigate the question to be applicative*". This indicated that the students' inquiry level is expected to be of the highest level (level 3, independent) when formulating the Bio-Tech research question.

Analyzing the implemented curriculum in one Bio-Tech class revealed a different inquiry level result. In his interview, the class teacher said: "*At the end, I'm giving them [the students] the [research] questions we planned for the Weizmann Institute…the students can't investigate the questions they ask*". When observing that teacher's lesson, it appeared that he allowed the students to come up with their own research questions while assisting them to do so. Following the lesson in which the students formulated their research questions, the teacher altered the questions, sometimes presenting the students with completely different questions from those they suggested. This indicated that the students experienced an intermediate level of inquiry (level 2) with high level of teacher involvement during the formulation of their research questions feature (Fig 12).

Hypothesize

According to the intended curriculum, students are expected to formulate their own hypothesis, based on their research question, and to connect it to the known scientific background (independent inquiry level). The teacher is supposed to assist the students in the process (medium level of teacher involvement). In the intended curriculum, as seen in class observations and recordings, the class teacher was highly involved in the process and the students were not independent. This gap between the intended and implemented curricula can be explained by the lack of teacher's confidence in his students' ability to successfully formulate their hypothesis, based on his view regarding his students' cognitive level. The teaching of hypothesizing took much time in the class and the students did not show high level of understanding of this feature, which caused the teacher to be more involved in assisting his students with formulating their hypothesis (Fig 12).

Plan investigation

According to the intended curriculum, students are expected to be involved in planning their Bio-Tech research. However, there are a limited number of tools and methods that can be used in the research institute, and for this reason the feature of planning the investigation was given a medium level of inquiry (intermediate). The Bio-Tech teachers are expected to be partially involved during the planning of the students' investigations, assisting the students to get familiarized with the tools and methods and direct them in planning their investigations.

In the implemented curriculum, however, the inquiry level that was observed in Sam's class was low (dependent), since the tools and methods were chosen in advance by the class teacher, science educator, and young scientist instructor, and the research questions had to be suitable to the selected methods. Prior to their arrival to the research institute, the students were given the experimental protocols that they were expected to use. The teacher, the science educator and the young scientist instructor were highly involved during the planning of the experiments (Fig 12). As said by the class teacher: *"The experiment is dropped down [on the students] when it comes to the methods…usually the student arrives to the laboratory after receiving the protocols and starts to work with it. Only then he begins to understand what he does"*.

This gap between the intended and implemented curricula can be explained by the students' lack of experience in planning experimental procedures and their lack of familiarity with the different tools and methods that can be used. The teacher did not have the time to focus on planning the investigations because of the time limitations, and instead he decided to limit the students' independence and to provide them the specific methods that were used in their research.

Collect data

Students are expected to perform the experiments and collect the data by themselves through hands-on experience in the research institute, according to the intended curriculum. The teacher, the science educator and the young scientist instructor were present during the data collection and assisted the students who required help, but they were expected to allow the students to perform the work themselves. Observations of the Bio-Tech class revealed that this was the case in the implemented curriculum. Most of the students used the equipment and tools themselves, with occasional guidance of the teacher, the science educator, or the young scientist instructor. The science educator or young scientist instructor usually gave a short class briefing prior to each of the experimental steps and then allowed the students to execute the procedure themselves (Fig 12).

Analyze and represent data

According to the intended curriculum, students are expected to perform the data analysis, process and represent their collected data on their own (independent inquiry level) with medium level of teacher's involvement. Sam, the class teacher, demonstrated a medium level of involvement, but the students had less independence in their work and they were directed how to analyze and represent the data during the classroom lessons following the main experiments in the research institute and by internet correspondence with the teacher (Fig 12). This gap between the intended and the implemented curricula can be explained by the students' lack of experience in analyzing and representing data.

Explain and justify

Explaining and justifying the results were found to reflect similar levels of students' high inquiry level and teacher's medium involvement in both the intended and the implemented curricula. The Bio-Tech students are expected to formulate explanations from their results in their final report. Sam was partially involved in this process, depending on the students' level and abilities. Some students required higher guidance of the teacher, where he helped them to formulate their explanations. Some students didn't require high level of teacher involvement, since they were able to formulate their explanations by themselves and the teacher was only required to approve their final submitted report (Fig 12).

Link resources to explanations

According to the intended curriculum, students are expected to find other scientific resources as background material for their final research report and to connect their results to these resources (independent inquiry level). The teacher is expected to be partially involved in this feature. In the implemented curriculum, it was observed that the students were mostly independent in linking resources to their explanations. Sam's involvement in this stage was found to be low. He allowed the students to independently find the resources without being involved in the process (Fig 12). This gap in the teacher involvement may be explained by the teacher's lack of time or his view that finding the appropriate resources could be performed independently by the students without his assistance.

Present an artifact

In this feature of the Bio-Tech program, the intended and the implemented curricula reflected high inquiry level (independent) and medium level of teacher's involvement. By the end of the Bio-Tech program, students are expected to submit their final research portfolio which includes their research report and several assignments that were performed during the school year. Following the submission of the research portfolio, students were individually examined by another Bio-Tech teacher. In the examined class, most students were highly independent while preparing and presenting their final report. However, Sam was partially involved with some of the students that required more assistance in their preparations (Fig 12).

Summary

In both the intended and the implemented curricula, the initial inquiry features of the Bio-Tech program were characterized as low inquiry level and high level of teacher's involvement, while the later features of the Bio-Tech program showed a higher students' inquiry level and a lower level of teacher's involvement. Some gaps were found between the intended and the implemented inquiry curricula, mostly in the initial features of the inquiry process, where the intended curriculum aimed to allow more student independence but the implemented curriculum revealed lower inquiry level and more teacher involvement.

The I-MAP tool was found to be appropriate in revealing the gaps between the intended and the implemented curricula. The resulting I-MAP stars gave a graphically illustrated description of the intended and the implemented curricula. However, some difficulties in using the tool were revealed. The difficulties were in determining the inquiry level and teacher's involvement in the intended curriculum due to lack of explicit references to some inquiry features, such as hypothesizing, plan investigation and link resources to explanation, in the documents and interviews with the Bio-Tech program developers.

7.6 What are the Bio-Tech participants’ views regarding the program’s inquiry level?

This part of the study aimed to expose the Bio-Tech participants’ views regarding the inquiry level and authenticity of the program. A total of 57 students, 6 teachers, 7 young scientist instructors and 3 developers of the Bio-Tech program were interviewed following their participation in the program. Interviews with the participants were recorded, transcribed and analyzed. In addition, the I-MAP tool was used in order to further explore the Bio-Tech teachers’ views regarding the inquiry level of the program. This tool was employed during a Bio-Tech teachers’ workshop at the end of the 2012/13 academic year. The analysis of the 10 Bio-Tech teachers that filled-out the I-MAP star was based on their written sheets and transcripts of the group discussions during the I-MAP workshop.

Bio-Tech students’ views regarding the Bio-Tech inquiry level

Most of the Bio-Tech students viewed the program as reflecting high inquiry level which allowed them to independently perform their research. When asked which of the Bio-Tech stages they view as the highest inquiry level, the stages of writing the research portfolio, performing the main experiment at the research institute, and formulation of the research question were mostly mentioned (Table 14).

When asked about the advantages and disadvantages of performing high inquiry level, the Bio-Tech students mentioned the improvement in their learning of the scientific content, the increase in their understanding about scientific research, the increase in their interest, motivation and enjoyment from the inquiry process, the benefits of learning how to work independently, and the development of their scientific thinking skills. Some students mentioned the support that was given to them in their independent work and the contribution of the teacher and the other Bio-Tech staff in facilitating the inquiry process, as said by one of the Bio-Tech students: *"We did the work on our own, but the teacher was leading and supporting us all the time, we could always turn for his help. He helped us to do it by ourselves"* (C2S38).

Table 14: Bio-Tech stages considered as high inquiry level by the students
In brackets the percentage of students that mentioned this stage, n=57.

Bio-Tech stage	**Quotes taken from the Bio-Tech students' interviews**
Writing the research portfolio (54.4%)	*"Most of our independent work was carried out when we prepared and wrote the Bio-Tech portfolio, answered the questions, reached conclusions and wrote the discussion- all of that was our own work."* (C2S41)
Performing the main experiment (45.6%)	*"The research we've done in the Weizmann Institute was our own work, we explored the research question we've asked and we did the experiment."* (C1S23)
Formulating the research question (15.8%)	"*Choosing the research question was independent [for us], we had all the options. This is the main part of the work. The whole work was independent if we had the opportunity to choose what we do*." (C1S15)
Analyzing the data (5.3%)	*"We felt independent during almost the entire work, in the Weizmann Institute and while writing the portfolio and analyzing the results…I prefer the work to be independent, it feels good."* (C1S17)
Reaching conclusions (5.3%)	*"We did the work ourselves. We reached conclusions; we did a real experiment, from the beginning to the end."* (C1S13)

Bio-Tech teachers' views regarding the program's inquiry level

Most of the teachers (5 out of 6) viewed the Bio-Tech as high inquiry level in the stage of formulating the research question. Similar to most of the Bio-Tech students, three of the teachers viewed the stage of analyzing the results and writing the research portfolio as high inquiry level (Teacher #3: *"The writing of the portfolio is very independent for the students. I supported them all the time but they were the ones to do it"*). Three teachers viewed the stage of finding other scientific resources as high inquiry level, and two teachers mentioned performing the main experiments as high inquiry level.

In order to further explore the Bio-Tech teachers' views regarding the program's inquiry level, the I-MAP tool was used during a Bio-Tech teachers' workshop at the end of the 2012/13 academic year. Ten teachers participated in the workshop and their resulting I-MAP stars were taken for analysis. The average score that was given by the teachers was calculated from their filled-out inquiry stars, where 1 was the lowest inquiry level (dependent), 2 was the medium inquiry level (intermediate) and 3 was the highest inquiry level (independent). Some teachers marked two inquiry levels for the same feature, since they believed the inquiry level was somewhat in between the two levels. In these cases, the inquiry level was scored as the middle point between the two levels. It should be noted that there was some misunderstanding among the teachers regarding the teacher's involvement level. It was not clear to them if the teacher involvement level refers only to their own involvement or to the involvement of others, such as the young scientist instructors or the science educators. Therefore, the results of the I-MAP tool teacher involvement level were not taken for analysis. The original I-MAP stars of the ten Bio-Tech teacher are presented in Appendix 8.

Most the teachers viewed the feature of engaging in a phenomenon as low inquiry level (average score of 1.3), since in the beginning of the program students are presented with the Bio-Tech topic and study the selected APL article and had no opportunity to independently choose the research topic. Low inquiry levels were also found in the features of planning the investigation (average score of 1.4) and presenting an artifact (average score of 1.2), indicating that in these features the students were given less independence according to the Bio-Tech teachers. In their interviews, some of the teachers mentioned that when planning the experiment, the involvement level of the young scientist instructors was very high, since they were required to check if the experiments were appropriate for the tools and methods available in the research institute. All other inquiry features (formulating questions, collecting data, analyzing and representing results, explaining and justifying conclusions, and linking resources to explanations) were viewed by the teachers as medium or high inquiry level with medium or high level of teacher involvement, ranging between 2 to 2.75 (Fig. 13).

High resemblance was found between the inquiry stars of the Bio-Tech teachers in most of the program's features, indicating that the program was similarly perceived and implemented by the teachers who participated in the workshop. It was also found to resemble the I-MAP tool results of the intended and the implemented curricula (presented in section 7.5), except for a low inquiry level in the last feature of presenting an artifact that was viewed by the Bio-Tech teachers, in contrast to the high inquiry level found at the intended and implemented curricula.

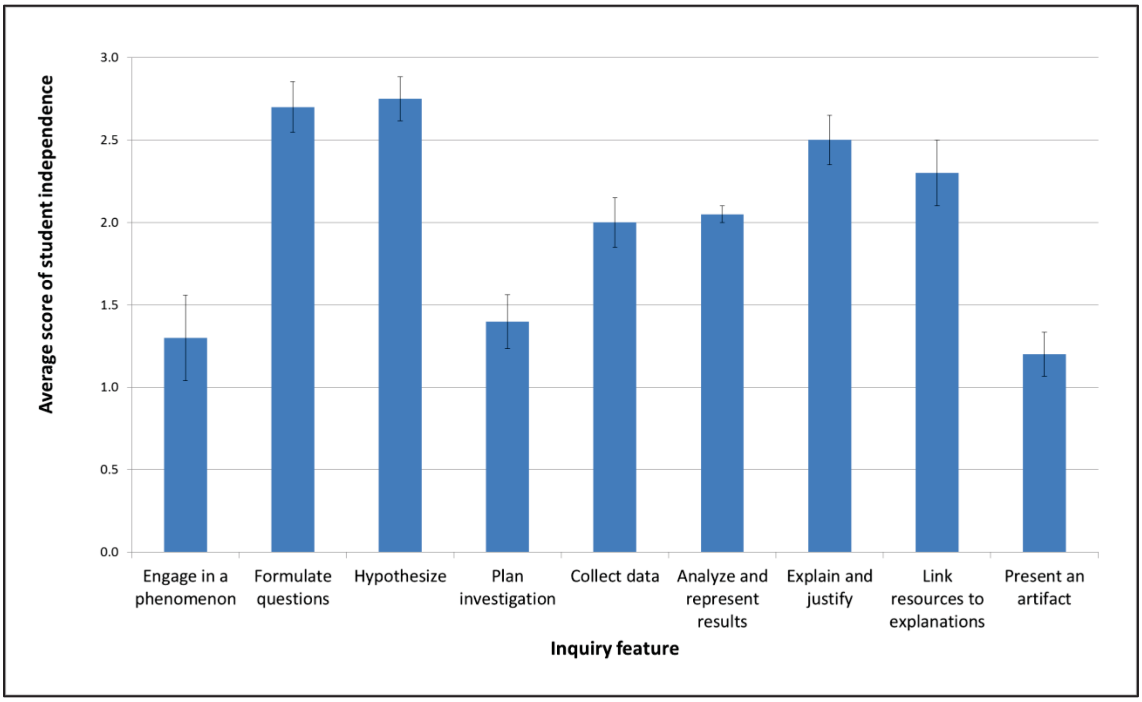


Fig. 13: Bio-Tech teachers' average score of the program's inquiry level
Number of teachers=10, error bars=standard error.

During the whole group discussion, while presenting their I-MAP stars, the Bio-Tech teachers discussed about the students' independence level and teachers' involvement during the Bio-Tech program, mentioning that some of the inquiry features were more independent for the students while other features required more teacher involvement (e.g., "*I think that while planning the experiment all the responsibility was placed on the Weizmann Institute and less on the teacher. So here our involvement is minor. The student raised the research question but he was pretty limited…The place where they [the students] had the most independence in my class was in formulating the research question, performing the experiments, and collecting the data. In the other places the [teacher] involvement was medium or sometimes high*"). In another part of the discussion, some teachers mentioned that the cutting-edge tools and methods and encounter with the research institute are the main program goals, while other teachers mentioned that they view the students' independence level and allowing them to explore their questions as the main goal.

Most of the teachers mentioned that the I-MAP activity was meaningful and helpful, since it gave them an opportunity to analyze, evaluate and reflect on the inquiry level and on their involvement level during the Bio-Tech program (e.g., "*I felt that at the end [of the activity], when the inquiry star was portrayed and I could look at it closely in retrospect, I felt a need to talk with the people around me. I suddenly had a spotlight on how much I was involved in the program and where it was open to the students*").

Bio-Tech Developers' views regarding the inquiry level

All three program developers that were interviewed mentioned that the inquiry level varied among different classes and depended mostly on the teacher's decision (Developer #1: *"The students' independence depends on the teacher. I think some teachers allow open inquiry because they don't care about the experiment results. They believe, like us, that the students learn more from the process than whether the experiment works or not"*). One of the developers mentioned the stage of performing the main experiment at the research institute as high inquiry level. The other developers did not mention any specific inquiry stages that they viewed as high inquiry level.

Young scientist instructors' views regarding the inquiry level

Most of the young scientist instructors (6 out of 7) mentioned the stage of formulating the research question as medium or high level of inquiry. Two of them considered the stage of planning the research as high inquiry level, while one instructor considered this stage as low inquiry level. Four instructors mentioned the stage of performing the main experiment at the research institute as low or medium inquiry level (Instructor #5: *"In the stage of performing the experiments and collecting the data, they [the students] are not independent …they work with their hands but they do not have the freedom to plan the experiment. The experiment is prepared and they need to carry it out as written"*).

Summary

Most the Bio-Tech participants perceived the program as reflecting high inquiry level in some of the inquiry features. Most of the Bio-Tech students viewed the stages of writing the research portfolio, performing the main experiments and formulating their research questions as the most independent stages of the program. Most of the Bio-Tech teachers viewed the program’s high inquiry level in the stages of formulating the research question, performing the experiments, analyzing the results, reaching conclusions and linking the conclusions to other scientific resources. The Bio-Tech developers mentioned that the inquiry level depends mostly on the teachers’ abilities and preferences, and the young scientist instructors viewed the stage of formulating the research questions as high inquiry level. Altogether, the Bio-Tech participants recognized and emphasized the importance of high inquiry level and students’ independence in the program, but were also aware of the programs’ limitations in allowing high inquiry level, such as time and available tools and methods. This indicates that the Bio-Tech program could be considered as reflecting high inquiry.

7.7 What are the Bio-Tech participants' views regarding the program's authenticity?

In order to examine the perceived authenticity level of the Bio-Tech program, 57 students, 6 teachers, 7 young scientist instructors and 3 developers were interviewed. The participants were asked if the Bio-Tech program is similar or different from authentic scientific research and how. Chinn and Malhotra (2002) described the cognitive processes that are required for authentic scientific inquiry: (i) generating research questions, (ii) designing studies (including selecting and controlling variables, planning procedures and planning measures), (iii) making observations, (iv) explaining results (which includes the transforming of observations to other data formats, finding flaws, indirect reasoning, generalization and employing multiple types of reasoning), (v) developing theories, and (vi) studying research reports. Participants' answers were classified based on these six cognitive processes. One additional category emerged from analyzing the answers and added to the classification. This category ('other aspects') included aspects that were not specific to any of the six prior cognitive processes. The results are presented in Table 15.

Several advantages and disadvantages of the Bio-Tech program were revealed by analyzing the participants' answers. Most of the Bio-Tech participants considered the program to resemble authentic scientific research in the aspect of the tools and methods that were used. Another aspect of resemblance that was mentioned by some of the participants was formulating the research questions. The main aspect of difference between the Bio-Tech and authentic research that was mentioned by the participants was that the Bio-Tech was not as complicated as real research. Many of the participants also mentioned that in authentic research the experimental process includes using more variables, repeating the experiments and using more control treatments. These results indicate that the Bio-Tech program was mostly considered as reflecting authentic scientific research by the program participants.

Table 15: Aspects of resemblance and difference between the Bio-Tech and authentic research mentioned by the program participants

Cognitive process based on Chinn & Malhotra (2002)	Aspect of resemblance	Aspect of difference
(i) Generating research questions	Choosing and formulating research question (5S, 2T, 1D, 4Y)	In the Bio-Tech program only one research question is explored (1S, 3Y)
(ii) Designing the study	Hypothesizing (4S, 1T, 1Y)	
	Examining different experimental conditions (1S)	
	Choosing appropriate tools and methods (1Y)	
(iii) Making observations	Similar methods, tools and equipment used in the experiments (20S, 4T, 2Y)	Scientists repeat the experiments and use controls (10S, 1T, 1D, 4Y)
	Collecting data and results (5S, 1Y)	Scientists explore more variables (6S)
	Performing the experiments (5S, 1D, 1Y)	The Bio-Tech students don’t prepare the equipment and experiments themselves (3S)
	Requires Sterile work (2S)	The Bio-Tech results are already known and the experiments were done in the past (9S, 1T)
	Requires precision and accuracy (1S)	Scientists are more sterile and precise (2S)
		The results of the Bio-Tech program are not reliable as authentic research (1S)
		The Bio-Tech students must receive some results from

		their experiments (1T, 1Y)
(v) Developing theories	Not mentioned	Not mentioned
(vi) Studying research reports	Reading and studying research reports (1S, 3T, 1D, 2Y)	The scientific articles in the Bio-Tech program are more simple than authentic scientific articles (1T)
		The Bio-Tech students do not understand the scientific articles they read (1Y)
(vii) Other aspects	Independence (4S)	The Bio-Tech research is not as complicated as scientific research (24S, 3Y)
	Interesting (4S)	The Bio-Tech program does not allow students to work independently (11S, 1Y)
	Making new scientific discoveries (2S)	Time limitations of the Bio-Tech program (8S, 1T)
	Fun (2S)	Scientists have more knowledge, abilities and experience (5S, 1T)
	Developing scientific thinking abilities (1S, 1D, 1Y)	Scientists have their own laboratory (3S)
	Ownership of the research process and personal responsibility (1S, 1T)	Scientists are thinking by themselves (1S)
	Involves using scientific language (1S)	Scientific research is more beneficial human knowledge (1S)
	Working under tight schedule (1S)	Scientists are more professional (1S)

	Requires Team work (1S)	The Bio-Tech program does not reflect the latest contemporary science (1T)
	Requires persistence (1S)	
	Brainstorming with peers (2D)	
	Gaining new scientific knowledge (1D, 1Y)	
	Confronting technical difficulties (1D)	
	Encounter with scientists and research institute (1T)	
	Familiarizing with the research field (1T)	
	Learning contemporary science (1Y)	
	Performing high level of scientific research (1Y)	

Students (S) n=57, teachers (T) n=6, young scientist instructors (Y) n=7, developers (D) n=3. Frequently mentioned aspects are underlined.

In brackets the number of participants that mentioned this aspect.

“Tell me and I will forget,

Show me and I may remember,

Involve me and I will understand.”

Confucius

8. Discussion

Experiencing inquiry and gaining an appreciation of authentic scientific practices are key elements of science learning and teaching (Bybee, 2000; Chinn & Malhotra, 2002; National Research Council [NRC], 2012). Practicing inquiry was previously reported to support students' learning outcomes (Furtak et al., 2012; Minner et al., 2010) and increase their motivation, interest, and positive attitudes towards science (McConney et al., 2014). Students are expected to develop higher order science process skills by experiencing authentic and independent inquiry (Roth & Roychoudhury, 1993). In this research, the teaching and learning of inquiry in general and of specific scientific practices in particular were investigated in the context of an innovative inquiry-oriented program called the Bio-Tech. The Bio-Tech is a yearlong program designed for 11th grade high school biotechnology majors, involving a co-teaching approach by the class teacher, science educator and a young scientist instructor at a research institute, where students are expected to experience high inquiry level while performing cutting-edge scientific research.

Results from this research indicated that participating in the Bio-Tech program contributed to high school students' ability to use scientific language and improved their understanding of the experimental process while practicing asking questions and critiquing. It is suggested that the Bio-Tech program is appropriate for the teaching and learning of formulating research questions and that a student-centered, interactive and dialogic teaching approach should be implemented by the teachers in classrooms in order to promote the students' scientific language and learning of scientific practices and the inquiry process. To the best of my understanding, this is the first study indicating a positive correlation between the teachers' dialogic and interactive communicative approach and their students' learning of formulating research questions in the context of an inquiry-oriented high school program. Moreover, the characterization of the Bio-Tech program indicates that most of the inquiry features can be characterized as high inquiry level and authentic.

8.1 The teaching and learning of scientific practices in the Bio-Tech program

8.1.1 Development of students' asking questions practice

Asking questions is one of the core scientific practices which are needed for developing students' science literacy and understanding of the inquiry process (Chin, 2002; Cuccio-Schirripa & Steiner, 2000; National Research Council [NRC], 2012). Participation in the Bio-Tech program improved students' ability to focus their questions on the experimental process. The increase in students' attention to the experimental process can be explained by the fact that during the Bio-Tech program the students have many opportunities to practice the experimental process: while planning the research, while collecting the data, while analyzing the results and while reaching conclusions. This notion is further supported by the fact that an increase in the students' ability to focus their questions on the experimental process was also found in students' critiquing claims. The Bio-Tech students' ability to use metalanguage of science terms improved following their participation in the Bio-Tech program, indicating that the Bio-Tech program provided the students with an opportunity to practice the appropriate usage of scientific language, as recommended in previous studies (Lemke, 1990; Norris & Phillips, 1994; Shanahan, 2010). This issue is further discussed in section 8.1.3.

These results are in accord with previous studies that found that explicit teaching of asking research questions in inquiry environments improved students' learning of this practice (Chin, 2002; Cuccio-Schirripa & Steiner, 2000). This may contribute to the understanding of students' learning to ask research questions, as recommended in the recent NRC framework (2012). This finding suggests that inquiry-oriented high school programs are appropriate for teaching students to focus their questions on the experimental process and improved their mastery of using the metalanguage of science. Science educators, inquiry program developers and practitionairs are encouraged to consider using inquiry-oriented programs as a platform to promote students' asking questions practice.

Teaching and learning of asking research questions

One of the main aspects concerning students' asking questions practice is their ability to ask research questions. However, many students face difficulties in formulating their own research questions (Chin & Kayalvizhi, 2002), and the explicit teaching of asking research questions contribute to the students' learning of this practice (Chin, 2002). The teachers' instructional moves and communicative approach are meaningful for the students' learning (Mortimer & Scott, 2003; Pimentel & McNeill, 2013). The student-centered teaching strategies employed by elementary school teachers helped the students to elicit their ideas for questions, however students required assistance in developing their ideas into appropriate research questions (Harris et al., 2012). The process of teaching and learning to formulate research questions during two Bio-Tech classroom lessons was examined in order to explore the impact of the teachers' chosen lesson structure and communicative approach on the students' development of formulating research question ability.

Both the Bio-Tech and Control (11th grade biotechnology majors who did not participate in the Bio-Tech program) students' ability to ask research questions significantly increased by the end of the school year. This suggests that 11th grade biotechnology students' ability to ask questions developed during the school year for other reasons, not dependent on the participation in the Bio-Tech program. Such opportunities could be found in the biotechnology curriculum or in other school lessons and laboratories, as mentioned in interviews with the Bio-Tech teachers. Such learning opportunities were also reported by Roth and Roychoudhury (1993), who investigated 8th, 11th and 12th graders performing laboratory experiments. Therefore, it is recognized that the Bio-Tech is not the only environment that gives the students an opportunity to practice asking questions, but it may serve as an additional curricular program which further supports the students' development of this practice.

Examining the communicative approach demonstrated by the teachers during two lessons revealed that the students' formulating research questions ability developed during the lesson that was student-centered, dialogic, interactive, and included additional whole class discussions. Previous studies indicated that most whole class discussions are teacher-led, governed by the triadic Initiation-Response-Evaluation (I-R-E) dialog (Duschl & Osborne, 2002; Lemke, 1990), and that during whole class discussions secondary teachers tend to avoid probing and toss-back questions, which lead to limited and simple responses from the students (Pimentel & McNeill, 2013). Other studies reported that dialogic interaction during whole class discourse encourage students to share and discuss their own ideas and views (Lehesvuori et al., 2013). Pimentel and McNeill (2013) found that teachers who used more dialogic student-center interactions in their teaching encouraged their students to perform a more reflective thinking and meaningful discussions. In line with these studies, the Bio-Tech teacher who displayed a student-centered dialogic approach had greater success in teaching her students to formulate research questions than the other teacher who displayed a more teacher-centered and authoritative approach.

Previous findings regarding the teaching and learning of research questions in authentic inquiry environments suggest that students' ability to ask research questions improved following explicit classroom instruction (Chin, 2002; Chin & Osborne, 2008; Cuccio-Schirripa & Steiner, 2000; Roth & Roychoudhury, 1993). Similarly, my results indicate that 11th grade biotechnology students' ability to formulate research questions improved following explicit instruction of formulating research questions in a lesson that included dialogic and interactive whole class discussions.

It is suggested that the more experienced teachers are with performing authentic scientific inquiry, their abilities to teach inquiry improves (Blanchard, Southerland, & Granger, 2009). Therefore, a possible explanation for the differences that were found between the two Bio-Tech classes could be attributed to the teachers' scientific research experience. Studies regarding the correlation between teachers' research experience and their students' learning during inquiry activities had yielded mixed results. For example, Windschitl (2003) found that among pre-service science teachers, those who implemented open inquiry in their classes were those with significant undergraduate or professional scientific research experience. However, other studies concluded that neither the academic degree nor the research experience of the teachers impacted their students' learning during the inquiry school activities (McNeill, Pimentel, & Strauss, 2011; Monk, 1994).

In the two Bio-Tech case studies analyzed here, the teacher's academic research experience was in negative correlation to the development of his students' ability to ask research questions. This indicates that the academic level of the examined Bio-Tech teacher hindered the students' learning to formulate appropriate research questions. Another possible explanation to this result is that there were other more influential factors on students' learning. Such factors might be the students' low cognitive level prior to the lesson, as was seen in their limited ability to ask research questions in the pre-lesson questionnaire compared to the other teacher's students, or the teacher's authoritative / non-interactive communicative approach during the lesson that was previously discussed.

Alongside the improvement in the Bio-Tech students' ability to use metalanguage of science and to focus their questions on the experimental process, the development of several other asking questions abilities was investigated. Both the Bio-Tech and Control group students' tendency to ask questions regarding the theory of mechanism increased by the end of the school year, and no meaningful differences were found between the Bio-Tech and Control group students. Also, students' ability to ask questions of higher order improved throughout the school year by all 11th grade biotechnology students who participated in this study. Ratcliffe (1999) reported that students' questions regarding the theory of mechanism was the most prevalent in 7th and 9th grade students responses, and suggested that students are not well prepared to evaluate and question knowledge claims based on evidence presented to them, since this type of questions does not demonstrate high level of evidence evaluation skills in response to media reports. In line with Ratcliffe's study, it appears that the participation in the Bio-Tech program did not contribute to the students' development of this asking questions ability.

8.1.2 Development of students' critiquing practice

The ability to critique is crucial for the development of students' scientific literacy, contributing to their skills, abilities and understanding of scientific discourse and scientific habits of mind (Berland & Reiser, 2009; Ford, 2008). The centrality of critique is also emphasized in the NGSS recommendations of teaching scientific practices (Osborne, 2014b). Inquiry program students are expected to experience critical thinking and critiquing during their participation in the program and to have opportunities to engage in critiquing while planning their investigations, collaborating with peers, and communicating their results and conclusions (National Research Council [NRC], 2012). Therefore, it was postulated that the critiquing practice would develop among the Bio-Tech students more than among students who did not participate in any inquiry oriented program.

Participation in the Bio-Tech program was found to improve the students' ability to focus their arguments on the experimental process and to use metalanguage of science terms in their arguments. This improvement is similar to the abilities that were found to improve in the students' written questions, and further discussed in section 8.1.3. However, none of the Bio-Tech teachers or developers mentioned that they perform explicit teaching of the critiquing practice during the Bio-Tech program, indicating that the teachers assume that their students already master this practice or that there is a lack of time or resources for teaching students how to critique. This issue should be addressed by program developers and teachers, and some adjustments could be implemented in the Bio-Tech program in order to advance and support the students' learning of critiquing while participating in the Bio-Tech program.

The peer-critique activity during the formulating research questions lessons encouraged the students to evaluate their peers and their own research questions, and gave them the opportunity to communicate their ideas and thoughts. In line with the constructivist theory (Wheatley, 1991), the cooperative peer-critique activity and communicative sharing of ideas contributed to the Bio-Tech students' shared meaning making. The students were able to critique their peer's questions and to suggest more appropriate research questions. The peer-critique activity encouraged the students' collaborative work, fostered communication, and improved their inquiry skills, as recommended by Chin and Osborne (2008). Therefore, it is recommended to encourage inquiry-oriented program teachers and developers to incorporate peer-critique activities while practicing scientific inquiry.

Alongside the improvements that were found in the Bio-Tech students' abilities to use metalanguage of science terms in their arguments and to focus their critiquing argument on the experimental process, other critiquing abilities were examined. Participation in the Bio-Tech program did not increase the students' tendency to dispute an arguable claim, suggesting that the development of students' ability to reject and contradict peer claims requires deeper and more explicit learning of critiquing. This result stands in contrast to the findings of Ford (2012), who found that the tendency of students to disagree with an arguable claim of another student increased following learning to critique while practicing inquiry-oriented scientific activities. This discrepancy could be explained by the fact that in Ford's study, more focus on explicit instruction was made, unlike in the Bio-Tech program, where usually critiquing is not explicitly taught and practiced. However, results of my research are in line with the findings of Norris and Phillips (1994), who reported that top high school science students attributed higher degree of certainty and confidence to media reports and had difficulties with applying appropriate pragmatic meaning to these reports.

Students often fail to incorporate sufficient data in their argumentative claims (Sandoval & Millwood, 2005). In line with this, it was found that students in both the Bio-Tech and Control groups used fewer arguments in their responses to an arguable claim by the end of the school year. This decrease could be explained by the fact that the students were already familiar with the article presented in the pre-questionnaire and they refrained from deeply engaging in their writing arguments. Phillips and Norris (2009) argued that students need to learn the justificatory shape of argumentation, which is the line of arguments that are required to support a justified conclusion.

Explicit teaching of inquiry practices by teachers, such as critiquing and argumentation, are crucial for successful learning of these practices by the students (Driver et al., 2000; McNeill & Krajcik, 2007). Based on the class observations and analysis of formal documents and interviews with the program participants, it was concluded that no explicit teaching of critiquing is performed during the Bio-Tech program. The development of students’ critiquing ability is not one of the main program’s goals, and therefore teachers did not focus on this ability. The fact that neither the Bio-Tech nor the Control group students’ tendency to disagree or use more arguments in response to an arguable claim increased by the end of the school year indicates that teachers and program developers should put more emphasis on students’ argumentation and critiquing practices. Specific teacher training may provide opportunities to promote the teaching of argumentation and critiquing in classroom, as suggested by Osborne et al. (2004), and this should be considered by the Bio-Tech program developers.

8.1.3 Development of students' metalanguage of science

Teaching students the appropriate usage of scientific language is central for gaining scientific literacy (Lemke, 1990; Phillips & Norris, 2009). As claimed by Osborne (2002): "*the central goal of science education is to help students to use the language of science to construct and interpret meaning*" (p. 208). Norris and Phillips (1994) found that high school science majors were not adapted to proper usage of metalanguage of science terms. It is the responsibility of the teacher to provide students with opportunities to develop their scientific language, by practicing scientific writing, reading and argumentation (Lemke, 1990; Osborne, 2002). In line with this notion, this study shows that participation in the Bio-Tech program contributed to the students' scientific language mastery, as was observed by the improvement in their ability to use metalanguage of science terms in their questions and in their critiquing arguments.

The Bio-Tech students engaged in using the scientific language while performing the different inquiry stages: participating in whole class discussions, reading and discussing the APL articles, formulating their research questions, performing the experiments at the research institute, interacting with the researchers at the research institute, collecting and analyzing data, searching for more scientific literature, and writing their research portfolio. The Bio-Tech students learned how to use the scientific language while reading, writing and discussing the Bio-Tech issues, and while interacting with the class teacher, science educator, and young scientist instructor at the research institute. All of these activities provided the students with an appropriate environment to develop their understanding and mastery of the scientific language, as recommended by other science education researchers (Lemke, 1990; Phillips & Norris, 2009; Yore et al., 2003). These activities are also in correlation with the major communicative activities of science that are crucial for students' scientific literacy: writing science, talking science, reading science, representing scientific ideas and doing science (Osborne, 2014a), indicating that the Bio-Tech program may contribute to the development of students' scientific literacy.

8.2 Characterization of the Bio-Tech program’s inquiry level and authenticity

8.2.1 Gaps between the intended and implemented curricula

There is tension between the developers’ curricular intentions and goals and the curriculum implementation by the teachers in their classroom (Anderson & Helms, 2001; Goodlad et al., 1979). Science teachers are dependent on science curriculum materials in their lesson plans, and are usually able to assess and adapt them to be more inquiry-oriented (Forbes & Davis, 2010). In my research, some gaps were found between the intended and implemented Bio-Tech curricula, mostly in the initial stages of the program, where the intended curriculum was expected to reflect higher inquiry level and to support student independence while the implemented curriculum was found to be less open and was more teacher-centered. The later Bio-Tech stages were found to reflect high inquiry levels by both the intended and implemented curricula.

Arnold, Kremer, and Mayer (2014) found that high school students’ ability to design experiments were usually limited and required substantial amount of teacher support, mostly concerning the procedural knowledge and understanding. In line with their result, my research indicated that the implemented curriculum of the Bio-Tech program was less open and more teacher-directed in the early stages of planning the research. The gaps that were found between the intended and the implemented curricula in some of the inquiry features indicate that some changes in the Bio-Tech program are required, mostly concerning the initial program stages.

Several explanations could be offered to these findings. Teachers’ views and beliefs influence the implementation of the intended curriculum, as was found by Cronin-Jones (1991). Among the most influencing factors that Cronin-Jones identified, teachers’ views regarding the students’ learning and the teacher’s role in the classroom were the most prominent. Similarly, Crawford (2007) found that the influential factor on teachers’ abilities to teach inquiry was their personal believes and attitudes towards inquiry. McNeill et al. (2011) found that teachers’ beliefs about inquiry, as was manifested in their self-efficacy and beliefs about inquiry-based curriculum implementation, influenced their willingness to use inquiry-based teaching strategies and effected their students’ learning outcomes. In my research, the teacher who’s implemented curricula was investigated viewed his role as central and dominant during the formulating research questions lesson, and therefore it can be speculated that his views regarding the teacher's role in classroom contributed to the gap that was found between the initial inquiry stages of the intended and the implemented curricula.

8.2.2 Inquiry level of the Bio-Tech program

Previous studies have been calling for increasing the students' engagement, responsibility and involvement while practicing scientific inquiry (Barrow, 2006; Blanchard et al., 2010; Minner et al., 2010). One of the goals of inquiry teaching is to promote students' experience with high inquiry, in order to improve their scientific understanding and develop their inquiry practices (Zion et al., 2004). Carefully designed inquiry curriculum with minimal teacher guidance could support students' collaborative work, communication skills and learning of scientific practices (Patchen & Smithenry, 2013). Also, students' high order process skills can develop by experiencing open-ended inquiry laboratory tasks (Roth & Roychoudhury, 1993). However, there is much debate regarding the most appropriate inquiry level that should be experienced by students while performing scientific inquiry (Arnold et al., 2014; Blanchard et al., 2010; Hmelo-Silver et al., 2007; Kirschner et al., 2006), and regarding the most effective level that can support students' learning outcomes (McConney et al., 2014; Minner et al., 2010). In my research, the inquiry level of the Bio-Tech program was investigated by portraying the participants' views regarding the Bio-Tech program's inquiry level.

As presented in the theoretical framework, the inquiry level ranges from the lowest level of conformational inquiry, through structured inquiry and guided inquiry, and peaks at the highest level of inquiry, where students independently perform all the inquiry research stages (Blanchard et al., 2010; Germann et al., 1996; Zion & Sadeh, 2007). The Bio-Tech program reflected a rather unique inquiry level: while much emphasis was placed on students' independence and responsibility for choosing and formulating their own research question, the stage of planning the research and choosing the research tools and methods was less independent, mostly due to the research institute limitations. The students experienced independent inquiry again in the later stages of the program, while performing the experiments, collecting data, analyzing and interpreting their results, reaching conclusions and writing the research portfolio. Therefore, the Bio-Tech classes that were investigated in this research could be classified somewhere between guided to open inquiry, with some variations among the different classes. This indicates that the accepted model of inquiry levels (Germann et al., 1996; Sadeh & Zion, 2012), where the inquiry level starts at the later inquiry stages and progresses hierarchically toward the initial stage of asking the research questions, may not be appropriate for all inquiry-oriented programs.

The characterization of the Bio-Tech program revealed that each inquiry stage reflected different inquiry level, which was not depended on the other inquiry stages, suggesting that each inquiry feature reflects its own inquiry level, and that not all inquiry-oriented programs fit exactly into the common inquiry level model. Teachers and program developers should choose the most appropriate inquiry level for each stage according to their goals, experience and understanding of the program limitations. Most of the Bio-Tech students, teachers and developers of the program held positive views regarding the importance of practicing high inquiry levels, keeping in mind the program's limitations, such as the available time and appropriate tools and methods at the research institute. This is consistent with the results of Gillies and Nichols (2015), who reported that teachers had positive attitudes towards inquiry teaching but that they were also aware of the challenges and limitations and McConney et al. (2014) that found that 14 years old students, who reported experiencing high levels of inquiry-oriented activities in classroom, also expressed high motivation and interest in science.

In my research, most of the Bio-Tech students expressed their satisfaction from the Bio-Tech inquiry level and their independence during the program, and mentioned its contribution to their motivation and interest in the topic. They considered the stages of writing the research portfolio, performing the main experiment and asking the research questions as independent. Sadeh and Zion (2012), who investigated Israeli high school biology majors that experienced open or guided inquiry, reported that the open inquiry students were more satisfied from their independent inquiry, felt more involved, cooperated with their peers, and spent more time on the first stage of choosing their research question, while the guided inquiry students spent more time on documentation and writing the final research report. Similarly, the Bio-Tech program students held positive attitudes towards the high inquiry level of the program. However the Bio-Tech students also mentioned that unlike real scientists, they don't have enough independence in the program. Taken together, these results indicate that experiencing high level inquiry contributed to students' positive attitudes and motivation to perform scientific research.

The Bio-Tech participants emphasized the importance of high inquiry level, but mentioned that several Bio-Tech stages are more guided or closed. These findings resonance with previous studies, which suggest that support from the teachers is needed in order to achieve better understanding of the inquiry process by the students (Arnold et al., 2014; Furtak et al., 2012). Some of the Bio-Tech developers and young scientist instructors claimed that the inquiry level depends mostly on the individual teacher and his/ her approach to teaching inquiry in the Bio-Tech program. This is in line with Crawford (2007), who suggested that the teacher's attitudes towards inquiry are a critical factor influencing their inquiry teaching and therefore the inquiry level experienced by the students. These results indicate that the inquiry level of the Bio-Tech may increase with the appropriate teachers training and support that the teachers will be given in order to promote their students' inquiry learning in the program.

8.2.3 Authenticity of the Bio-Tech program

The challenge of bridging the gap between authentic 'real world' scientific inquiry and school inquiry activities had been one of the main goals of the science education community (National Research Council [NRC], 2000; Yarden & Carvalho, 2011). Students are expected to learn about the nature of science, develop their scientific habits of mind, and gain the cognitive processes knowledge that are required from scientific literate citizens and future scientists and engineers (Chinn & Malhotra, 2002; Schwartz et al., 2004). Chinn and Malhotra (2002) argued that common school inquiry tasks evoke reasoning processes that are epistemologically different from those used in authentic science. They suggest that inquiry tasks, developed by science researchers, usually include more features of authentic science. In order for students to gain full appreciation of authentic inquiry, they need to experience inquiry as a whole process and engage in practices such as producing, evaluating and communicating knowledge (Jimenez-Aleixandre & Fernandez-Lopez, 2010).

The results presented here demonstrate that the Bio-Tech program, which was developed by science educators and science researchers, capture some of the authentic scientific features, as viewed by the program participants. The Bio-Tech program aims to provide students with an authentic scientific experience which reflects the cognitive processes experienced by scientists. During the program, students learn and use highly-advanced scientific equipment, materials and methods used in the research institute laboratories. Hasson and Yarden (2012) found that increasing the students' knowledge and experience with laboratory methods and techniques improved their ability to formulate their own research questions while practicing authentic inquiry. In line with this notion, the Bio-Tech students learn about the specific research laboratory's materials and methods and perform experiments with them in the preliminary visit to the research institute. Only after the students are familiarized with the relevant tools and methods, they are expected to choose and formulate their research questions that will be investigated in the main experiments and plan their research. This separation between learning about the laboratory techniques and formulating the research questions may have contributed to students' understanding of scientific habits-of-mind and nature of science. Rahm, Miller, Hartley, and Moore (2003) suggested that authentic inquiry should be experienced as an emerged contextual learning by dynamic collaboration between students, teachers and scientists. The Bio-Tech program provides a collaborative environment that supports this notion, in which students are performing research side by side with their teacher, science educator and scientist instructor, to answer their own research questions.

The aspects of difference between authentic research and the Bio-Tech program that were mentioned by the participants should be addressed by the program developers in order to allow students to experience a more authentic scientific inquiry. This may require changes in the Bio-Tech curricula and teacher training in order to help the teachers in supporting the development of their students' knowledge and understanding of authentic scientific inquiry processes. McLaughlin and MacFadden (2014) suggested that teachers should experience more authentic scientific research in their training by working side by side with real scientists. This recommendation may also be adopted in the Bio-Tech program, meaning that the Bio-Tech teachers would spend more time in the specific research laboratories at the research institute during their training.

8.3 A shift from teaching inquiry to teaching of scientific practices

The recently published Next Generation Science Standards (NGSS) in the United States call for a shift from teaching science by inquiry to teaching scientific practices (Bybee, 2014; National Research Council [NRC], 2012; Osborne, 2014a). In line with this notion, the Bio-Tech program may be considered as a program that reflects both the teaching of inquiry and the teaching of scientific practices. Participation in the Bio-Tech program developed students' practices of asking questions and critiquing and supported their mastery of the scientific language while reflecting high inquiry level and authenticity. The Bio-Tech students engaged in cutting-edge authentic inquiry at the research institute, side by side with the scientists, performing investigations that may potentially produce new scientific knowledge (at least as far as the students perceived this process). Therefore, it is suggested that inquiry-oriented high school programs, such as the Bio-Tech, are appropriate for developing students' scientific practices while allowing meaningful learning experiences in authentic scientific environment. Nevertheless, this kind of cognitive and epistemic shift requires adjustments to the inquiry-oriented programs' goals, curricula, teacher training and available resources at the research institute.

Osborne (2014b) suggested that meaningful learning of scientific practices requires development of students' scientific reasoning abilities, based on psychological and philosophical learning theories (Klahr & Dunbar, 1988). Scientific reasoning could be achieved by allowing students to experience three distinctive activity processes: experimenting, hypothesis generation, and evidence evaluation. Experimenting activities include practical investigations and data collection in the material world. Much of the Bio-Tech program reflected experimenting activities, as observed in the intended and implemented curricula. The Bio-Tech students were engaged in investigating their research questions and collecting data from experiments. This was also emphasized by the program participants in their interviews. The Bio-Tech students were highly engaged in hypothesis generation activities as well: while they formulate their research questions, hypothesize, and develop explanations to their findings. However, the characterization of the Bio-Tech program did not clearly indicate that the students were engaged in evidence evaluation activities, since only several of their critiquing abilities improved and no explicit teaching of critiquing, modeling or argumentation was observed in the examined classes or mentioned by the participants in the interviews. Moreover, when considering the Bio-Tech participants' views regarding the program's inquiry level and authenticity, most of them focused only on the experimenting activities and not on hypothesis generation or evidence evaluation activities. Altogether, it is suggested that the Bio-Tech may be considered as an inquiry-oriented program appropriate for developing students' reasoning. However, some additional activities should be integrated in the program in order to further support the students' reasoning, critiquing and argumentation practices.

8.4 Research limitations

This study focused on the teaching and learning of inquiry in one inquiry-oriented program for 11th grade biotechnology majors. The main limitation, therefore, is the ability to extend the conclusions to other inquiry-oriented programs and other grades. It is hypothesized that similar results would be expected from other high school students participating in inquiry programs, providing that those programs allow the students to experience meaningful, independent, and authentic inquiry. As reported in other studies, inquiry teaching in K-12 classes may improve students' procedural understanding and content learning (Furtak et al., 2012; Minner et al., 2010). Zion and Sadeh (2007) found that Israeli high school biology majors who participated in another inquiry-oriented program, the 'Bio-Da', also developed their inquiry level and scientific practices. Therefore, this research provides further evidence for the positive effect of inquiry-based teaching on students' learning, and indicates that other K-12 students may develop their scientific practices while participating in inquiry-oriented programs.

Another limitation concerns the examination of the formulating research questions process. This research focused only on two exemplary Bio-Tech teachers and their classes. However, it is believed that these teachers represent typical cases and other Bio-Tech teachers are aligned somewhere among these two teachers in their communicative approach and chosen lesson structures. Further research is required in order to gain a broader view of the teaching and learning of formulating research questions in inquiry-oriented programs. Further investigation of students' performance during peer-critique activities is also needed, together with a more detailed examination of students' suggested research questions and how they are transferred into practical investigations performed by the students during the program.

Also, no in-depth examination of the teaching of critiquing in the Bio-Tech program was performed. This is due to the fact that critiquing was not explicitly taught in any of the examined lessons, as was further supported by the participants in their interviews. Altogether, this research serves as a proof-of-concept study, indicating that participation in an inquiry-oriented program may develop students' scientific practices and reflect high inquiry level and authenticity. Further research is required in order to gain full appreciation of the development of students' scientific practices during participation in inquiry-oriented programs.

8.5 Research implications

Teachers, program developers, and policy makers should consider promoting inquiry-oriented programs for high school students, such as the Bio-Tech, as a platform for developing students' scientific practices by allowing them to experience authentic scientific inquiry. Experiencing high inquiry level may contribute to the development of students' learning of the scientific practices, increase their understanding of the scientific process, and improve their mastery of the scientific language. These recommendations are in line with those suggested by the recent NRC frameworks (National Research Council [NRC], 2000, 2012). Program developers and policy makers may benefit from these recommendations and should consider implementing them in order to promote inquiry and scientific practices teaching in formal and informal educational environments. This may also benefit professional development and teacher training practitioners aiming to promote inquiry and scientific practices teaching in classrooms.

8.5.1 Recommendation for inquiry-oriented programs practitioners

In light of the research conclusions, several adjustments to the Bio-Tech curricula, teacher training and classroom practice are suggested in order to support and promote the Bio-Tech program's inquiry and scientific practices teaching:

- The Bio-Tech students should be given enough time and support while formulating their research questions. The Bio-Tech teachers should promote their students' creative thinking, independence, and ownership during this process, but also explain that their questions need to be appropriate to the Bio-Tech program and its limitations.

- The Bio-Tech teachers should implement a student-centered, interactive and dialogic classroom discourse while teaching the Bio-Tech program as a meaningful strategy to support their students' learning of the scientific language, to develop their students' communicative abilities, and to increase their students' engagement, motivation and interest in the inquiry process.
- The Bio-Tech teachers should explicitly teach about critiquing and emphasize its crucial role in the inquiry process, and the Bio-Tech students should be provided with opportunities to experience critiquing. This will require some adjustments to the Bio-Tech curricula. One such opportunity could be by introducing peer-critique activities, like the one described in this research.
- Additional research tools and methods should be available at the research institute, appropriate to the Bio-Tech program. Both the teachers and students should be trained in implementing these tools in their research. This would allow the students to experience more independence in choosing their research questions and promote their ability to plan their research.
- The Bio-Tech students' should be more engaged in the process of planning the research at the research institute. This will require some adjustments to the Bio-Tech curricula, focusing on this process during the teacher training, and allocating more time in the classrooms to allow the students to perform this process. This should increase the students' engagement in the inquiry process, promote their ownership and independence, and prevent the students' confusion and stress feeling when performing the main experiments in the research institute, which was reported by some of the students and teachers.
- The Bio-Tech teachers training should include more opportunities for the teachers to experience authentic scientific research in the laboratories at the research institute in order to promote their knowledge and understanding of inquiry and scientific practices. This should support their inquiry and scientific practices teaching in the classrooms.

8.5.2 Implementation of the I-MAP tool

The I-MAP tool, developed by the Science Teaching Department's 'inquiry forum' at the Weizmann Institute of Science, was successfully implemented in this research. It was found to be appropriate for revealing gaps between the intended and implemented curricula, providing a graphically illustrated description of the intended and implemented Bio-Tech curricula. The I-MAP activity also provided the teachers with an opportunity to reflect on their teaching, helped them to communicate their views and goals of the program, and encouraged them to evaluate their teaching in the program. This indicates that the I-MAP tool is a suitable instrument for characterizing inquiry-oriented programs. Using the I-MAP tool could be implemented in other inquiry-oriented programs for purposes such as exposing participants' views regarding the inquiry process, evaluating programs and activities inquiry levels, and examining inquiry-oriented programs' curricula. It may also be used in other disciplinary domains and in a wider range of students' ages.

Publications from this thesis

Bielik T., and Yarden A. (2013). *Development of the Ability to Critique in the Course of Inquiry-Oriented Program in Biology*. In D. Kruger, and M. Ekborg (Eds.), Proceedings of the 9th Conference of European Researchers in Didactics of Biology, Berlin, Germany, 135-148 (Appendix 7).

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Bielik T., and Yarden A. (2014). *Characterizing the Development of Students' Ability to Ask Questions and to Critique in a Biotechnology Inquiry-Oriented Program***.** Proceedings of the 10th Conference of European Researchers in Didactics of Biology, Haifa, Israel (submitted).

Bielik T., and Yarden A. *Promoting the Practice of Asking Research Questions in a High School Biotechnology Inquiry-Oriented Program* (in preparation).

Bielik T., Machluf Y., and Yarden A. *Bringing Contemporary Authentic Scientific Research into a Biotechnology Curriculum Through a Novel Teaching Model* (in preparation).

Bielik T., Schwartz Y., and Yarden A. *Inquiry-based Teaching and Learning Mapping Tool (I-MAP): Implications for Research and Teacher Development* (in preparation).

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Appendices

Appendix 1- Bio-Tech students’ pre- and post-questionnaires

קראו את המאמר המצורף ולאחר מכן ענו על שאלות 1-10

צעצועי פלסטיק רכים לתינוקות יכולים להיות רעילים
המדען החדש, ארה"ב, 1997

חנויות בדנמרק, שבדיה, איטליה וספרד מורידות צעצועי פלסטיק רכים לתינוקות מהמדפים לאחר שמדענים מדנמרק גילו שחלק מהם משחררים כמויות גדולות של רעלנים (טוקסינים) הנקראים פְּטַלָאטִים. בדנמרק קוראים להגביל את השימוש בפְּטַלָאטִים ובכימיקלים אחרים בצעצועים בכל מדינות האיחוד האירופי.

פְּטַלָאטִים מוספים למוצרים כדי לרכך את הפלסטיק. הפְּטַלָאטִים בהם משתמשים בטבעות לעיסה דווחו בעבר כמסוכנים לכבד ולמערכת הרבייה ויכולים לגרום סרטן. הסוכנות הדנית להגנת הסביבה (דפ"ה) חקרה 11 סוגים של טבעות לעיסה המיוצרות בחברות שונות- צעצועי פלסטיק רכים הניתנים לתינוקות כדי להקל על הכאב משיניהם הבוקעות. נמצא כי שלוש מהטבעות, שיוצרו על ידי חברת 'צ'יקו', אחת מיצרניות צעצועי ומוצרי ילדים הגדולות בעולם, שיחררו כמויות גדולות של פְּטַלָאטִים כאשר עורבבו בתוך רוק מלאכותי במשך שלוש שעות.

ליסבט סידורף, ראש המחלקה לכימיקלים בדפ"ה, דיווח שטבעת לעיסה רכה בטעם וניל של צ'יקו שיחררה 2219 מיקרוגרם של פְּטַלָאטִים לאחר שלוש שעות. כמות זו גדולה פי 44 מהכמות המרבית המותרת במזון לפי חוקי האיחוד האירופי. טבעת הלעיסה השנייה שיחררה 1044 מיקרוגרם פְּטַלָאטִים לאחר שהושרתה ברוק המלאכותי במשך שלוש שעות. טבעת הלעיסה השלישית שיחררה רק 9 מיקרוגרם, אך דפ"ה עדין ממליצים שהיא תצא מהשוק, בגלל שלעיסתו של התינוק יכולה ללחוץ החוצה יותר פְּטַלָאטִים מאשר יכולים לשחרר המנערים (שייקרים) בהם השתמשו בבדיקות.

חנויות בדנמרק ובשבדיה הסכימו להוריד את טבעות הלעיסה מהמדפים בסוף מאי. בנוסף, נשלחו 75 צעצועי פלסטיק רכים נוספים לבדיקת פְּטַלָאטִים. החודש, חנויות באיטליה ובספרד הורידו את טבעות הלעיסה של צ'יקו מהמדפים, אך הן נמכרות במקומות אחרים, היות וצ'יקו לא הוציאה אותם מהשוק. תגובת החברה לא הושגה.

בשבוע שעבר, התאחדות תעשיות הצעצועים האירופיות הקימה ועדת חירום לבדיקת המחקר שנערך בדנמרק. "נראה אם נסכים עם הדרך שבה הבדיקות נעשו", אומר ראש ההתאחדות. "אנו תוהים אם צריך ליישם הגבלה חוקית שנועדה במקורה למזון על צעצועים."

סידורף טוען שהבעיה העיקרית היא שתקנות האיחוד האירופי לגבי בטיחות צעצועים מגבילות את השחרור של מתכות כבדות אך לא קובעות סטנדרטים לכימיקלים אחרים. דנמרק ושבדיה לוחצות לשינוי התקנות. המחקר שנערך בדנמרק נשלח לועדות הייעוץ המדעיות של האיחוד האירופי אשר צפויות להציע מגבלות לשחרור כימיקלים ע"י צעצועים בהמשך שנה זו.

שאלון לתלמיד

שם התלמיד ___________________________________

1. מהי שאלת המחקר שנבדקה בניסוי המתואר בכתבה?

___

2. מהי השערת המחקר?

___

3. מה היה הניסוי אותו ביצעו החוקרים לבדיקת שאלת המחקר?

___

4. מהן תוצאות הניסוי המתואר בכתבה?

___

5. מהן מסקנות המחקר?

___

6. רשמו לפחות שתי שאלות מדעיות חדשות העולות אצלכם בעקבות קריאת הכתבה.

___

7. כיצד הייתם עונים על השאלות שהעליתם בצורה מדעית?

___

8. תלמיד שקרא את הכתבה טען כי הכתבה *מוכיחה* שטבעות לעיסה מסוכנות לתינוקות. האם אתם מסכימים או חולקים על התלמיד? מדוע?

___

במידה והסכמתם עם התלמיד בשאלה 8 ענו על שאלה 9.

במידה וחלקתם על התלמיד בשאלה 8 ענו על שאלה 10.

9. אילו טיעונים הייתם מציגים כנגד טענת התלמיד?

___

___

10. אילו טיעונים הייתם מציגים לתמיכה בטענת התלמיד?

___

___

Appendix 2- Peer-critique activity designed for formulating research questions lesson in the Bio-Tech program

פעילות העלאת שאלות חקר וביקורת עמיתים

שמות התלמידים בקבוצה:______________________________

1. כתבו לפחות שלוש שאלות חקר המעניינות אתכם ומתאימות לתוכנית הביוטק.

2. בחרו שאלה אחת מהשאלות שכתבתם ונסחו אותה בתור שאלת חקר מפורטת לפי הקריטריונים שלמדתם.

העבירו את הדף שכתבתם לקבוצה אחרת

3. ביקורת עמיתים- קראו את שאלת החקר הרשומה בסעיף 2 וענו על השאלות הבאות:

א. שמות התלמידים המבקרים:______________________________

ב. האם השאלה מתאימה לתוכנית הביוטק? מדוע?

ג. האם השאלה עומדת בכל הקריטריונים של שאלת חקר שלמדתם? פרטו.

ד. הציעו נוסח מתוקן של שאלת החקר.

החזירו את הדף לקבוצה ממנה קיבלתם אותו

4. האם אתם מסכימים עם ההערות שקיבלתם מעמיתיכם? פרטו.

5. כתבו את הנוסח הסופי של שאלת החקר שבחרתם, העתיקו את השאלה למחברתכם והגישו את הטופס למורה.

Appendix 3- Interview questions for the Bio-Tech students

1. תארו את שלבי תוכנית הביוטק שעברתם.
2. באילו מהשלבים של תוכנית הביוטק אתם חושבים שהייתה לכם רמת עצמאות וחופש פעולה גבוהים או נמוכים? האם זה היה יעיל? מה הייתה מעורבותו של המורה בשלבים אלה?
3. מהי השאלה המדעית אותה חקרתם בביוטק? כיצד הגעתם לשאלה זו? מדוע בחרתם בה?
4. מהי ההשערה שלכם בנוגע לשאלת החקר? על סמך מה אתם מבססים אותה?
5. מהו מהלך הניסוי אותו אתם מתכננים לבצע\ ביצעתם על מנת לענות על שאלת החקר?
6. מה היו תוצאות הניסוי שערכתם?
7. מהן המסקנות אליהן הגעתם? על סמך מה קבעתם אותן? האם הן מתאימות לרקע המדעי שלמדתם?
8. האם השערתכם התאימה לתוצאות הניסוי? אם לא, האם תוכלו לנסח השערה חדשה? (בראיון הסיום)
9. אילו שאלות חקר נוספות או הצעות לניסויים חדשים תוכלו להציע בעקבות המחקר שביצעתם?
10. האם הצגתם את מסקנותיכם בפני המורה, תלמידים אחרים בכיתה או במסגרת אחרת? באיזו דרך?
11. מהם לדעתכם שלבי החקר המדעי של המדען החוקר בתחום המדעים?
12. האם אתם חושבים שאתם עוברים\ עברתם שלבים דומים לשלבי החקר המדעי של המדען במהלך ההשתתפות בתוכנית הביוטק? אם כן, פרטו באילו שלבים מדובר.
13. איזה ידע חדש רכשתם במהלך ההשתתפות בתוכנית הביוטק? האם רכשתם מיומנויות חקר חדשות? האם יש מיומנויות שלא למדתם או תרגלתם מספיק שהייתם רוצים לשפר?
14. האם אתם חושבים שתמשיכו בקריירה בתחום המדעים והמחקר? מדוע?

Appendix 4- Interview questions for the Bio-Tech program teachers, developers, and young scientist instructors

1. תארו את התהליך אותו עוברים התלמידים במהלך ההשתתפות בתוכנית הביוטק.
2. מהם היתרונות והחסרונות העיקריים של תוכנית הביוטק?
3. במה שונה תוכנית הביוטק מתוכניות חקר אחרות?
4. האם תלמיד שעבר את כל שלבי תוכנית הביוטק רוכש הבנה של תהליך החקר המדעי ושליטה במיומנויות חקר?
5. האם במהלך עבודתכם עם התלמידים אתם נותנים להם את האפשרות לשאול שאלות חקר? במידה וכן, מה הדרכים בהן אתם נוקטים כדי להנחות את התלמידים בהעלאת שאלת חקר מתאימה? איזה סוג שאלות התלמידים מעלים?

5. האם תוכנית הביוטק משקפת לדעתכם חקר מדעי אותנטי?

6. האם תוכנית הביוטק הינה לדעתכם תוכנית חקר פתוחה בעלת דרגת עצמאות גבוהה של התלמידים?

Appendix 5- Observation sheet for the Bio-Tech classes

דף תצפית לשיעור

תאריך:____________ שעה:__________
מורה:______________ כיתה:________________ נושא:_____________________
מהלך השיעור:

התייחסות למאפייני החקר (שאלות, הוכחות, הסברים, קישור לידע קיים, תקשורת):

הערות \ שאלות תלמידים:

הערות \ שאלות מורה:

נקודות נוספות:

Appendix 6- I-MAP tool as presented to the Bio-Tech teachers

רמת חקר ומעורבות המורה בתוכניות חקר

נתחו את תוכנית החקר בעזרת המאפיינים שבטבלה א'. לגבי כל מאפיין, סמנו אם הוא קיים בפעילות, ובמידה והוא קיים סמנו לאיזו רמת חקר הוא מתאים (סגור, מודרך או עצמאי) ומהי רמת מעורבות המורה (לפי המקרא בטבלה ב').

טבלה א'- רמת החקר ומעורבות המורה במאפייני החקר.

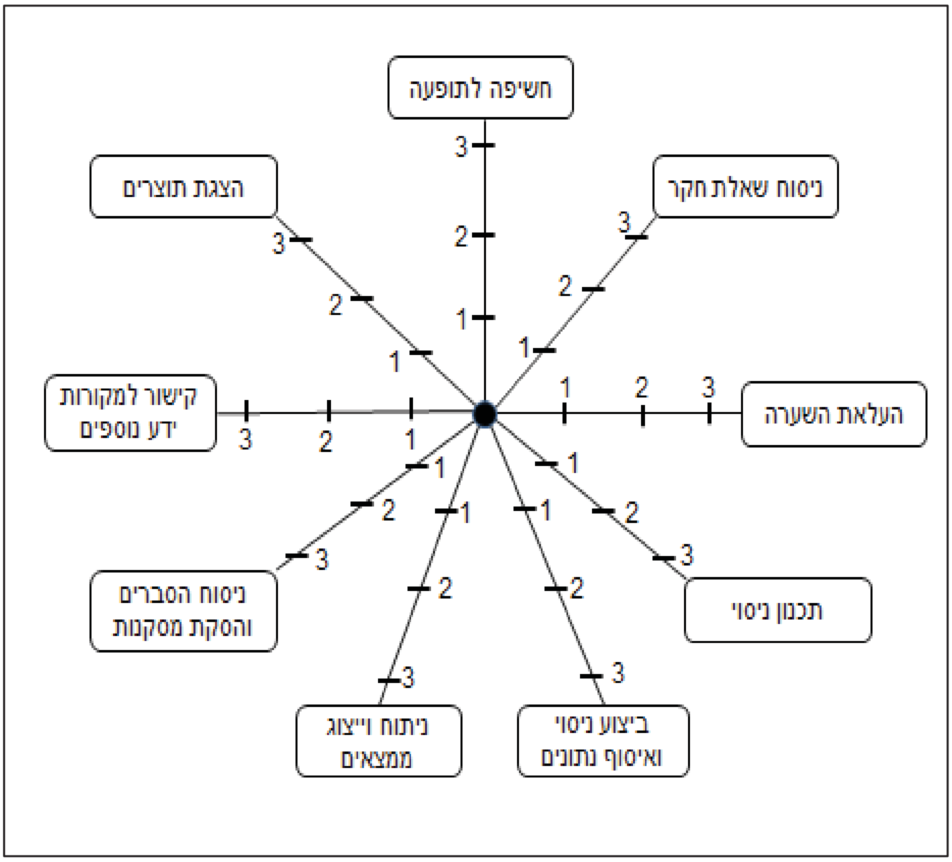
מאפיין החקר	**המרכיב קיים בפעילות?**	**1 חקר סגור**	**2 חקר מודרך**	**3 חקר עצמאי**	**רמת מעורבות המורה**
1. חשיפה לתופעה	כן \ לא	התלמיד נחשף לתופעה שהוגדרה על ידי המורה	התלמיד בוחר תופעה מאוסף תופעות	התלמיד בוחר בתופעה אותה מצא באופן עצמאי	נ \ ב \ ג
2. ניסוח שאלת חקר	כן \ לא	התלמיד עוסק בשאלה שניתנה על ידי המורה	התלמיד בוחר שאלה מתוך אוסף שאלות או מונחה לניסוח שאלה	התלמיד מנסח בעצמו את השאלה	נ \ ב \ ג
3. העלאת השערה	כן \ לא	התלמיד בוחן השערה שניתנה על ידי המורה	התלמיד מונחה להעלות השערה מתוך אוסף השערות או לחדד השערה נתונה	התלמיד מעלה השערה באופן עצמאי	נ \ ב \ ג
4. תכנון ניסוי	כן \ לא	התלמיד מנתח ניסוי המתוכנן על ידי המורה	התלמיד מונחה לתכנן ניסוי בכלים נתונים ובשיטות נתונות	התלמיד מתכנן ניסוי באופן עצמאי	נ \ ב \ ג
5. ביצוע ניסוי ואיסוף נתונים	כן \ לא	התלמיד בוחן מידע שניתן על ידי המורה	התלמיד מכוון לאסוף מידע מוגדר	התלמיד אוסף מידע באופן עצמאי	נ \ ב \ ג
6. ניתוח וייצוג ממצאים	כן \ לא	התלמיד מייצג מידע שקיבל מהמורה	התלמיד מודרך לניתוח וייצוג מידע	התלמיד מנתח מידע ומציג אותו באופן עצמאי	נ \ ב \ ג
7. ניסוח הסברים והצדקת מסקנות	כן \ לא	התלמיד מתמודד עם הסבר הניתן על ידי המורה	התלמיד מונחה בתהליך של ניסוח הסבר ומסקנה המבוססים על המידע	התלמיד מנסח הסבר המבוסס על המידע ומצדיק את מסקנותיו	נ \ ב \ ג
8. קישור למקורות ידע נוספים	כן \ לא	התלמיד מקשר למקור ידע הניתן על ידי המורה	התלמיד מונחה על ידי המורה למספר מקורות ידע רלוונטיים	התלמיד מקשר באופן עצמאי למקורות ידע נוספים	נ \ ב \ ג
9. הצגת תוצרים (מצגת, עבודה כתובה, פוסטר וכו')	כן \ לא	התלמיד מודרך כיצד להכין ולהציג את התוצרים	התלמיד בוחר מבין מספר דרכים להצגת תוצריו	התלמיד מכין ומציג את התוצרים באופן עצמאי	נ \ ב \ ג

טבלה ב'- רמת מעורבות המורה בתוכנית החקר

רמת מעורבות מורה	הסבר
נ- נמוכה	המורה לא מעורב כלל בעבודת התלמיד או רק בודק את התקדמותו ומאשר את המשך העבודה.
ב- בינונית	המורה מעורב בצורה חלקית ומוגבלת, משיב לשאלות התלמידים ומכוון אותם.
ג- גבוהה	המורה מעורב בצורה פעילה ומרכזית, מכוון את הדיון עם התלמידים.

על סמך טבלה א' שמילאתם, מלאו את כוכב החקר בעזרת המדבקות הצבעוניות, כאשר מיקום המדבקה לאורך זרוע המאפיין מייצגת את רמת החקר (0=הלא קיים, 1=סגור, 2=מודרך, 3=עצמאי) וצבע המדבקה מייצג את רמת מעורבות המורה (אדום=גבוהה, צהוב=בינונית, ירוק=גבוהה).
כמו כן, סמנו בחצים את הרצף הכרונולוגי של ביצוע המאפיינים השונים במהלך תוכנית החקר

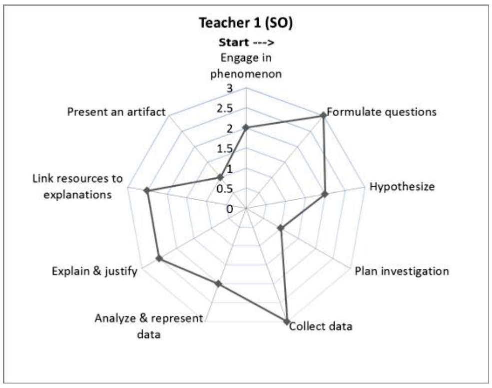
כוכב החקר

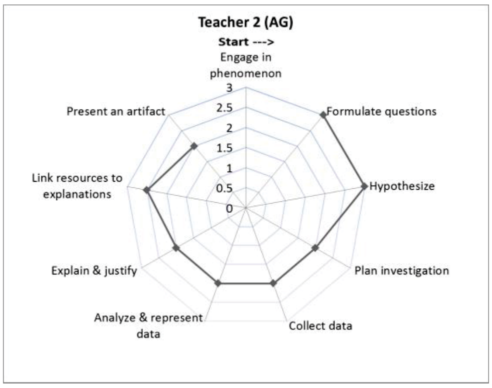


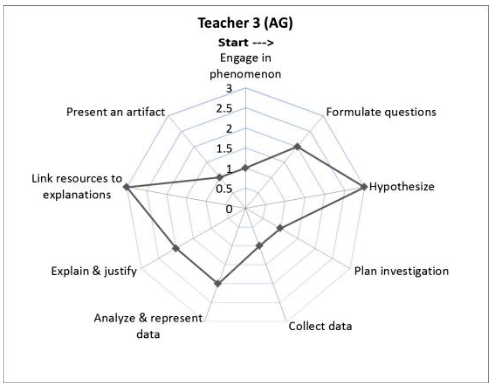
Appendix 7- Bielik T., and Yarden A. (2013). Development of the Ability to Critique in the Course of Inquiry-Oriented Program in Biology

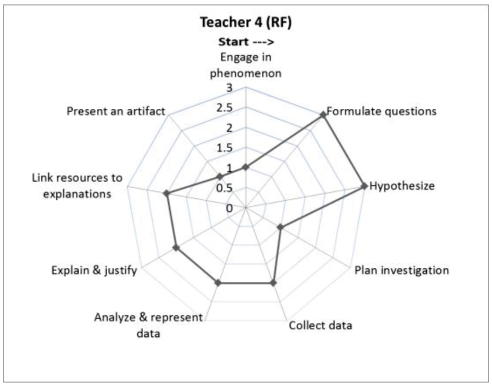
In D. Kruger, and M. Ekborg (Eds.), Proceedings of the 9th Conference of European Researchers in Didactics of Biology, Berlin, Germany, 2013 (Attached documen

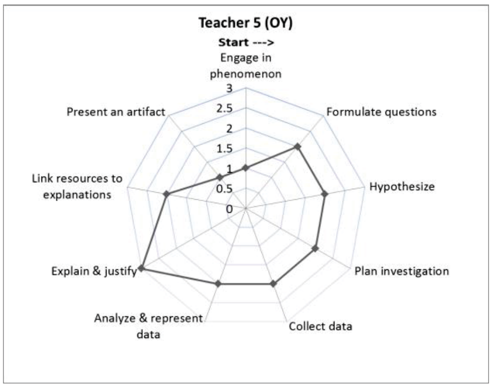
Appendix 8- Bio-Tech teachers I-MAP stars

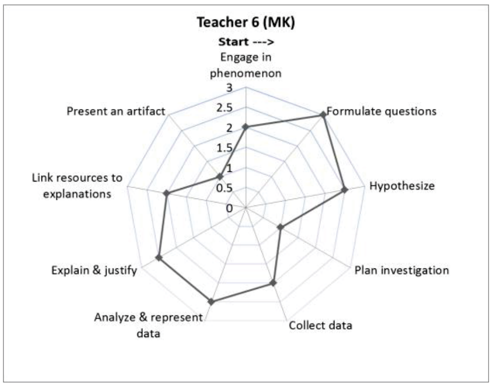


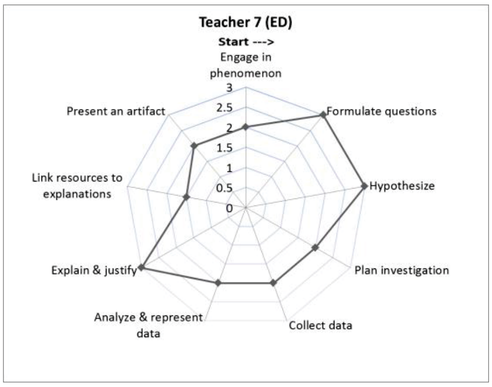


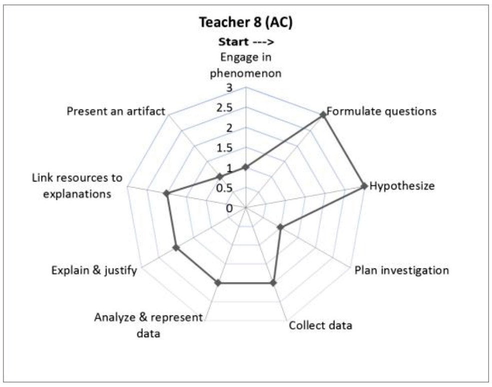


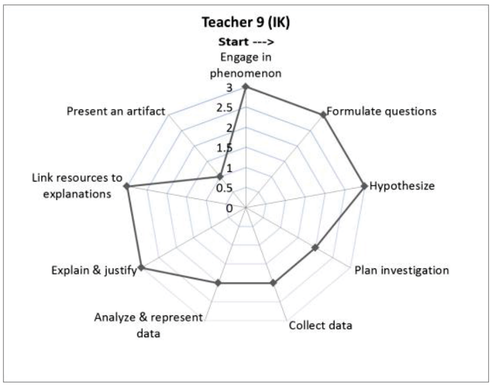








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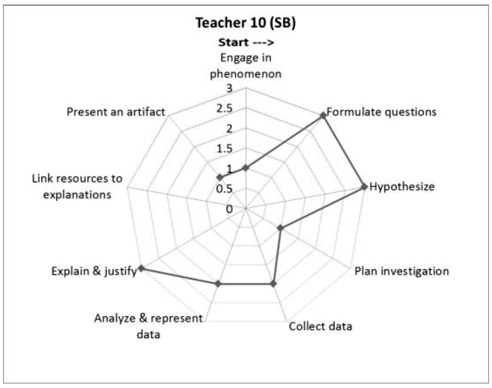
Formulate questions
Hypothesize
Plan investigation
Collect data
Analyze & represent data
Explain & justify
Link resources to explanations
Present an artifact


Teacher 10 (SB)
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Formulate questions
Hypothesize
Plan investigation
Collect data
Analyze & represent data
Explain & justify
Link resources to explanations
Present an artifact

9

DEVELOPING THE ABILITY TO CRITIQUE IN THE COURSE OF INQUIRY-ORIENTED PROGRAMS IN BIOLOGY

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Abstract

Authentic scientific practices are designed to facilitate students' understanding of how scientific knowledge develops, including the ability to critique, which constitutes an important part of scientific inquiry. Students should be able to identify potential weaknesses and flaws in scientific claims, articulate the merits and limitations of peer views and read media reports in a critical manner. Even though the importance of incorporating critique in science education classrooms is well accepted and emphasized by the science education research community, much debate still remains regarding how this practice should be taught. We set out to explore the contribution of an inquiry-oriented program for high-school students which emphasizes critiquing. Pre- and post-questionnaires were administered to students participating in an inquiry-oriented program (Bio-Tech), and to students who were not participating in the program. Students of both groups tended to be more in agreement with an arguable claim presented to them in the post-questionnaires compared to the pre-questionnaires. However, the Bio-Tech students tended to use more arguments and focused more on the experimental process described to them than the Control group students. These results indicate that students can develop some critiquing abilities in the context of an inquiry-oriented program in biology.

Keywords: Inquiry; Critique; Scientific practice; Authenticity; Argumentation

1. Introduction

Most recent policy documents present the ongoing call for successful implementation of authentic scientific practices in science classrooms (European Commission, 2007; National Research Council [NRC], 2000, 2012). The ability to practice inquiry requires that students not only learn the traditional process skills, but also combine them with scientific knowledge, reasoning and the ability to critique. Authentic scientific practices include not only skills but also specific knowledge required for investigating and building models and theories about the natural world (National Research Council [NRC], 2012). Much emphasis is directed to the social and cognitive aspects of the scientific process: the communication, argumentation and model-generating practices. Authentic scientific practices are designed to facilitate students' understanding of how scientific knowledge develops, and of 'scientific habits-of-mind' and engagement in scientific inquiry (National Research Council [NRC], 2012; Osborne, 2010).

The ability to critique is generally defined as "reasonable reflective thinking that is focused on deciding what to believe or do" (Ennis, 1987). The ability to critique makes up an important part of scientific inquiry and consists of overlapping skills and abilities, such as testing hypotheses, designing experiments and drawing conclusions from results (Berland & Reiser, 2009; Ford, 2008). Students should be able to identify possible weaknesses and flaws in scientific claims, articulate the merits and limitations of peer views and read media reports in a critical manner (National Research Council [NRC], 2012). The ability to critique is crucial for productive participation in scientific practice and discourse (National Research Council [NRC], 2007). Berland and Reiser (2011) considered critiquing to be a key part of the goals of sense-making and persuasion in scientific argumentation.

Critiquing is strongly connected to the practice of argumentation, which is one of the central goals of science education and the focus of several recent articles and policy documents (Berland & McNeill, 2010; National Research Council [NRC], 2007, 2012; Osborne, 2010). Argumentation is connected to other scientific skills and abilities, such as reasoning, critical and logical thinking, language skills, communication and justification. An argument is defined as an assertion or conclusion with justification, reasons and support (Osborne et al., 2004). Ford (2008) reported that scientists are more likely to have less confidence in a given scientific claim and that their critique mostly concerns the methods used to collect the data and the analysis and evaluation of the results. Non-scientists, on the other hand, are more likely to accept the given scientific claims and relate their reasoning arguments mostly to their personal experiences. In a more recent work, Ford (2012) claimed that constructing and critiquing arguments are fundamental parts of scientific sense-making during engagement in scientific discourse.

Even though the importance of incorporating critique in science education classrooms is well accepted and emphasized by the science education research community, much debate still remains on how this practice should be taught. Osborne (2010) argued that students in contemporary classrooms lack the opportunity to develop and master their abilities to reason out and critique scientific claims. It was suggested that students rarely have opportunities to be engaged in critiquing and in scientific argumentation because traditional approaches to science instruction do not promote or support student engagement in scientific argumentation (Sampson & Clark, 2011). Others indicated that students, in general, lack the abilities to construct and present arguments and are poor at addressing different points of view regarding learned scientific issues. It was claimed that more activities are needed to develop these abilities in the classroom, mainly by restructuring current science lessons (Berland & Reiser, 2011; Driver et al., 2000).

Appropriate means of incorporating critique in science classrooms remain to be clarified and explored. There is a need to characterize the development of critiquing ability among students in science classrooms and to explore possible activities which can engage students in this activity. Here we suggest that inquiry-oriented scientific programs are adequate as a platform for developing students' ability to critique, providing the appropriate support to teachers and the scientific environment.

In this study, we explore the contribution of an inquiry-oriented program for high-school students which emphasizes critique. Our aim is to characterize and evaluate possible changes in students' arguments in response to an arguable claim made by a hypothetical student, focusing on their tendency to agree or disagree with the claim, the number of arguments they use in their answer in response to the claim, the categories of arguments they use and their qualitative characteristics. Our research question is whether participation in an inquiry-oriented program improves high-school biotechnology majors' ability to critique. In order to answer this question, we set to examine whether students who participate in the inquiry-oriented program tend to be in agreement with peer claims, do they use more arguments in response to peer claims and whether they focus their arguments more on the experimental process, methods or chain of inferences.

2. Research design and method

This research was designed to evaluate and characterize possible changes in students' ability to critique following their participation in an inquiry-oriented program in biology termed Bio-Tech program. Pre- and post-questionnaires were administered to 11th-grade biotechnology majors who were either participating or not participating in the Bio-Tech program. The questionnaires included a scientific article and a deliberately arguable hypothetical student's claim.

2.1 Research context

The Bio-Tech program at the Weizmann Institute of Science (hereon referred to as 'the Bio-Tech program') is an optional part (1 credit out of a total of 5 credits) of the Israeli matriculation examinations for biotechnology majors during the 11th grade (Israeli Ministry of Education, 2005). It is based on a visit to a biotechnology laboratory in an industrial or academic facility. The Weizmann Institute began supporting the Bio-Tech program in 2009 and the current research was carried out during the 2011/12 academic year. The Bio-Tech program design originates from the Teacher-Led Outreach Laboratory (TLOL) program that is practiced at the Weizmann Institute (Stolarsky Ben-Nun & Yarden, 2009).

The Bio-Tech program is unique and innovative in the following aspects: the inquiry-based approach allows students to practice high levels of open inquiry, a co-teaching approach is implemented (teaching is performed by the class teacher, a research scientist, and a science educator), and the topic of inquiry is learned using the Adapted Primary Literature (APL) approach with an adapted scientific article. This allows the students to learn up-to-date scientific concepts, practice technologically advanced methods and tools and experience a firsthand encounter with authentic science (Yarden et al., 2001).

The investigated biological systems range from the molecular and genetic level, including proteins and organelles, to the living organism level of bacteria, fungi, yeast, and tissue-cultured cells. Currently, six research groups from the Weizmann Institute and from the Robert H. Smith Faculty of Agriculture, Food and Environment of the Hebrew University are taking part in the Bio-Tech program. The techniques used in this program range from simple observational methods (such as bacterial colony growth on plates, color changes in medium, microscope observation) to the use of highly advanced tools and equipment (such as spectrophotometer, PCR, fluorescence microscope). The protocols are specially designed and adapted to fit the students' cognitive abilities and the time constraints of the program.

The Bio-Tech program is carried out during an entire academic school year. It is comprised of learning the background knowledge using an APL article, a preliminary visit to the research institute where students visit the particular laboratory related to their specific project and perform a series of short experiments in which they acquire key concepts and techniques related to the specific inquiry project, formulating the research questions and planning the main experiments in dyads back in the classroom, performing the experiment in a two days main visit to the research institute and analyze their findings and prepare their research portfolio in a 2-5 months long process back in school with the assistance of the teacher. The final grade of each student is determined based on an oral examination which takes place around the end of the school year, conducted by an external examiner (a biotechnology teacher from another school) and the class teacher.

In the Bio-Tech program, much emphasis is explicitly directed to developing the students' ability to critique and articulate their own knowledge and claims. At the beginning of the program, when students study the APL paper, they are engaged in classroom discussions, led by the teacher, in which they are confronted with the scientific knowledge together with the reasons for using the specific scientific methods and tools. They are expected to understand the scientific content and process by the time they arrive at the research laboratory for their preliminary visit. When formulating their research question and planning the experiment, students are actively engaged in communicating with their peers and their teacher. They learn how to defend and explain their research question and are expected to master all stages of the planned experimental process. During their discussions with the teacher, the scientist and the science educator, students are frequently required to justify what they do, to demonstrate their understanding of the research and to explain their results and analysis. Although this process is long and sometimes frustrating for the students, the class instructors are well trained and experienced in providing adequate support and guidance for the students. In the final part of the program, students write a scientific report in the form of a research article, which is a major part of the research portfolio. In the oral examination, the student is expected to defend his/her work and justify its conclusions, as well as present both content and procedural understanding. Taken together, during the Bio-Tech program, students are given numerous opportunities to develop their ability to critique.

Some specific activities, designed for developing the Bio-Tech students' peer-critique and critique abilities, were incorporated into the program. For example, when dyads of students are working on formulating their research question and hypothesis, they are requested to choose among several research questions that they generate and to present the chosen question to another dyad. The other dyad is expected to review and critique the question according to the teachers' instructions. Following this activity, the original dyad receives their peer-reviewed question and asked to relate and consider the comments and to formulate their final research question to be presented to the teacher for further review and approval

2.2 Population

The research population was comprised of 11th-grade biotechnology majors (16-17 years old). Four classes participating in the Bio-Tech program (the Bio-Tech group) and four classes not participating in this or in any other inquiry-oriented program (the Control group) were chosen. In total, 73 students from the Bio-Tech group and 58 students from the Control group filled in both pre- and post-questionnaires.

2.3 Tools

Pre- and post-questionnaires were designed to investigate students' identification of authentic scientific practices in a popular scientific article ('Alarm sounds over toxic teething rings', The New Scientist, July 14, 1997). After reading the article, students were given an arguable statement from a hypothetical student claiming a specific conclusion regarding the article ("This article *proves* that teething rings hurt babies" emphasis in original). This method was based on the previously published work of Ford (2012).

The article discusses the biological health issue of toxins released from babies' teething rings and its implications on their health. In the article, an experiment that was performed is presented, describing the methods and obtained results. After reading the article, students were asked to answer several open-ended questions designed to evaluate their understanding of the inquiry process presented in the article and to explore their question-asking practice. In one of the questions, students were given the hypothetical student's arguable claim (see above) and asked if they agree or disagree with the claim and why. The claim was deliberately arguable, and students were provoked to critique it from various aspects, such as the certainty and confidence level of the claim, the lack of evidence to support this claim and the flaws in the chain of inferences. The pre-questionnaires were administered at the beginning of the school year, before the selected classes had engaged in the Bio-Tech program. The post-questionnaires were administered at around the same time as the oral exam for the Bio-Tech students at the end of the school year.

2.4 Analysis

Only questionnaires of students who answered both the pre- and post-questionnaires were taken for analysis. Each answer was classified according to the students' agreement or disagreement with the arguable claim and the arguments they used were analyzed and categorized. Initial categories, depicted in a bottom-up process by the first author, were reviewed and validated by the second author and two other science education researchers. The classification of arguments to the different categories was unanimous in over 80% of the cases. The non-agreeable categories and arguments were further discussed until an agreement between the validators was reached regarding the classification of the arguments.

Students' answers were statistically analyzed using Statistical Analysis System (SAS) program for both descriptive statistics and comparing frequencies (Chi-square comparing). Results were statistically analyzed using the Wilcoxon signed-rank test for significant differences (Wilcoxon, 1945) and McNemar's test (Siegel & Castellan, 1988). Agreement or disagreement with the arguable claim was calculated as the percentage of students from the total number of students who answered the questionnaire in each group.

To categorize students' arguments, in-depth analysis of their answers was performed. Students' answers were classified into three main categories: (1) arguments regarding the different stages of the experiment described in the article (the ‘described experiment’ category), excluding arguments relating to the connection between the experimental results and the conclusions, which were classified in the second category, (2) arguments concerning the ‘chain of inferences’, namely the arguments made by the hypothetical student that connect the experimental results and the conclusions, and (3) arguments focusing on other issues presented in the article. The first category of arguments regarding the experiment described in the article was further split into the following three subcategories: (1) general arguments, (2) arguments focusing on the experimental process and protocol, and (3) arguments concerning the experimental conditions. The categories, subcategories and examples are detailed below (Table 1). Students’ arguments in response to the arguable claim were qualitatively classified into the above categories and quantitatively analyzed.

Table 1. Categories of students' arguments regarding the hypothetical student's arguable claim

Category	**Subcategories**	**Examples**
1. Described experiment	A. General	*"I agree with the student because the article presents the results of a scientific experiment that proves that teething rings release a toxic substance that damages the baby." (Bio-Tech, #21)*
	B. Experimental process	"*I disagree with the student's opinion because the experiment was only performed once with no control and no repeats.*" (Bio-Tech, #5)
	C. Experimental conditions	*"The conditions under which the experiment was performed do not match the conditions under which babies use the teething rings." (Control, #23)*
2. Chain of inferences		"*I agree with the claim because we really see in the experiment that the rings release huge amounts of dangerous poisons.*" (Control, #5)
3. Other issues in the article		"*I disagree with the student…The article mentions that these substances may cause cancer, but it is not certain.*" (Control, #28)

3. Results

3.1 Students' responses to the arguable claim

To examine the possible changes in students' tendency to critique an arguable claim made by a hypothetical student following their participation in the Bio-Tech program, students' answers to the pre- and post-questionnaires were analyzed and compared to those of the Control group who did not participate in any inquiry-oriented program (Figure 1). No significant differences were found between the Bio-Tech and the Control groups in the pre-questionnaire regarding the percentage of students agreeing or disagreeing with the arguable claim ($p>0.05$).

A decrease in the percentage of students who disagreed with the arguable claim was observed in both the Bio-Tech and Control groups (from 64% to 49% and from 69% to 53%, respectively). This decrease was found to be statistically significant in both groups according to McNemar's test (Bio-Tech chi-square=4.17, $p<0.05$; Control chi-square=4.26, $p<0.05$). This decrease was accompanied by an increase in the percentage of students who agreed with the arguable claim in both groups (Biotech from 30% to 49%, chi-square=7, $p<0.01$; Control from 27% to 40%, chi-square=3.26, $p=0.07$).

A more detailed analysis of the shift from disagreement with the arguable claim in the pre-questionnaire to agreement in the post-questionnaire showed that a high percentage of both the Bio-Tech and Control group students shifted from disagreement to agreement (26% and 17%, respectively) with no significant differences between the two groups.

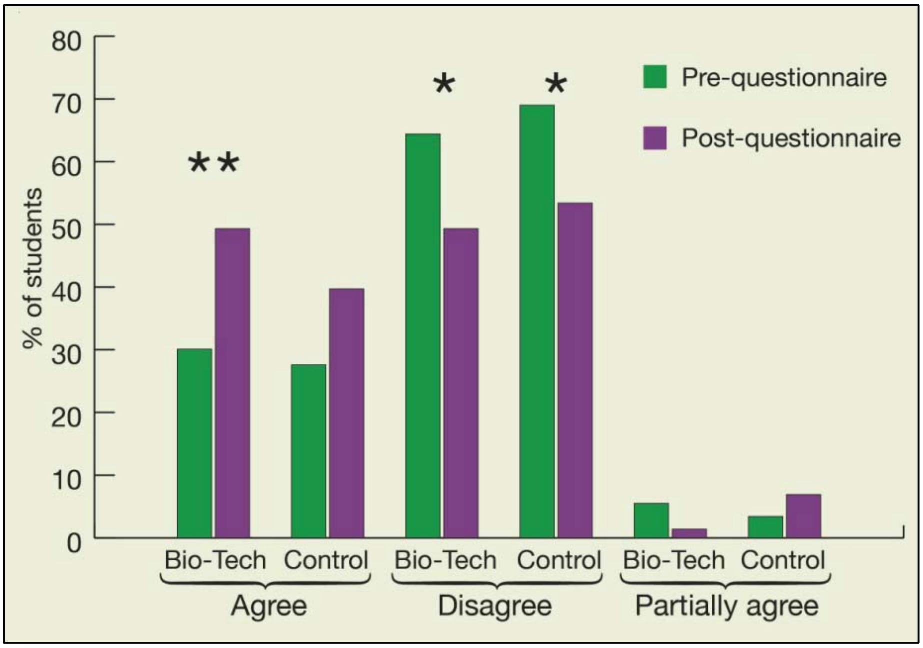

Figure 1. Comparison of students' positions toward the arguable claim in pre- and post-questionnaires (Bio-Tech n=73, Control n=58, *$p<0.05$, **$p<0.01$).

An example of students' tendency to shift from disagreement to agreement with the arguable claim, seen in both the Bio-Tech and Control groups, can be found in the analysis of one of the student's answers. This Bio-Tech group student (#55) disagreed with the arguable claim in his pre-questionnaire answer, using arguments related to the chain of inferences (*"I disagree with the student since this article didn't prove that all of the teething rings are dangerous for babies. It proved that there are specific kinds of teething rings that release phthalates and are dangerous for use, but that there are other teething rings which are not considered dangerous."*). In the post-questionnaire, the same student changed his opinion, agreeing with the claim and using arguments related to the experiment described in the article (*"I agree with the student since after establishing the hypothesis, the researchers performed the experiment in order to prove their hypothesis and with the experiment they proved that teething rings are dangerous for babies because of the phthalates that are released from them").*

In summary, students of both the Bio-Tech group and the Control group tended to be more in agreement with the arguable claim in the post-questionnaire, indicating that participation in the Bio-Tech program did not make the students more opposed to or less likely to agree with a peer's claim.

3.2 The number of arguments used by the students

We then explored possible changes in the number of arguments used by students in their answers following participation in the Bio-Tech program. We assumed that an increase in the average number of arguments might indicate a possible change in the students' ability to critique. However, no significant differences were found in the average number of arguments used by the Bio-Tech group students in the pre- and post-questionnaires (1.69 and 1.67, respectively, Figure 2). On the other hand, a statistically significant (*p*<0.05) decrease in the average number of arguments was found among students of the Control group (1.84 and 1.39, respectively, Figure 2). This indicates that the ability to use arguments was retained by the Bio-Tech students, while this ability showed a regression among students who did not participate in the inquiry-oriented program.

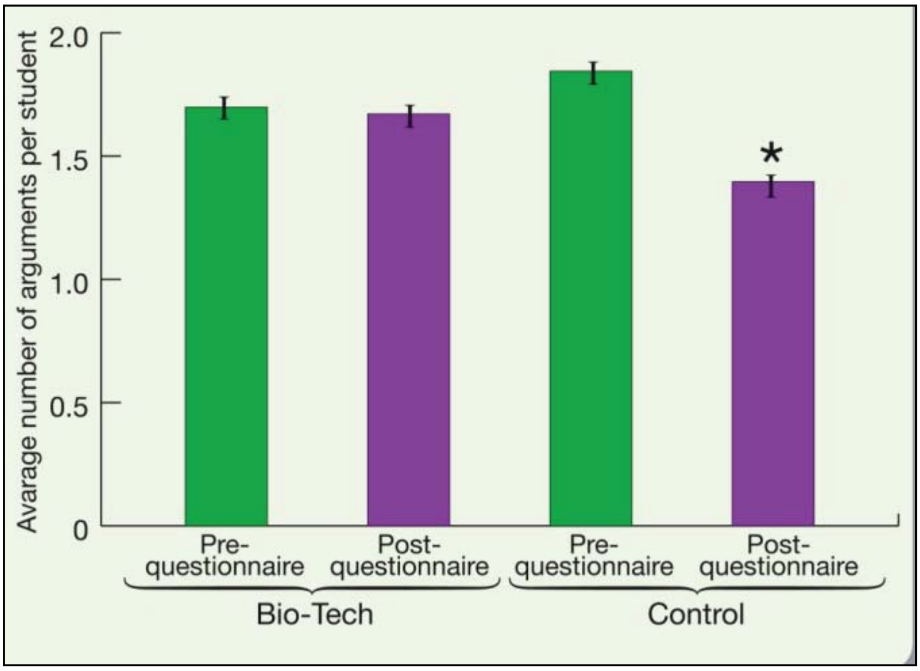

Figure 2. Average number of student arguments in pre- and post-questionnaires (Bio-Tech n=73, Control n=58, *$p<0.05$).

An example of the decreased average number of arguments in the answers of Control group students is presented in the following quote. This student (#55) from the Control group, who did not participate in the Bio-Tech program, disagreed with the arguable claim in the pre-questionnaire, using three arguments from the category of 'chain of inferences' ("*I disagree with the student, since the experiment in the article was performed on only 11 types of teething rings and this is not enough to determine and generalize that all teething rings are dangerous. There may be other companies that are not using this substance*"). In her post-questionnaire, however, this student agreed with the arguable claim and used only one argument in her answer ("*I agree. The article shows an experiment that proves that the teething rings are dangerous*").

3.3 In-depth analysis of students' arguments

To further explore the students' arguments and understand the possible changes in their arguments before and after the intervention, an in-depth investigation of the type of arguments used by the students was carried out. Students' answers were classified into categories and subcategories, as detailed in the methods section.

Classification of the students' arguments revealed that most of them, in both the Bio-Tech and Control groups, focused on the chain of inferences in both pre- and post-questionnaires

(Figure 3). There was a significantly (p<0.005) higher percentage of arguments related to the experiment described in the article in the pre-questionnaires compared to the post-questionnaires among the Bio-Tech group (from 10.6% to 25.6%), while no statistically significant change was observed among the Control group students according to Wilcoxon test.

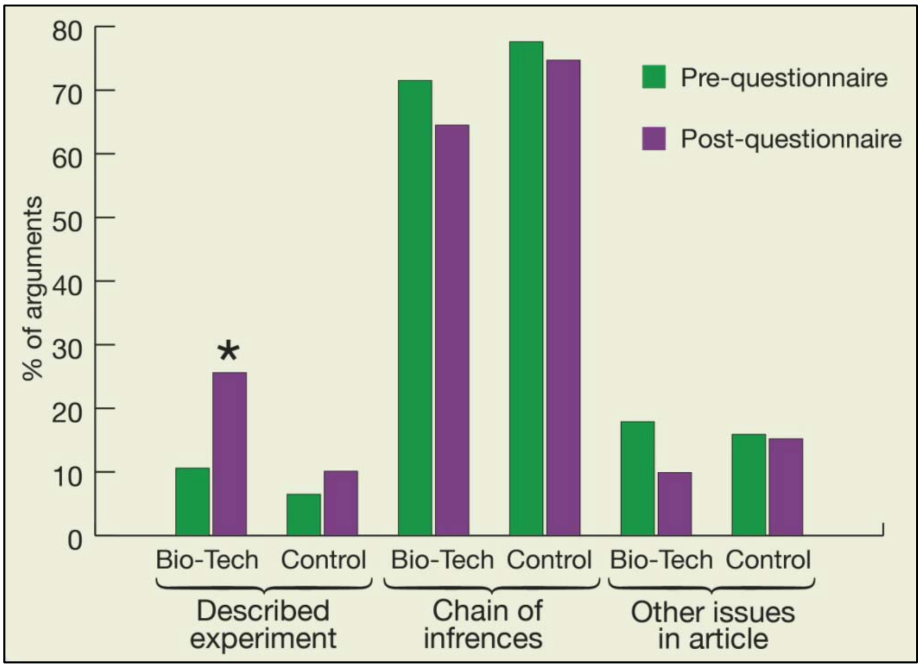

Figure 3. Comparison of students' argument types in pre- and post-questionnaires (Bio-Tech pre n=124, Bio-Tech post n=122, Control pre n=107, Control post n=81, *p<0.005).

An example of the increased tendency of Bio-Tech students to use arguments relating to the experiment described in the article is presented here. One of the students (#27) from the Bio-Tech group wrote an answer in the pre-questionnaire which included an argument from the category of other issues in the article, specifically arguments concerning the health issues of babies who use teething rings (*"I don't agree with the student. It was not experimentally examined or written in the article if phthalates are dangerous for babies or how they affect them. Maybe babies have immunity to phthalates? They didn't examine the activity of the baby who uses the teething rings compared to a baby who does not, therefore you can't know if the teething rings are dangerous."*). In the post-questionnaire, however, the same student still disagreed with the arguable claim but used arguments from the category of the chain of inferences (*"I disagree. The third ring released only 9 mg of phthalates and this amount is small and harmless").* In addition, he used an argument from the category of the described experiment ("*They need to repeat the experiment to validate the results, examine all kinds of rings and only then determine which rings are dangerous").*

A closer examination of the total number of arguments used by the Bio-Tech students that are related to the category of the described experiment (Figure 4) revealed an increase in the post-questionnaires in all three subcategories: general issues of the experiment (from 2 arguments in the pre-questionnaire to 7 in the post-questionnaire), the experimental process (from 8 arguments in the pre-questionnaire to 17 in the post-questionnaire) and the experimental conditions (from 3 arguments in the pre-questionnaire to 7 in the post-questionnaire). This indicates improvement in the Bio-Tech students' ability to critique all aspects of the experiment presented to them.

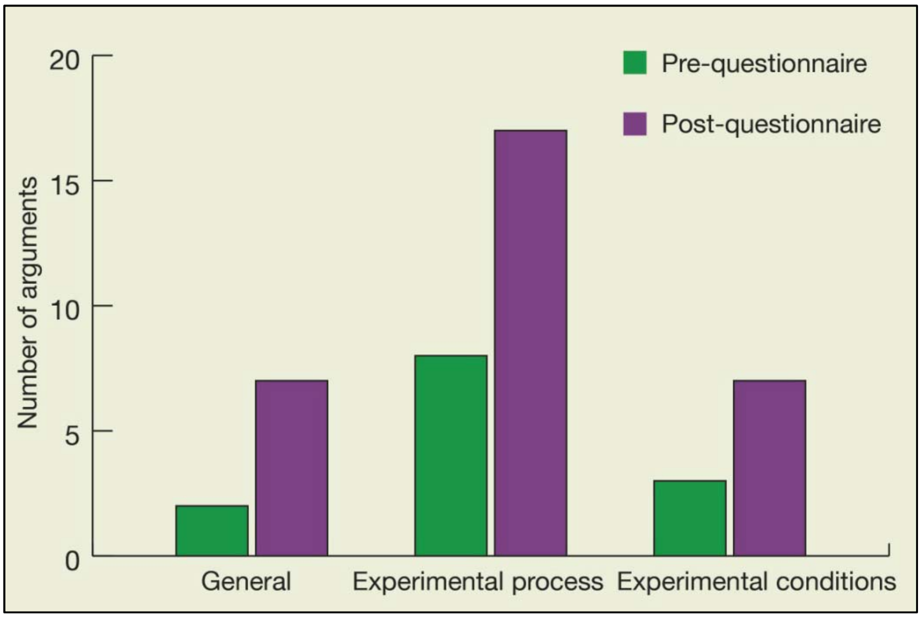

Figure 4. Number of Bio-Tech students' arguments related to the experiment described in the article (Bio-Tech, n=73).

Altogether, the results show that even though the overall tendency of the Bio-Tech students to disagree with the arguable claim does not increase following their participation in the Bio-Tech program compared to Control students, the former were better able to use arguments, and the number of arguments that focused on the experiment described in the article increased among the Bio-Tech students. The qualitative analysis supports the observed change in the type of arguments used by the Bio-Tech students before and after the intervention.

4. Discussion

Experiencing inquiry and gaining an appreciation of authentic scientific practices are key elements of science learning and teaching (National Research Council [NRC], 2012). The ability to critique is crucial in students' development of skills, abilities and understanding of scientific discourse and habits of mind (Berland & Reiser, 2009; Ford, 2008). In the study described herein, we explored possible development of students' ability to critique following their participation in the inquiry-oriented Bio-Tech program. No differences were observed in students' tendency to disagree with an arguable claim that was presented to them following the intervention between the Bio-Tech group and the Control group. Students from both groups appeared to be more in agreement with the arguable claim. This indicates that participation in the Bio-Tech program does not affect the students' ability to disagree more with an arguable claim. It may imply that developing students' ability to dispute and reject peer claims requires deeper and more explicit learning of critiquing. However, we found that participation in the Bio-Tech program leads to some improvement in students' ability to critique, mostly in their tendency to use more arguments and to critique experiments presented to them. Following participation in the program, the average number of arguments used in the pre- and post-questionnaires was sustained among the Bio-Tech group, in comparison to the Control group in which a significant decrease in the number of arguments used was observed in the post-questionnaires. This indicates that participation in the Bio-Tech program may have supported the students' argumentation and critiquing abilities.

The decrease in the average number of arguments used by the Control group might be explained by the fact that they were already familiar with the article presented in the questionnaire and they refrained from seriously engaging in answering the questionnaire. This may indicate that the ability and dedication of the Bio-Tech students to engage in critique about a topic that was already introduced in earlier experience have improved.

Furthermore, students of the Bio-Tech program tended to focus more on the experiment that was described in the article in their answers. This indicates that the Bio-Tech students improved some of their ability to critique and implies the possible development of this ability following participation in the Bio-Tech program.

Our results partially correlate with those presented by Ford (2012), who showed that students who focus on learning to critique while practicing an inquiry-oriented scientific activity improve their peer-review practice and their reasoning and argumentation abilities. The Bio-Tech students demonstrated development of their ability to critique, mostly enhancing the number of arguments used and the use of arguments related to the experimental process and method compared to the Control group. It should be noted that the Bio-Tech students’ tendency to disagree with an arguable claim did not increase compared to students from the Control group, unlike the students who participated in Ford's Research (Ford, 2012).

Further research and analysis is required for a full understanding and appreciation of the development of students’ ability to critique in the course of participation in inquiry-oriented programs. Deeper examination of the development of the ability to critique by inquiry-oriented students is required, due the relatively small number of students who participated in this research and the limited number of differences between the groups that were found. Our aim is to further analyze the development of students' ability to critique, to explore the students' long-term learning of critiquing and other abilities of the authentic scientific practice and to examine the learning of these abilities in other inquiry-oriented programs. We also plan to further and more deeply explore the development of students' ability to critique while participating in the Bio-Tech program, focusing on their ability to critique their own and their peers' research processes.

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