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Purposely Teaching for the Promotion of Higher-order Thinking Skills: A Case of Critical Thinking

Barak Miri · Ben-Chaim David · Zoller Uri

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Abstract This longitudinal case-study aimed at examining whether purposely teaching for the promotion of higher order thinking skills enhances students' critical thinking (CT), within the framework of science education. Within a pre-, post-, and post–post experimental design, high school students, were divided into three research groups. The experimental group (n=57) consisted of science students who were exposed to teaching strategies designed for enhancing higher order thinking skills. Two other groups: science (n=41) and non-science majors (n=79), were taught traditionally, and acted as control. By using critical thinking assessment instruments, we have found that the experimental group showed a statistically significant improvement on critical thinking skills components and disposition towards critical thinking subscales, such as truth-seeking, open-mindedness, self-confidence, and maturity, compared with the control groups. Our findings suggest that if teachers purposely and persistently practice higher order thinking strategies for example, dealing in class with real-world problems, encouraging open-ended class discussions, and fostering inquiry-oriented experiments, there is a good chance for a consequent development of critical thinking capabilities.

Key words class discussions · critical thinking · higher-order thinking skills · inquiry-oriented learning · real-world cases · teaching strategies

B. Miri (✉)
The Department of Education in Technology and Science, Technion-Israel Institute of Technology, 32000 Technion, Israel
e-mail: bmiriam@tx.technion.ac.il

B.-C. David · Z. Uri
Faculty of Science and Science Education, University of Haifa-Oranim, Kiryat Tivon 36006, Israel

B.-C. David
e-mail: david.ben-chaim@weizmann.ac.il

Z. Uri
e-mail: uriz@research.haifa.ac.il

Introduction

Our ever-changing and challenging world requires students, our future citizens, to go beyond the building of their knowledge capacity; they need to develop their higher-order thinking skills, such as critical system thinking, decision making, and problem solving. The development of higher-order thinking skills, or higher order cognitive skills by others (Ben-Chaim, Ron, & Zoller, 2000; Zoller, 1993, 1999) is prominent in order to facilitate the transition of students' knowledge and skills into responsible action, regardless of their particular future role in society (Zoller, 1999, 2001). Meeting this challenge requires, among others, the development of students' capacities of critical thinking (CT), which is necessary for the analysis of unfamiliar situations, so that their question-asking, problem-solving, and decision-making capabilities will be based on a framework of rational thinking (Ennis, 1989; Zoller, Ben-Chaim, Ron, Pentimalli, & Borsese, 2000).

A major component of the current reforms in science education worldwide is the shift from the dominant traditional teaching for algorithmic, lower-order cognitive skills, to higher-order cognitive/thinking skills (Leou, Abder, Riordan, & Zoller, 2006; Zoller, 1993, 1999). This shift includes, among others, a scientific inquiry component (National Academy of Science, 1995), learning science within students' personal, social, and environmental contexts, and the integration of critical thinking (Zoller, 1993).

Although the guiding ideas of science education reforms and the corresponding supporting teaching strategies have been, and are incorporated into teachers' pre-service courses and in-service professional development programs, a substantial portion of these strategies are not implemented in the teachers' classrooms (Barak & Dori, 2005; Windschitl, 2003). Indeed, the design and implementation of teaching strategies that enhance higher-order thinking among students are not a simple endeavor; they challenge even the most expert teachers (Tobin, Kahle, & Fraser, 1990).

In view of the importance of promoting the paradigm shift from the still dominant algorithmic low-order thinking to higher-order thinking skills in contemporary science education, the longitudinal case-study, presented here, aimed at examining teaching strategies that might meaningfully affect the development of students' CT skills and dispositions. Specifically, we have investigated whether and how teaching strategies applied for enhancing higher-order thinking skills promote science students' CT capabilities.

Theoretical Background

Higher Order Thinking

Science education reforms worldwide are derived from the constructivist views of teaching and learning. These reforms explicitly ask teachers to change their teaching strategies by shifting the emphasis from the traditional textbook-based, rote learning, to exploration, inquiry-based learning situated in real-world phenomena (National Research Council, 1996). The constructivist theory recognises that students need to be exposed to learning experiences that enable them to construct their own knowledge and promote their thinking skills (Cobb, 1994; Driver, Asoko, Leach, Mortimer, & Scott, 1994). For decades, the promotion of students' thinking has been the focus of educational studies and programs (Boddy, Watson, & Aubusson, 2003; de Bono, 1976; Ennis, 1989; Kuhn, 1999; Watts, Jofili, & Bezerra, 1997). Each of these programs has its own definition of thinking and/or of skills. Some use the phrase 'cognitive skills' (Leou et al., 2006; Zoller, 2001) and others refer to 'thinking skills' (Resnick, 1987; Zohar & Dori, 2003), but they all distinguish between higher- and lower-order skills. Resnick (1987) maintained that thinking skills resist precise forms of definition; yet, higher order thinking skills can be recognised when they occur.

Higher order thinking can be conceptualised as a non-algorithmic, complex mode of thinking that often generates multiple solutions. Such thinking involves uncertainty, application of multiple criteria, reflection, and self-regulation (Resnick, 1987). Framed in more traditional terms, higher order thinking corresponds with the taxonomy of Bloom, Englehart, Furst, Hill, and Krathwohl (1956), overlapping levels above comprehension. Accordingly, recall of information would be an example of a lower order cognitive pattern, or thinking skills, whereas analysis, evaluation, and synthesis would be considered higher order thinking skills. Indeed, learning experiences focused around analysis, evaluation, and synthesis, develop skills in problem solving, inferring, estimating, predicting, generalising and creative thinking (Wilks, 1995), which are all considered as higher order thinking skills. Other examples of such skills include: question posing, decision making, and critical and systemic thinking (Dillon, 2002; Zohar & Dori, 2003; Zoller, Dori, & Lubezky, 2002).

Although there are different ways to perceive higher order thinking (Boddy et al., 2003; Resnick, 1987), in this study we depicted it as an 'umbrella' encompassing various forms of thinking such as critical, systemic, and creative thinking. In relation to the constructivist theory and its implementation in schools, higher order thinking can be viewed as the strategy – the setting of meta-objectives; whereas critical, systemic, and creative thinking are the tactics – the activities needed to achieve the proclaimed objectives. Taking into consideration that investigating all forms of higher order thinking skills will be too complex, we focused, herein, on students' critical thinking, in an attempt to identify whether and to what extent this thinking skill can be promoted while purposely teaching for the development of higher order thinking.

It is well established that education is our principal means of preparing students – our future citizens – for active and responsible life within our modern society (Zoller, 1999). Therefore, schools at all levels should become the hub of the fostering of higher order thinking skills. Accordingly, a major purpose of science education should be the development of such skills in the context of both the specific content of science, and related disciplines. Nevertheless, it is well known that educational theories are not always implemented properly in the classroom (Boddy et al., 2003). Because of the gap between theory and practice, we examined science teachers who claimed to purposely teach for the promotion of higher order thinking skills. What characterises their teaching? How did it affect their students' critical thinking? These are some of the questions investigated in the current study.

Critical Thinking

Critical thinking (CT) in this study is conceptualised as an operative example of higher order thinking that can be accounted for due to reliable and validated tests. In the literature, CT has been defined as a skill of taking responsibility and control of our own mind (Paul, 1996), or as a logical and reflective thought which focuses on a decision in what to believe and what to do (Ennis, 1985). Critical thinking involves a variety of skills such as the individual identifying the source of information, analysing its credibility, reflecting on whether that information is consistent with their prior knowledge, and drawing conclusions based on their critical thinking (Linn, 2000). In the literature, CT skills are considered to be essential for the promotion of metacognitive understanding (Kuhn, 1999; Schraw, Crippen, & Hartley, 2006).

Watson and Glaser (1980) stated that CT is: (1) an attitude of enquiry that involves an ability to recognise the existence and an acceptance of the general need for evidence in what is asserted to be true; (2) knowledge of the nature of valid inferences, abstractions and generalisations in which the weight of accuracy of different kinds of evidence are logically determined; and (3) skills in employing and applying the above attitudes and knowledge. CT was also conceptualised as results-oriented, rational, logical, and reflective evaluative thinking, in terms of what to accept (or reject) and what to believe in, followed by a decision what to do (or not to do); then to act accordingly and to take responsibility of both – the decisions made and their consequences (Zoller, 1999).

Research has indicated the need for improving critical thinking skills among students since many of them fail to utilise sophisticated reasoning even at the college level (Halpern, 1998; Kuhn, 1999). It is generally agreed upon that the ability to think critically is becoming an imperative to success in modern life, as the pace of change continues to accelerate, and complexity and interdependence continue to intensify. Nowadays people are not expected to know their place but to determine and regenerate their own position (Ten Dam & Volman, 2004). As the world progresses, more and more people are required to make rational decisions based-on evaluative/critical thinking rather than to accept authority. Therefore, students should be prepared to question truisms, raise doubts, investigate situations, and probe alternatives (i.e., think critically), in the context of both schooling and daily life.

In line with the above, de Bono (1976) has long ago suggested that the teaching of thinking skills may not be adequately achieved through the process of formal logic using principles and axioms. He has developed several approaches for teaching thinking, and showed that students who have undergone some thinking lessons can produce a greater number of possible solutions to problems than those who have not had any training. Indeed, CT capabilities can be divided into two categories: (a) skills – the ability to analyse, evaluate and make inferences, and (b) disposition – the motivation, inclination and drive of the learner to involve her/himself in meaningful CT while dealing with thinking about issues, making decisions and/or solving problems (P. A. Facione, N. C. Facione, & Giancarlo, 1996). It is important to assess not only CT skills, but also students' disposition toward critical thinking, since they may point to the tendency of the learner to actually apply CT in different contexts.

Recent publications in this area have focused on assessing post secondary students' CT and identifying areas for curricular reforms in pharmacy education (Phillips, Chesnut, & Rospond, 2004), nursing education (P. A. Facione & N. C. Facione, 1994), and in mathematics and science courses (Elliott, Oty, McArthur, & Clark, 2001; Zoller et al. 2000). However, only a few studies on CT skills and disposition among high school science students are available (Ben-Chaim et al., 2000; Watts et al., 1997). In view of the importance of the development of CT, in the context of higher order thinking, we have carried out a longitudinal case-study aimed at examining the effect of teaching strategies, applied for enhancing students' higher-order thinking skills, on their CT capabilities. Our guiding rationale was that purposely teaching for the promotion of higher-order thinking might cultivate students' disposition toward CT and CT skills.

Objectives and Methodology

In view of the importance of promoting higher-order thinking skills in contemporary science education, this longitudinal case-study aimed at examining whether purposely teaching for the promotion of higher order thinking skills enhances students' critical thinking (CT), within the framework of science education.

The guiding research questions were:

1. How does teaching for the promotion of higher order thinking skills affect students' disposition towards CT and CT Skills?
2. How do teachers, purposely targeting at promoting higher order thinking skills, reflect on their teaching strategies and their conceptualisation of CT?
3. What are the characterisations of the teaching strategies that are applied by the teachers who claim to promote higher order thinking among their students?

The longitudinal case-study was conducted throughout three academic years: 2002–2005. Data collection was based on both qualitative and quantitative methodologies applied in an empirical research, within a pre- post- and post–post experimental design.

Research Population

The research population consisted of 177 students in an accessible, representative, rural high-school in the northern part of Israel (97 females and 80 males). The school population is diverse, about 20% are new immigrants, most of them from former USSR countries or Ethiopia. In addition, the school includes students from various cultures and religions: Jews, Moslems, Christians, and Druze.

The students were divided into three groups: group A, the experimental group ($n=57$), consisted of science students that their science teachers purposely apply teaching strategies that fostered their higher-order thinking skills capabilities; group B, the science control group ($n=41$), consisted of science students that their science teachers did not proclaim to foster higher-order thinking skills; group C, the non-science control group ($n=79$), consisted of media and theatre studies, physical education, and mechanics students that their teachers did not proclaim to foster higher-order thinking skills.

The study was designed to include two control groups (science and non-science) in order to confirm or refute the possibility that the development of disposition toward CT and CT skills are discipline-dependent. All students (science and non-science) studied their major courses between 6 to 10 h per week throughout the three school years (from grade 10 to 12).

The researchers, acting as external investigators, interviewed a sample of science ($n=5$) and non-science ($n=4$) teachers and conducted in-class observations. Non of the teachers received special training nor was there any intervention by the researchers. Since our main goal was to examine teaching strategies that enhance higher order thinking, we decided that exemplary teaching will be the foci of our results and conclusions. Accordingly, the two science teachers who proclaimed to teach for the promotion of students' higher order thinking are the centre of our study.

Procedure and Data Analysis

A rigorous, pre test, post test, and post–post test, control group design was used to empirically assess the effect of the teaching strategies on both students' dispositions towards CT and their CT skills. This design enabled the comparison between science students who were exposed to CT-promoting instruction and those who studied in a traditional, teacher-centered approach. Furthermore, the pre-, post, and post–post experimental design enabled the analysis of the impact of the different instructional approaches over time, indicating changes throughout the three years.

The mixed methods research model, which incorporates both quantitative and qualitative methodologies in the analysis and interpretation of data (Johnston & Onwuegbuzie, 2004) was employed. The quantitative research tools – the CT tests (CCTDI and CCTST instruments - see following section), were pre-post administered at the beginning and the end of the 2002–2003 school year, when the students (n=177) were in their 10th grade; and post–post administered two years later to a representative sample (n=68), when the students were in their 12th grade.

Only about 40% of the students who took the pre- post-test were present to take the post–post tests two years later. Some of the students left school or moved to another one, and some that were in school, did not participate since they were busy with their matriculation examinations and other projects. However, the students' characteristics in the representative sample was similar in gender distribution, major course in science, and the number of learning units in math, to those in the first phase.

Based on prior experience in administrating the CT-related questionnaires to high-school students (Ben-Chaim et al., 2000), it was decided to administer both the CCTDI and the CCTST instruments in parts, and randomly distribute them among the students in the research classes. Each student had responded to the same parts of the instruments during the three administrations and data were analysed in the aggregate.

For statistically-based comparison of student's relative improvement, Hake's normalised gain equation (Hake, 1998, p. 65) was used. That is, in order to compare among the three research groups, the ratio between each student's actual gain and his/her maximum possible gain was calculated as follows:

$$\langle g \rangle = \frac{\%Correct_{post-test} - \%Correct_{pre-test}}{\%Max - \%Correct_{pre-test}}$$

Instruments

1. *The California Critical Thinking Disposition Inventory (CCTDI)* (P. A. Facione & N. C. Facione, 1992) was developed, validated, and used to assess students' disposition toward CT. It consisted of 75 statements, divided into seven subscales: Truth-seeking, Open-mindedness, Analyticity, Systematicity, Self-confidence, Inquisitiveness, and Maturity. Responses were made on a 6-point Likert-type scale. The CCTDI reports a total score, which is the sum of its seven subscales, ranging from 70 to 420. A total score more than 280 indicates a positive overall disposition toward CT. The development and validation process is described in P. A. Facione and N. C. Facione (1992). The CCTDI was translated into Hebrew with only very slight adjustments to the Israeli setting (Ben-Chaim et al., 2000).
2. *The California Critical Thinking Skills Test (CCTST)* (Facione, 1990; P. A. Facione & N. C. Facione, 1994) was developed, validated, and used for assessing students' CT skills. It is a standardised, 34-item multiple choice test, non discipline-specific that targets core critical thinking skills. Each item on the CCTST is assigned to one of three subscales: Analysis, Evaluation, and Inference. Like the CCTDI, the CCTST was translated into Hebrew with only very slight adjustments to the Israeli setting.

3. *Semi-structured interviews* were carried out during the first and third (last) year of the study. Their purpose was to identify and distinguish teaching strategies that might promote higher order thinking skills, and shed light on the way teachers conceptualise CT. Each interview was about 30 min long. The interviews were recorded with the permission of the interviewee along with shorthand notes. The interviews were transcribed by one researcher with the assistance of a colleague. All of the interviews were read, reread, and later, broken into coded segments. Two expert researchers reviewed and discussed the coded interviews in order to achieve consensus.
4. *Class observations* were conducted in order to examine the actual teaching strategies of the (science and non-science) teachers. The class observations were conducted sporadically throughout the first and third (last) year of the research. The data was collected by using a logbook which was analysed and interpreted by the researchers. One researcher sat among the students, in the back of the classroom, and documented the teacher's way of presenting new topics, her/his use of diverse instructional methods, and her/his interactions with students, centring on critical thinking-related strategies. The researcher logs were content analysed by one researcher, and assigned with categories. Three expert researchers reviewed the assigned categories in order to attain the trustworthiness of the findings.

Results and Discussion

The mean scores, standard deviations, minimum and maximum, of the overall scores, on both the CCTDI and CCTST instruments are presented in Table 1.

An examination of the entire research population's scores on both the CCTDI and CCTST instruments points to an overall improvement, throughout the three years of study. This may suggest that students keep developing their generic disposition toward CT and CT skills during their natural process of maturation, within the traditional teaching and learning framework.

The CCTDI post and post–post scores (Table 1), are consistent with the findings of Ben-Chaim et al. (2000) that established a baseline reference for disposition toward CT of high school science students in Israel, indicating a norm mean of M = 281.7 (SD = 33.62), based on 588 11th grade students. That study indicated that the overall scores of high school and university science students were essentially the same (Ben-Chaim et al., 2000).

Table 1 High School Students' Minimum, Maximum, Means and Standard Deviations on the CCTDI and CCTST Instruments

Instrument		N	Minimum	Maximum	Mean	SD
CCTDI (420 points scale)	Pre	177	154.00	326.00	220.10	32.34
	Post	177	176.00	386.00	277.23	41.27
	Post–post	68[a]	165.00	379.00	278.14	39.67
CCTST (34 points scale)	Pre	153	5.00	20.00	9.75	3.33
	Post	153	8.00	25.00	16.86	3.23
	Post–post	68[a]	13.00	28.00	20.58	3.47

[a] A representative student sample to which the post–post test was administered

Since, to the best of our knowledge, there is no baseline reference for high school students' CT skills and, since Ben-Chaim et al. (2000) found similarities between high school and university science students' scores, our CCTST results were compared with those of college students. The mean and standard deviation of 781 college students in the US was found to be M = 15.89 (SD = 4.46) (Facione, 1990), quite similar to our post-test results (M = 16.86 (SD = 3.23)). However, our post–post means (M = 20.58 (SD = 3.47)) were found to be somewhat higher than the above reported norms.

A paired sample *t*-test, comparing between the pre-and post scores on both the CCTDI and CCTST, showed a statistically significant difference ($t_{(176)}$ =16.92 p<0.001, $t_{(152)}$= 16.91 p<0.001, respectively). However, no statistically significant difference was found between the post- and post–post CCTDI and CCTST. These results suggest that the major development of both the students' disposition toward CT and CT skills occurred during the first year of the study, when the students were in the 10th grade. These results can be explained by the matriculation examinations that students need to pass during the 11th and 12th grades. Consequently, during these years, teachers tend to allocate more time, and invest more effort in preparing their students for these exams via rote, technical, algorithmic exercising of problems similar to those expected in these tests, and invest less time in activities that might promote higher-order thinking.

Effect of Teaching Strategies on Students' Disposition Toward CT and CT Skills

No statistically significant difference was found in comparing the mean scores of groups B (science majors) and C (non-science majors) on the post- and post–post CCTDI and CCTST. This may suggest that disposition toward CT and CT skills are not science discipline, nor learning tracks dependent.

The total and subscales of the CCTDI and CCTST mean scores and standard deviations, by research groups, are presented in Tables 2 and 3, respectively. The results indicate that on most of the CCTDI subscales, except for the CT self-confidence category, group A achieved the highest scores on the post test (Table 2). On the CCTST subscales, group A scored the highest on all subscales in both the post- and post–post tests (Table 3). A plausible explanation to these results is that a persistent effort to promote higher-order thinking fosters not only students' CT capabilities, during the learning period, but also contributes to the sustainability of these capabilities in the long run, as an integral part of students' thinking habit.

Our statistical comparison of the students' mean scores on both the CCTDI and the CCTST focused on their relative improvement gains, based on Hake's (1998) equation. An ANOVA test indicated that group A students improved their disposition toward CT significantly more than groups B and C, on the total CCTDI ($F_{(2)}$=8.62, p<0.01), and on four of its subscales: Truth-seeking ($F_{(2)}$=7.41, p<0.01), Open-mindedness ($F_{(2)}$=8.08, p<0.01), CT Self-Confidence ($F_{(2)}$=4.37, p<0.02), and Maturity ($F_{(2)}$=6.40, p<0.01). On some of the CCTDI subscales, group B improved comparable with the improvement of group A, whereas, group C, scored the lowest rates on these subscales. Similarly, group A improved its CT skills significantly more than groups B and C, on the total CCTST ($F_{(2)}$=10.11, p<0.01), and on two of its subscales: Evaluation ($F_{(2)}$=5.22, p<0.01) and Inference ($F_{(2)}$=8.39, p<0.01).

The above results strongly suggest that persistence in teaching for enhancing higher-order thinking skills, as has been done by the teachers who proclaimed of doing so, indeed, developed the students' critical thinking components of: Truth-seeking, Open-mindedness,

Table 2 Means and Standard Deviations of High School Students' Disposition Toward Critical Thinking by Subscales and Research Groups

CCTDI scale[a]	A $_{N=57}$ Mean (SD)			B $_{N=41}$ Mean (SD)			C $_{N=79}$ Mean (SD)		
	Pre	Post	Post–post	Pre	Post	Post–post	Pre	Post	Post–post
Truth-seeking	30.93 (6.05)	35.74 (6.39)	36.42 (6.35)	32.58 (5.66)	35.70 (6.16)	32.63 (5.52)	29.95 (6.24)	33.48 (6.44)	34.52 (6.32)
Open-minded	31.32 (6.66)	38.40 (6.73)	37.87 (6.53)	33.45 (5.16)	35.36 (4.13)	35.45 (5.02)	33.41 (6.50)	35.32 (4.94)	36.38 (5.64)
CT Self-confidence	26.56 (6.27)	39.46 (7.40)	40.32 (6.73)	32.11 (6.36)	40.58 (3.50)	38.76 (5.48)	30.12 (7.18)	36.67 (7.00)	34.56 (6.96)
Maturity	30.58 (5.70)	40.02 (6.64)	39.51 (5.96)	31.74 (5.10)	35.34 (5.82)	35.81 (5..91)	29.55 (5.82)	34.86 (6.28)	35.57 (6.18)
Total[b]	217.53 (25.84)	288.84 (42.21)	291.50 (40.45)	220.58 (34.20)	273.65 (37.69)	272.93 (35.48)	223.06 (35.55)	265.50 (38.70)	266.19 (36.78)

[a] Presented are the four subscales (out of seven) that were found to indicate statistically significant difference between the research groups

[b] The total CCTDI score including all seven subscales

Self-confidence in their own CT capabilities, and Maturity – judicious in their decision making. Moreover, teaching for enhancing higher-order thinking skills promoted students' ability to assess information (Evaluation) as well as, the ability to identify and secure information needed to draw conclusions (Inference).

All of the above constitute desirable results within the context of higher-order thinking skills, which further emphasise the promising potential in identifying the specific teaching strategies in a direct cause–effect relationship.

Teachers' Reflection About Their Teaching Strategies and Their Conceptualisation of CT

The semi-structured interviews conducted with the two experimental science teachers M and L (pseudonyms initials) focused on their teaching strategies and their conceptualisation

Table 3 Mean Scores and Standard Deviations of High School Students' Critical Thinking Skills by Subscales and Research Groups

CCTST scale	A $_{N=54}$ Mean (SD)			B $_{N=38}$ Mean (SD)			C $_{N=61}$ Mean (SD)		
	Pre	Post	Post–post	Pre	Post	Post–post	Pre	Post	Post–post
Analysis	3.35 (1.39)	5.93 (2.38)	6.44 (0.65)	2.89 (1.20)	5.06 (1.18)	5.11 (1.27)	3.17 (0.75)	5.17 (0.75)	4.82 (1.00)
Evaluation	3.38 (2.05)	7.35 (2.56)	9.33 (0.95)	3.70 (1.83)	5.10 (1.20)	7.13 (2.00)	3.33 (2.08)	3.43 (1.15)	7.82 (1.74)
Inference	3.67 (1.83)	7.38 (2.47)	8.81 (0.76)	3.58 (1.44)	5.05 (1.42)	6.32 (1.56)	2.75 (1.26)	4.93 (1.15)	5.91 (1.31)
Total	9.89 (3.47)	20.38 (3.19)	22.47 (2.12)	9.31 (2.60)	15.25 (2.52)	18.56 (3.37)	9.73 (3.32)	13.23 (2.71)	18.19 (3.33)

of CT. M is a relatively young teacher having had only 5 years of teaching experience at the beginning of the study. He holds a B.Sc. degree in chemistry, and a Masters degree in chemical education. He often participates in after school science education teachers' development workshops, and he is updated with respected to new teaching/learning and assessment strategies. He loves teaching science and, based on his in-class observations, it seems that his students admire him.

L is a very skilled teacher, having about 20 years of teaching experience who holds a Masters degree in chemical education. She is the head of the chemistry teachers group in her school and a member of the school's management team. She often participates in science teachers' professional development programs as both a participant and a lecturer, and takes an active part in the development and implementation of innovative teaching and curricular materials.

Both teachers were asked to give examples of how specifically they promote higher order thinking among their students, and how do they conceptualise CT. In separately conducted interviews, both M and L were found to have a so-called global/holistic view of the world; namely, emphasising the importance of the whole and the interdependence of its parts and hence, connecting science to every-day life and real-world issues. Their teaching strategies were found, via their statements, to include the presentation of real-world problems followed by hands-on inquiry-based experiments. Thus, M strongly believes that his way of teaching encourages critical thinking:

> In my class I encourage students to ask questions, investigate a phenomenon, and make assumptions... I teach new concepts in daily-life context. You can not stay in the knowledge level, you must teach them to think.

He also finds it important to connect science concepts to the students' daily life:

> One way of hooking students into 'the science world' is teaching them that science is everything and everywhere... science can explain many phenomena in life. It is a great challenge for me to construct these connections. Quite often I relate to physical and biology phenomena; for example, when I teach acids and bases I refer to the pH of our blood or spit... I do not stop in the borders of the disciplines.

Indeed, from M's interviews one gets the impression that he deliberately blurs discipline borders. When asked to conceptualise CT, M's response was:

> I believe CT is a way of organising thinking, basing it on logic in an orderly way. I expect my students to use critical thinking while solving a problem in a systematic way. I expect them to be able to make assumptions and draw conclusions based on their prior knowledge by using tools taught in class.

His conceptualisation of CT is close to that of Ennis (1985) that conceptualised CT as a logical and reflective thought. When asked about the importance of CT his answer was:

> I believe that critical thinking is important when learning math and science; it is also important when learning other disciplines, but it is most important when dealing with real-life situations, and having the tools to deal with them.

Similarly, as derived from her interviews, L's related beliefs are that:

> It is important to teach not only 'facts and figures' related to science, but also to think in a critical and a creative way.

She found it very difficult to conceptualise CT, but once she did, her conceptualisation of CT was close to that of Zoller (1993):

It is very difficult to define thinking... I think it is important for students to reflect on their thoughts and understand in depth the meaning of things... and help them reach a decision.

Enhancing students' motivation was one of M's goals in teaching. Similarly, L's goal is to foster students experience and positive emotions toward science:

> I would like them to 'live through' science... that my teaching would have a positive affect on their feeling toward this discipline.

L uses various teaching methods and aids:

> In my classes I apply diverse teaching methods such as: relevant movies, interesting stories, newspaper articles, scientific articles, hands-on experiments, and individual or group assignments. Especially, I encourage students to work with plastic molecular models so they would 'feel' the spatial structure of molecules.

Similarly to M, L connects science topics, taught in class, to her students' daily life:

> I always present science concepts in relation to phenomena that my students can relate to. For example when I teach about proteins, I always refer to the structure of their hair, or if I present the topic on oxidation and reduction I refer to hair dye or alternatively, the function of batteries.

L does not only talk about the connections of daily-life and science but she also involves her students in hands-on, teamwork experiments, investigating daily phenomena such as the different rates of CO_2 release from a warm and cold coke bottles. When asked about the importance of CT she, like M, asserted that it is most important for students who grow to become the citizens of our society.

Characterisation of Teaching Strategies that Targeted at Enhancing Higher-order Thinking Among Students

Class observations conducted in both the first and the third year of the study confirmed that both M and L do integrate teaching strategies that promote higher-order thinking skills. For example, they both foster the 'making of connections' between what is learned in class and everyday life; they integrate inquiry-based learning, and present stimulating open-ended questions which encourage students to think. They also encourage students to ask questions; the following are a few example questions posed by students during M's class on oxidation and reduction: What daily life phenomenon can be connected to oxidation-reduction process? Is iron-rust an oxidation-reduction reaction? In what regions iron will rust faster? What can be done to prevent oxidation-reduction reaction? In response, the students were asked to explore on their own possible answers.

Via class observations conducted in the third year of study, three major teaching strategies, employed by both teachers (M and L), were categorised as: (a) dealing with interdisciplinary real-world cases; (b) encouraging open-ended class discussions; and (c) fostering short inquiry experiments to be performed in groups. We relate these teaching strategies to M and L students' statistically significant pre-post improvement on their disposition toward truth seeking, open-mindedness, CT-self confidence, and maturity (Table 2), as well as, on their CT skills, particularly on the evaluation and inference categories (Table 3).

We detail here selected examples which illustrate the teaching strategies employed by M. Similar strategies were observed in L's classes. In the following examples Stu1, Stu2, Stu3, and Stu4, are students in M's science class, and hence belong to group A, the experimental group in this study.

a. *Presenting real-world cases – encouraging students to cope with relevant situations*

At the beginning of the session, M presented a situation drawn from his own personal life in which a 'problem' was embedded; he then asked questions that require students to think about relevant connections between the presented situation and science concepts they have already learned.

M: Last week I visited a friend who is growing peanuts. Before I left, he gave me this package of peanuts [showing the peanuts to the students] which, as I heard, are very fattening. What should I examine before I decide whether to eat them or not?

Stu1: You need to check how many calories are in, say, 100 grams of peanuts.

M: How should we do that? Do you have any suggestions? Can you relate this problem to what you have learned in the past few sessions? Can you suggest an experiment that will solve now our problem?

M's teaching strategy encouraged students to think about the presented problem, in relation to what they have studied in class and to come up, on their own, with relevant connections.

We have spent the last several sessions talking about ways to calculate the enthalpy of different chemical reactions, taking in to account the amount and type of bonds broken and created. What other types of energy are you familiar with? Think about your physics and biology courses... We all say that our body needs energy, think what for? Think about our body activities and the chemical compounds that are involved.

M introduced new topics and concepts by connecting them to those discussed in previous sessions, to similar topics studied in other science disciplines, as well as, to daily life and current events. This teaching strategy is expected to foster cognitive maturity which is the making, suspending, or revising judgment (P. A. Facione & N. C. Facione, 1992) or, perhaps, even system thinking. During this learning process, students studied not only science but also where encouraged to think beyond the disciplinary boundaries, so that multiple possible solutions were acceptable. This aspect of CT disposition is characterised as *Maturity* in the CCTDI instrument

b. *Directing class discussionsrelated to a concept/phenomenon or a problem – encouraging students to ask questions and present their own solutions*

M: Chemistry bonding, what does it actually mean? Look at the chemical reaction I wrote on the blackboard, what are the bonds? How many do we need to break and create in order for the reaction to occur? Think about various energy forms you are familiar with, how do they relate to chemical energy?

In his class, M asked the students many questions, and fostered their inquisitiveness by encouraging them to generate their own questions. This teaching strategy is purposed at fostering his students' desire to search information and gain the best relevant solution. This CT-related disposition is characterised as *Truth-Seeking* in the CCTDI instrument.

M: Your assignment in class is to formulate your own questions related to the peanut problem. Try to use concepts related to chemical reactions and energy transfer.

Stu2: We learned to calculate the enthalpy of different reactions, but all the data we needed for that was written in the text books, such as bond enthalpy, molar heat capacity... how can we gather this data ourselves?

Stu1: What are the peanut's chemical components?

M: A very good question. Think about more questions.

Stu3: Do peanuts burn?

Stu4: This is a stupid question, why does it matter?

M: There are no stupid questions or bad ideas in this classroom. Actually, this is a wonderful question. Stu4, please think why this is a good question. Try to follow Stu3 thoughts; remember the inquiry experiment we have conducted last week.

In his classes, M purposely builds up his students' self-confidence by encouraging them to express freely their ideas and opinions (even if they are not always correct or relevant), and prevents any signs of intolerance on part of their classmates. His teaching is purposed at fostering his students' trust and confidence in their own reasoning skills and abilities. This kind of CT disposition is characterised as *CT Self-Confidence* in the CCTDI instrument.

c. *Guiding short inquiry-type experiments in groups – encouraging students to learn in cooperation*

M: Let us investigate the amount of kilocalories accumulated in the peanuts that I brought from my friend. Let us start by grouping into pairs or threesome. Think about the problem, design an experiment, taking into account the apparatus you have on your trays, write down your hypothesis, and specify the instruments needed. I would like each member of the group to think of their own idea, present it to your group and conduct peer-review. In the next step, choose the best idea and work together.

Thus, M fostered teamwork, knowledge sharing and collaboration by assigning group experiments within an inquiry-based learning. In fact, his teaching purposed at fostering his students' ability to listen to other peoples' ideas and to evaluate them. This CT disposition is characterised as *Open-mindedness* in the CCTDI instrument.

Summary and Implication

In the context of higher order thinking, many in-service programs aim at enhancing teachers teaching capabilities and expanding their repository of instructional strategies by emphasising the connections between theory and practice. Indeed, making the connections between educational theories and practice in the classroom is, with out no doubt, essential (Osborne, Erduran, & Simon, 2004). However, are these connections actually being made? More specifically, do teachers incorporate advanced instructional strategies into their teaching? And if so, can these strategies promote students' higher order thinking?

The examination of teachers' instructional strategies for the promotion of students' higher order thinking was the essence of the current study, which resulted in the interesting findings that are summarised in the following:

1. Only a marginal part of the teachers (2 out of 10 science and non-science alike) proclaimed to apply teaching strategies that promote higher order thinking skills among

their students. Even those who do (i.e., the experimental teachers, M and L, in this study) found it difficult to conceptualise CT per se, and what it is comprised of.

2. Throughout the 3 year-study, students from all research groups advanced, at least to some extent, on both their CT skills and disposition toward CT. This moderate improvement may be assigned to maturation, accumulation of life experience, and schooling per se, which play a role in the development of students' CT, within the framework of their higher-order thinking skills scheme.
3. Purposely teaching for the promotion of higher-order thinking skills does contribute to the development of CT skills and disposition toward CT; that is, if one persistently teaches for enhancing higher-order thinking skills, there are chances for success.
4. No significant differences, in CT skills and disposition toward CT, were found, when comparing high school science and non-science majors from traditional classes that there teachers did not declare to purposely promote higher-order thinking. This may suggest that CT capabilities are not disciplinary dependent.
5. Three teaching strategies were identified as promoting higher-order thinking skills: dealing in class with real-world cases; encouraging open-ended class discussions, and fostering inquiry-oriented experiments. Each was related to the promotion of a certain CT components, as presented in Fig. 1.

Numerous studies show that teachers' conceptualisation of teaching and learning is mostly that of the transmission-of-knowledge model rather than a constructivist-based approach (Tobin & Fraser, 1989; Tobin, Tippins, & Hook, 1994). This is in line with our findings that only two teachers (20% of the investigated teachers) purposely integrated teaching strategies targeted at promoting higher order thinking skills. Our results reinforce the assertion that teaching strategies of many of the science (and also non-science) teachers are not always compatible with the fostering and development of students' higher order thinking (Watts et al., 1997; Zohar, 2004).

It is well established that conventional teaching is short of preparing students to our ever-changing and challenging world that requires the making of critical/evaluative

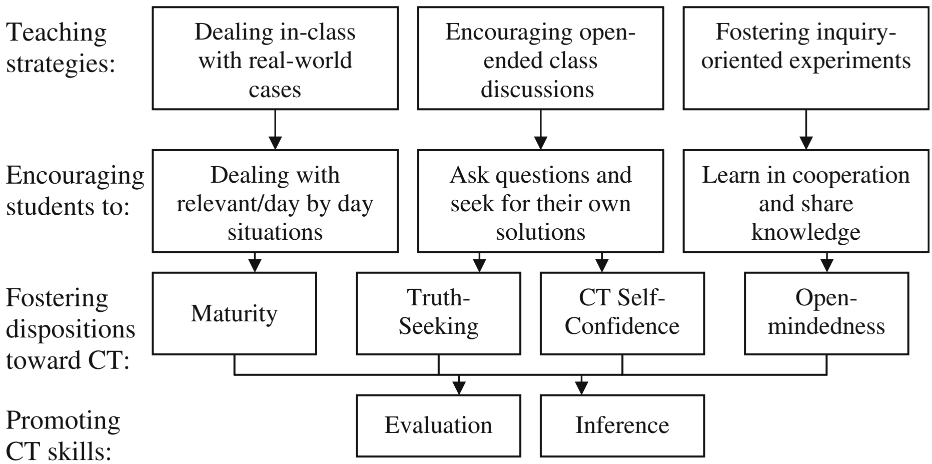

Fig. 1 Teaching strategies that are targeted at promoting higher-order thinking skills and their impact on students' CT capabilities

thinking-based rational decisions (Ben-Chaim et al., 2000; Zoller, 1993, 1999). In our study we have found that by incorporating teaching strategies, such as: students' question asking, self-investigating of phenomena, exercising open-ended inquiry-type experiments, and making inferences, students' CT skills and related capabilities are significantly being advanced. These results are in accord with previous reported studies (Dillon, 2002; Facione, 1990; Ten Dam & Volman, 2004; Watts et al., 1997) which demonstrated that CT involves cognitive activity applied within a purposeful, inquiry-oriented interpretation of relevant information.

One of the ultimate goals of teaching for the promotion of higher order thinking is the transfer of these capabilities across disciplines and domains (Zohar & Dori, 2003; Zoller, 1999). However, the roads to transfer within and across domains are rather rocky (Ennis, 1989; Salomon & Perkins, 1989). Although in this study the teaching strategies for the promotion of higher order thinking were applied in the context of science teaching, the students' success in the CT tests suggest that they were capable of transferring across domains, since the CT tests include generic non-disciplinary questions and statements.

Our findings bear educational significance for teacher development in the context of programs that involve higher order thinking. The compelling empirical evidence shows that if one knowingly, persistently and purposely teaches for promoting higher order thinking among her/his students, there are good chances for success. This conclusion should be made an important element in the process of changing teachers' beliefs and practices in this field. We suggest that professional development programs would be structured in such a way that teachers will have a better understanding of what higher order thinking is, and would be able to conceptualise CT in a more coherent way. We also suggest encouraging teachers to apply a variety of instructional strategies, as presented in this study and others (Dillon, 2002; Facione, 1990; Ten Dam & Volman, 2004) in order to help their students to accomplish tasks requiring higher order thinking, in general, and CT skills, specifically.

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