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Developing the skills of critical and creative thinking by probability teaching

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Abstract

The study reported here described a small step in the direction of developing additional learning units within the traditional curriculum. It is apparent that if a teacher makes a decision to focus on improving higher order thinking and perseveres over time, the chances are good that the teacher will succeed. The purpose of this study was to explore whether teaching our specially designed learning unit would enhance the students' critical and or creativity thinking. The unit "Probability in Daily Life" was taught to a group of tenth-grade students, with the purpose of encouraging critical thinking dispositions such as open-mindedness, truth-seeking, self-confidence and maturity. The teacher encouraged class discussion and planned investigative lessons. The students completed a pre and post CCTDI test. The findings of the present research are likely to help composing new study programs and methods that can be based on the connection between critical thinking, creative thinking and the study of mathematics, which this research brings.

Keywords: Critical Thinking, Creative thinking, Probabilty.

Current approaches in mathematics studies according to the new mathematics curriculum adhere to a conceptual understanding of mathematics and emphasize investigation, problem solution, high-order skills and mathematical discourse. The students are supposed to actively construct their knowledge and understanding, while the teachers function as 'mediators' by asking questions, posing challenges and assigning investigation tasks, and help the students to think in deeper ways about various concepts, ideas and mathematical contexts. To study and teach mathematics in such a way is a very difficult task, because the ways of teaching and learning are very demanding and creative, requiring, among the rest, deep knowledge and understanding of mathematics on the teacher's part, coping with the unknown on the student's part, and much intellectual effort on both the teacher's and the student's part. The implications of this research on the study program were expected while taking into account the findings of earlier researches; these findings point at the importance of learning experiences that develop critical thinking by means of various specially designed curricula. The findings of the present research are likely to help composing new study programs and methods that can be based on the connection between critical thinking and the study of mathematics, which this research brings to light. Thus, this research offers new possibilities of extending the use of critical and creative thinking development programs, and for their integration into the formal high-school mathematics curriculum.

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Theoretical Framework

1.1. Mathematics and Creativity

In general, creativity is defined as "the cognitive skill of proposing a solution to a problem or making something useful or novel from ordinary" (Hwang, Chen, Dung, & Yang, 2007, p. 193). Ervynck (1991) posits that mathematical creativity in problem solving is the ability to formulate mathematical objectives and find their innate relationships; it is the capacity to solve problems according to the appropriateness of integrating both the nature of logic-deduction in mathematics education and its evolved concepts into its core. According to Silver (1997) and Ervynck (1991), mathematical creativity has two characteristics, general and specific. General original or creative thinking enables problem-solving or problem-posing in various fields – creating innovative and original solutions of the highest quality. These ideas or solutions are elegant and surprising. This kind of thinking is characterized by mental flexibility, curiosity, a well-developed imagination, interest in finding solutions, the creation of metaphors, and goal-oriented thinking. It is measured by the quantity and quality of its outcomes. Specific original or creative thinking brings about creativity in a specific field. The realization of this creativity's potential requires a longer period of maturation and development. The development and maturity are the results of experience and usually manifest themselves in mature people. Chiu (2009) connected mathematical creativity with the students' ability to solve routine and non-routine problems and even to approach ill-structured problems. Creativity has been considered to be a critical component of advanced mathematical thinking (Ervynck, 1991).

1.2. Critical Thinking Abilities by Ennis and Dispositions

Seven aspects of critical thinking were considered as objective assessment criteria for evaluating the incorporation of critical thinking in students' mathematical education and they are induction, deduction, value judging, observation, credibility, assumptions, and meaning. Although these aspects of critical thinking are listed separately, overlap between them exists to a certain extent. For example, one might argue that deduction is involved in much induction, calling for the listing under deduction of the items listed under inductions. Similarly, one might also argue that observation and credibility judgements call for the implications of principles, a deductive process and should also be listed under deduction. This legitimate overlap is partially expressed by the items of the Cornell critical thinking of level Z (Ennis, Millman & Tomko 2005). Our ever-changing and challenging world requires students, our future citizens, to go beyond the building of their knowledge; they need to develop their higher-order thinking skills, such as system critical thinking, decision making, and problem solving (Profetto-McGrath, 2003; Riddell, 2007; Sezer, 2008). There have been significant changes in the past decades in the field of education. Whereas earlier the teacher was at the center and the emphasis was put on what to teach, today's education involves teaching how to think, and in particular, how to be a critical thinker. Critical thinking is necessary in every profession, and it allows one to deal with reality in a reasonable and independent manner (Harpaz, 1996,1997; Lipman, 1991, McPeck, 1994). Critical thinking has been investigated largely in terms of thinking skills that involve the cognitive domain. For decades, promotion of students' thinking has been the focus of educational studies and programs (Facione, 1987; Facione & Facione, 2000). Each of these programs has its own definition of thinking and/or of skills. Some use the phrase 'cognitive skills' (Zoller, 2007) while 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 recognized when they occur. Thus, there seems to be no clear consensus as to what exactly critical thinking is. Some see it as simply "everyday, informal reasoning" (Galotti, 1989), whereas others feel differently. Lipman considers it to be different from ordinary thinking because it is both more precise and more rigorous, as well as self-correcting. Our research is underpinned by several questions raised by Passmore (1980): what do we mean by teaching a student to

become a critical thinker? How can this be accomplished successfully? Does it merely involve giving the necessary facts or rather nurturing the student's disposition, molding the personality, or is something else involved? Is being a critical thinker a matter of habit? Passmore does not have answers to all these questions, but in his article he does claim that in the process of developing critical thinking we have to stress the student's "natural disposition." Facione and Facione (1996, 2000) propose a taxonomy of dispositions that includes such elements as cognitive maturity, searching for truth, open-mindedness, systematicity, analyticity, self-confidence, and curiosity. They developed the California Critical Thinking Disposition Inventory (CCTDI) which was originally intended to be used to measure critical thinking dispositions in college students but has been successfully adapted to be used in high school. Another question then arises as to whether dispositions are something that can be changed or improved. Through our research, we hope to shed some light on these questions. The California Critical Thinking Dispositions Inventory (CCTDI) was administered at the beginning and end of the unit.

1.3. The Infusion Approach by teaching Unit "Probability in the daily life"

There are two main approaches for fostering CT: the general skills approach, which is characterized by designing special courses for instructing CT skills, and the infusion approach (Swartz, 1992), which is characterized by developing these skills by embedding them in the teaching of the set learning material. According to this approach there is a need to reprocess the prescribed content material in order to integrate the teaching of thinking skills into the conventional instruction. In this report, we will show how we integrated the mathematical content of "probability in daily life" with CT skills from Ennis' taxonomy, reprocessed the curriculum, tested different learning units and evaluated the subjects' CT skills. One of the overall research purposes was to examine the effect of the infusion approach on the development of students' critical thinking skills through probability instruction. The overarching research purpose was to examine the effect of developing CT by the infusion approach. This evaluation was undertaken using the Cornell questionnaire (a quantitative test) and quantitative means of analysis. In this learning unit, which is a part of the formal National Curriculum in Israel, the student is required to analyse problems, raise questions and think critically about the data and the information. In our research we did it with probability in daily life. The purpose of the learning unit is not to be satisfied with a numerical answer but to examine the data and its validity. In cases where there is no single numerical answer, the students are expected to know what questions to ask and how to analyse the problem qualitatively, not only quantitatively. In addition to being provided with statistical tools students are encouraged to use their intuitive mechanisms to help them estimate probabilities in daily life. Simultaneously, students examine the logical premises of these intuitions, while being alerted to possible misjudgements in their application. Here, the key concepts are: probability rules, conditional probability and Bayes theorem, statistical relations, causal relations and subjective probability (Lieberman & Tversky 2002)

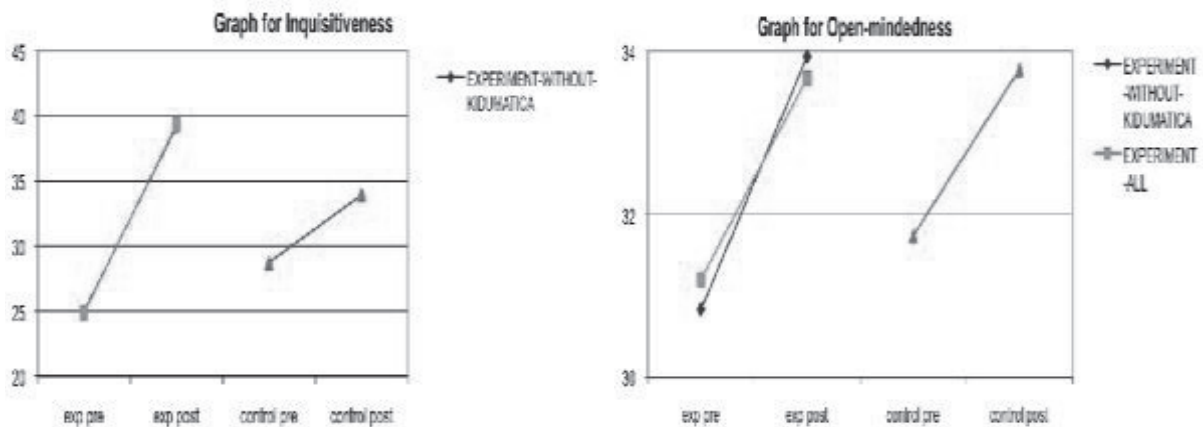
2. Methods

The pilot study reported here was conducted over the period of one academic year in the framework of a larger PhD research and involved one group (n=72) of tenth-grade students in regular high school. The group consisted of thirty students, all high achievers, aged fifteen to sixteen. The teacher was one of the researchers. The learning unit "Probability in Daily Life" (Lieberman & Tversky, 1996) comprised fifteen lessons, each lasting ninety minutes, and was modified by the researchers to combine critical thinking skills with the probability topics it initially contained (Aizikovitsh & Amit, 2008). This unit in probability studies, which is part of the formal mathematics curriculum of the Ministry of Education was chosen because of its rationale of "*learn[ing] issues relevant to the daily life, which include elements of critical thinking*" (Lieberman & Tversky, 2001, p.3). In the unit the student is required to analyze problems, raise questions and think critically about the data and the information. The purpose of the unit is to teach the students not to be satisfied with a numerical answer but to examine the data and their validity. In cases where there is no single numerical answer, the students are required to know what questions to ask and how to analyze the problem qualitatively, not only quantitatively. Along with being provided with statistical instruments,

students are redirected to their intuitive mechanisms to help them estimate probabilities in daily life. Simultaneously, students examine the logical premises of these intuitions, along with misjudgements of their application. This unit examines the term “probability” regarding everyday problems. The uniqueness of the original Lieberman and Tversky’s unit lies in the fact that it allows one to learn interesting subjects of everyday relevance through mathematics. This involves critical thinking elements such as: tangible examples from everyday life, questioning the reliability of information, accepting and dismissing generalizations, rechecking quantitative data, doubting, etc.

3. Results and Discussion

The research described here constitutes a small step in the direction of developing additional learning units within the traditional curriculum. Current research being undertaken by the authors is exploring possible additional methods of CT evaluation, including: the CCTDI scale (Facion, 1992), questionnaires employing various approaches, and a comprehensive test composed for future research. The general educational implications of this research suggest that we can and should leverage the intellectual development of the student beyond the technical content of the course, by creating learning environments that foster CT, and which will, in turn, encourage the student to investigate the issue at hand, evaluate the information and react to it as a critical thinker. It is important to note that, in addition to the skills mentioned above, in the course of this lesson the students also gained intellectual skills such as conceptual thinking and developed a class culture (climate) that fostered CT. Figures 1 and 2 show the sub-tests of the results of the CCTDI test (Fig. 1,2).



Students practiced critical thinking skills as, open mindedness and inquisitiveness by studying probability. In this program of instruction, the following skills were demonstrably practiced: referring to information sources, encouraging open-mindedness and mental flexibility (all questions), a change in attitude and searching for alternatives. A very important attribute is cognitive determination – to be able to express one's attitude and present an opinion that is supported by facts. In this instructional sequence, students could be seen to be searching for the truth, they were open-minded and self-confident.

4. Discussion

In much of the literature on critical thinking we see that there is no significant improvement in all the sub-tests during one year of learning (Barak & Dori, 2009; Ben-Chaim, Ron, & Zoller, 2000). In the sub-tests of our group we did see a marked improvement in systematicity, analyticity, and maturity. On re-examining these sub-tests we noticed that they consisted of a group of questions involving a certain experiment where all the information was presented in the form of tables. During this learning unit we repeatedly worked with tables and we therefore came to the conclusion that the familiarity of the students with the tables enabled them to deal with the statements made and

answer these specific questions more easily. The CCTDI is a self report of the students' beliefs, values, attitudes and opinions consisting of seventy-five separate items. Questions or statements are posed to which the students have to reply how strongly they agree or disagree (on a scale from one to six). By studying the students' responses, a profile of seven critical thinking sub-dispositions can be reached. The dispositions measured are: truth seeking, which shows flexibility in considering alternatives and opinions; open-mindedness, which shows the understanding of others' opinions; analyticity, which shows how persistent the student is in the light of difficulties encountered; systematicity, which shows how diligently the student went about seeking relevant information; confidence, which refers to the student's confidence in his/her own ability to reason; inquisitiveness, which shows how concerned the student is to become and stay well-informed; and maturity, which shows how careful the student is in making or changing his judgments. During the CCTDI we find we find the stages of the creative thinking by Ervynck (1991). Ervynck suggested three necessary stages for the development of mathematical creativity: (i) a preliminary technical stage, (ii) a stage of algorithmic activity, and (iii) a stage of creative (conceptual, constructive) activity. The first stage refers to the practical application of mathematical rules and procedures without knowledge of the theoretical source. The second stage emphasizes the use of procedures in order to perform a mathematical operation with the knowledge of the theoretical source. Finally, the third stage involves activity that is unrelated to a known algorithm, where it entails a new understanding of definitions or wording a new theorem and its proof.

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