Computers & Education 58 (2012) 931–941

Contents lists available at SciVerse ScienceDirect

Computers & Education

journal homepage: www.elsevier.com/locate/compedu

The effect of computer-assisted teaching on remedying misconceptions: The case of the subject "probability"

Ramazan Gürbüz [a,*], Osman Birgin [b]

[a] Adiyaman University, Faculty of Education, 02040 Adiyaman, Turkey
[b] Usak University, Faculty of Education, 64200 Usak, Turkey

ARTICLE INFO

Article history:
Received 8 April 2011
Received in revised form
4 November 2011
Accepted 5 November 2011

Keywords:
Improving classroom teaching
Interactive learning environments
Teaching/learning strategies
Secondary education

ABSTRACT

The aim of this study is to determine the effects of computer-assisted teaching (CAT) on remedying misconceptions students often have regarding some probability concepts in mathematics. Toward this aim, computer-assisted teaching materials were developed and used in the process of teaching. Within the true-experimental research method, a pre- and post-test control group study was carried out with 37 seventh-grade students-18 in the experimental group (CAT) and 19 in the control group (traditional teaching). A 12-item instrument, made up of 4 items related to each of the concepts "*Probability Comparisons* (PC)," "*Equiprobability* (E)," and "*Representativeness* (R)," was developed and implemented with the participants. After the teaching intervention, the same instrument was again administered to both groups as a post-test. In light of the findings, it can be concluded that computer-assisted teaching was significantly more effective than traditional methods in terms of remedying students' misconceptions.

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1. Introduction

Using computers in classrooms as an aid to teaching and learning processes has become increasingly popular during the last three decades. Indeed, a computer-assisted teaching (CAT) approach is highlighted in all current curriculum reforms around the world. CAT can be defined as an interactive strategy used in organizing teaching materials in a computer environment, presenting these materials to the students in a user-friendly format, promoting learning, and detecting and remedying misconceptions. CAT is an important strategy used to determine and to remedy these misconceptions (Baki, Kösa, & Güven, 2011; Chang & Chien, 1996; Gal-Ezer & Zur, 2004; Gürbüz, Çatlıoğlu, Birgin, & Toprak, 2009; Huang, Liu, & Shiu, 2008; Lee, 1988; Liu, Lin, & Kinshuk, 2010; Özdener, 2008; Tirosh, Tirosh, Graeber, & Wilson, 1990; Zydney, 2010). Most of the studies using this strategy demonstrated its effectiveness in remedying misconceptions.

1.1. Mathematics, misconceptions/difficulties, and probability

Various terms are used in order to define the difficulties faced in mathematics learning/teaching. These are the terms that will be used in this paper: *difficulty*, *misconception*, and *error*. The terms are used mostly interchangeably. *Difficulty* is a comprehensive term used herein to describe the difficulties faced by the students in mathematics learning in general (Bingölbali & Özmantar, 2009). Taken in this sense, the term *difficulty* falls short of defining and solving the learning difficulties of students. Because of the above-mentioned characteristic of the term *difficulty*, the difficulties faced by the students are handled primarily with the use of the term *misconception*. Misconception is defined as "perceptions or conceptions which are far from the meaning agreed upon by the experts" (Zembat, 2008). In other words, *misconception* can be defined as known perceptions that diverge from the views of experts in a field or subject matter (Hammer, 1996).

For the past 30 years, scholars have studied students' misconceptions regarding mathematics. Studies have shown that students' conceptions of scientific issues are often not in line with accepted scientific thinking; that is, they have misconceptions regarding various notions. Shaughnessy (1977), Fast (2001) and Gürbüz (2007) suggested that some misconceptions in probability stem from the nature of the

* Corresponding author. Tel.: +90 416 223 24 26; fax: +90 416 223 27 14.
E-mail addresses: rgurbuz@adiyaman.edu.tr, rgurbuz02@hotmail.com (R. Gürbüz).

0360-1315/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.compedu.2011.11.005

subject or the pupils' prior theoretical probability knowledge. So, misconceptions affect students' perceptions and understandings (Hammer, 1996).

Probability concepts are widely used in decision-making processes related to uncertain situations we encounter in our daily lives. In spite of this importance, due to several reasons, an understanding of probability is not being taught as effectively in Turkey as it is in many other countries. The most important reason that the subject of probability is not taught effectively is the rather widespread existence of misconceptions related to this subject. These misconceptions make it difficult to understand the subject. Indeed, many studies have been conducted about the misconceptions in teaching mathematics in general, and specifically in the subject of probability (Batanero & Serrano, 1999; Dooren, Bock, Depaepe, Janssens, & Verschaffel, 2003; Fast, 1997; Fischbein & Schnarch, 1997; Gal-Ezer & Zur, 2004; Garfield & Ahlgren, 1988; Gürbüz, Çatlıoğlu, Birgin, & Erdem, 2010; Huang et al., 2008; Kahneman & Tversky, 1972; Konold, 1989; Konold, Pollatsek, Well, Lohmeier, & Lipson, 1993; Lecoutre, 1992; Lee, 1988; Liu et al., 2010; Manage & Scariano, 2010; Morsanyi, Primi, Chiesi, & Handley, 2009; Özdener, 2008; Shaughnessy, 1977; Tirosh et al., 1990; Zydney, 2010).

1.1.1. Some types of misconceptions

1.1.1.1. Representativeness heuristic. When people make guesses about the outcomes of an experiment, they decide about the representativeness of these outcomes by examining them in certain ways. For example, when people are asked about the set of outcomes that can be obtained in an experiment of tossing a coin several times successively, they are inclined to think that the chances of heads and tails are equal and the distribution is random (Amir & Williams, 1999; Shaughnessy, 1977). This thought is known as 'Gambler's Fallacy'. According to the view of Tversky and Kahneman (2003, p. 207), "for example, after observing a long run of red on the roulette wheel, most people erroneously believe that black is now due, because the occurrence of black will result in a more representative sequence than the occurrence of an additional red."

1.1.1.2. Positive and negative recency. Positive recency misconception is the belief that the outcome obtained from successive experiments will re-occur in future trials. Negative recency misconception is, on the other side, the belief that the outcome obtained from successive experiments will not occur in future trials. For example, in an experiment of tossing a coin successively five times and obtaining 5 times heads repeatedly; the belief that the next trial will result in also a heads is an example for positive recency effect, as well as the belief that the next trial will result in a tails is known as the negative recency effect.

1.1.1.3. Equiprobability bias. This is the belief that the probabilities of the outcomes of an experiment are equal although they are not in fact. Jun (2000), showed a different approach and put the equiprobability bias in three categories. These categories are; a) *thinking that each n different probable outcomes have 50% probability,* b) *thinking that each outcome has a probability of 1/n,* c) thinking that the probabilities of *n* possible outcomes are all equal if they have similar probabilities in fact. For example, a random selection is made in a farm containing 100 sheeps and 250 goats. Thinking that the probabilities of choosing a sheep or a goat are equal is an example of type (a). In another experiment of rolling together two dice designed as (123 456) and (222 333); thinking that the sum of possible outcomes would be equal is an example of type (b). In another experiment of randomly selecting a student from a class of 20 boys and 25 girls; thinking that the probabilities of the outcome to be a girl or boy to be equal is an example of type (c).

1.2. Literature framework of the probability subject

Probability as a subject started to appear in school curricula after the nineteenth century, and since then, cognitive psychologists and mathematics educators have examined students' misconceptions and misunderstandings concerning probability within different age groups (Dooren et al., 2003; Fischbein, Nello, & Marino, 1991; Fischbein & Schnarch, 1997; Garfield & Ahlgren, 1988; Kahneman & Tversky, 1972; Konold et al., 1993; Lamprianou & Lamprianou, 2003; Lecoutre, 1992; Manage & Scariano, 2010; Pratt, 2000). For example, Fischbein and Schnarch (1997), who explored the changes in misconceptions among fifth-, sixth-, seventh-, ninth-, and eleventh-graders and college students who had not been educated about probability, reported that an increase in the students' education level either significantly decreased or increased or did not change their misconceptions about some concepts. In another work, conducted with eight groups consisting of two persons aged 10 or 11, by doing some experiments with materials prepared using a spinner, money, and dice in the computer environment, Pratt (2000) revealed systematic bias about probability in their daily lives. Then, since his students were exposed to numerous experiments by means of this material and various questions, he enabled them to overcome their systematic bias. Manage and Scariano (2010) made some comparative discoveries by investigating the common misconceptions related to "probabilistic independence" and "mutual exclusivity." Subsequently, they have presented some examples that can be used in classroom settings to remedy these misconceptions.

Among the various studies regarding the instruction of probability concepts, it can be seen that several of them were conducted on developing and implementing CAT materials and then assessing the reflections on these practices (e.g., Christmann, Badget, & Lucking, 1997; Gürbüz, 2007; Gürbüz et al., 2009; Pijls, Dekker, & Van Hout-Wolters, 2007; Pratt, 2000). Moreover, when the related literature (Chang & Chien, 1996; Gal-Ezer & Zur, 2004; Huang et al., 2008; Lee, 1988; Liu et al., 2010; Özdener, 2008; Tirosh et al., 1990; Zydney, 2010) was examined, it was determined that there had been no studies conducted on the remediation of students' misconceptions on probability concepts through the use of the CAT method. Therefore, this study aims to investigate the effects of computer-assisted teaching on remedying misconceptions students often have regarding some probability concepts in mathematics.

2. Method

2.1. Research design

Participants were randomly assigned to two groups. In one of the groups, computer-assisted teaching (CAT) (experimental group: E) was performed, and in the other group, traditional instruction (control group: C) was conducted.

2.2. Sample

This study was conducted during the 2009–2010 school year with a total of 37 pupils studying at seventh-grade level in a primary school in the southeastern region of Turkey. These students, studying in the same class, were divided into two groups according to whether their school numbers were even or odd (experimental group = 18 and control group = 19).

2.3. Instrument

The instrument used (*Misconception Test-MT*) was composed of 12 questions (see Appendix 1) using a two-tier question design that consisted of a multiple-choice portion and an open-ended response section. Some of the questions (E1, E4) were developed by the researcher, and others were developed with the help of related literature in the following: (1) question R1 (Batanero & Serrano, 1999; Kahneman & Tversky, 1972); (2) question PC2 (Fast, 1997); (3) question PC4 (Pratt, 2000); (4) question R2 (Dooren et al., 2003; Polaki, 2002); (5) question R4 (Watson & Kelly, 2004); (5) questions PC1, PC3, R3, E3 (Nilsson, 2007, 2009); and (6) question E2 (Tatsis, Kafoussi, & Skoumpourdi, 2008).

This instrument measures students' conceptions of three principal concepts, each of which was measured by four questions: probability comparisons (PC), representativeness (R), and equiprobability (E). The validity of the instrument was confirmed by two mathematics teachers and two mathematics educators. Furthermore, the pilot test was performed with 36 seventh-grade students who did not participate in the actual study. The administration of the pilot study took one class-hour (40 min). The pilot study revealed that questions on the subject of probability were understandable and clear for seventh-grade students. In this study, the Kuder-Richardson formula 20 (KR-20) reliability coefficient of the instrument was found as .81.

2.4. Computer-assisted teaching (CAT) material

More recently, researchers are beginning to examine the effect of more innovative teaching approaches that utilize computer-assisted learning environments to improve students' understanding and to remedy students' misconceptions (e.g., Chang & Chien, 1996; Demetriadis, Papadopoulos, Stamelos, & Fischer, 2008; Gal-Ezer & Zur, 2004; Huang et al., 2008; Lazakidou & Retalis, 2010; Lee, 1988; Liu et al., 2010; Özdener, 2008; Tirosh et al., 1990; Veerman, Andriessen, & Kanselaar, 2000; Zydney, 2010). In computer-supported collaborative learning environments, students can jointly work out a solution to a problem, increase their problem-solving skills in a relatively short period of time, and improve their approach to the solution of a given mathematical problem, showing significant signs of autonomy (Baki & Çakıroğlu, 2011; Baki & Güveli, 2008; Barron, 2000; Demetriadis et al., 2008; Lazakidou & Retalis, 2010; Monteserin, Schiaffino, & Amandi, 2010; Veerman et al., 2000).

Two different materials were used in the context of this study. One of these was material consisting of animations and simulations prepared by using Macromedia Dreamweaver and Flash MX 2004 software. The other was material prepared using Java language and NetBeans editor. The reason that these two materials were used together was that in using only the first material, just a limited number of experiments could be done, and the feedback obtained was also limited. In other words, this material provided only a general feedback for each wrong answer. On the other hand, the second material provided the opportunity to carry out an infinite number of experiments and to see the results of these experiments. The material also provided different types of feedback based on wrong answers. In summary, the first material was used to present theoretical knowledge to the students regarding the subjects and concepts. The second material, on the other hand, was used to exemplify theoretical knowledge, to conduct an infinite number of experiments, to verify the results, and to allow the students to see and interpret the results of their experiments. It was anticipated that, when used together, these two materials would multiply their individual effects and reduce each others' disadvantages.

The implementation started with the first material. For example, the subject was introduced in the experimental group (CAT group) using some events in daily life such as "*Which factors are involved to score a goal in a penalty kick?*" After a short group discussion, students were asked to write their opinions on the related concept and then to pass to another interface on which there was a definition related to the concept stated in the question. Afterwards, the definitions of the concepts *experiment*, *outcome*, *sample space*, and *event* were given, using example applications. Shortly after that, the theoretical aspect of the subject and a representative application were provided through the use of animations and simulations. Only a certain portion of the subject was administered in this initial process, and then the second material was introduced.

Throughout all processes, both sets of materials were kept running on the computer. The student groups worked on either the first or the second material, depending on the situation. However, in general, all the students were first introduced to the theoretical aspect of the subject and then presented with applications of the theory.

Briefly, the second set of material is a tool that allows the student to do experiments, see the results of these experiments, and when supplying a wrong answer, to be presented with tips that will lead to correct answers. In the interfaces in this material, several applications and complementary questions, respectively, were embedded regarding a classical dice, a differently designed dice, a classical coin and dice, two classical dice, two dice designed differently, a spinner, and two spinners. In both interfaces of the material, the students received feedback related to their answers. For example, one question asked, "*In an experiment of rolling two dice together, what are the chances of obtaining a 2 and another 6 on the dice?*" If the student gave the answer 2/36, then she would receive this feedback: "*Congratulations. Correct answer.*" Otherwise, she would receive a different kind of feedbacks. For example, for the answer 2/30, feedback such as "*How many outcomes are possible in throwing two classical dice?*" was provided; whereas, for the answer 1/36, she received feedback such as "*How many outcomes are possible for obtaining a 2 and another 6 on the dice?*" For both materials used throughout the study, the opportunity to make selections on the computer and to concretize abstract mathematical concepts was offered to the participants. Moreover, these materials provided an environment in which students could work in groups, communicate effectively, and construct their knowledge in cooperation.

Two sample interfaces from the designed computer-assisted materials are illustrated in Appendixes 2 and 3. These materials were pilot-studied with 28 seventh-grade students who did not participate in the actual study, and necessary corrections were made. For example, an

applause effect was used for the "check the answer" button in the pilot study. However, the pilot study showed that this sound negatively affected in-class communication; therefore, it was removed later.

2.5. Procedure

A Misconception Test (see Appendix 1) was administered to both groups as a pretest. Both groups were encouraged to answer all the questions. The implementations were carried out with students in experimental group. The students were requested to run the computer animations, and then they were asked to share their thoughts about probability with their friends. Moreover, the student groups asked such questions of each other as "*Why are you doing that?*" and "*How did you get that*" or made statements such as "… *oh no, that is not right, because* …" and "… *but that is wrong, because* …" during the implementations. For this reason, the teacher refrained from responding to correct answers; instead he asked some follow-up questions in a Socratic dialog fashion. During this process, instead of just lecturing, showing, giving tests, and evaluating, the teacher acted as an organizer, facilitator, counselor, cooperator, and supervisor. As a result, students became more active, improved their knowledge, questioned the knowledge they received, and were able to explain what they had just learned instead of behaving as merely passive receivers.

In the control group (traditional teaching group), the instructions were performed on a teacher-centered basis and delivered verbally, according to the book. The teacher would note down the necessary points on the chalkboard (talk-and-chalk type instruction). While writing on the board, the teacher framed the important parts using colored chalk. During the process the students sat in their seats silently and listened to the teacher. Then the teacher gave them some time to take notes from the board. The teacher also asked if they had any questions about the subject. Meanwhile, he walked around the class and answered their questions. However, as the teacher pointed out later in an informal interview, only some bright, hard-working students asked any questions.

In brief, 70–75% of the probability subject was composed of only the teacher's talk. At the end of the lesson, the teacher asked the students to answer the questions at the end of the unit. In the control group, questions such as "*Suppose that pair of dice is rolled* …" were generated and solved. To sum up, the experiments were done and the results were obtained by imagination without the use of any other materials or animations. This teaching intervention procedure was implemented by the same teacher within six class-hour periods for each group during spring of the 2009–2010 school year. During the study, most of the students in the control group wondered how their peers in the intervention group were doing. Therefore, they frequently checked the computer laboratory to figure out what was going on there. A flow of information was observed between the groups, but we think that this could be regarded as an insignificant factor in affecting the results of the study.

2.6. Data analysis

In analyzing the data, students' answers were classified in regard to the levels shown in Table 1. Since two external mathematics educators who had experience in analyzing qualitative data initially categorized the data separately, they discussed the consistency of the categorization. There was high agreement (approximately 90–95%) in most of the categorizations. All disagreements were resolved by negotiation. The instrument consisted of two phases (*first phase*, *multiple choice*; *second phase*, *open-ended*), and therefore the assessment criteria also consisted of two phases.

In this study, the Statistical Procedures for Social Sciences (SPSS 15.0) was used to code and analyze the data. Data were screened and verified for the assumptions of parametric statistics. Independent samples *t*-test was employed to determine the differences between the pretest scores of the groups related to the three concepts in the instrument. Then, the data for the post-tests were analyzed using a 2×1 (experimental versus control) analysis of covariance (ANCOVA), with the pretest as covariate. In fact, a covariance analysis was applied in order to observe any potential difference between the means of the post-test scores of the groups. A Bonferroni pairwise comparisons test was used to determine the direction of differentiation.

3. Results and discussion

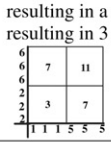
Descriptive statistical results of the pretests and post-tests for the experimental and control groups are given in Table 2 and Fig. 1. The results of the independent samples *t*-tests related to pretest scores of the groups are also provided in Table 3.

As shown in Table 3, the results of the independent samples *t*-test showed that no significant difference was found among pretest scores of the groups related to the three concepts ($p = .963$ for PC, $p = .574$ for R and $p = .541$ for E) in Misconception Test (MT). Therefore, it can be said that both groups had the same level of misconceptions in all concepts prior to the instructional process. Moreover, when the pretest results of the groups are compared, it can be seen that the least number of misconceptions were related to the concept PC. Both teachers and textbooks placed emphasis on this concept, which may be related to that previous finding. However, the concepts of E and R were mostly neglected, and some teachers did not even mention these concepts. For this reason, when the data in Table 2 and Fig. 1 are examined, it can be seen that, in particular, the students in the control group had misconceptions regarding the concepts E and R in both the pre- and post-tests. Moreover, post-test mean scores of both groups were better than their pretest mean scores. However, CAT and traditional instruction were seen to have different effects on remedying students' misconceptions.

In order to compare the effects of instructional strategies implemented with the groups on post-test scores using ANCOVA, tests of homogeneity of within-group regression slopes were conducted. As a result of the analysis – Group * PC-pretest ($p = .494$), Group * E-pretest ($p = .263$), and Group * R-pretest ($p = .600$) – within-groups slopes were found to be homogenous. Therefore, a covariance analysis was applied in order to observe any potential difference between the means of the post-test scores of the groups. The results of the one-way ANCOVA related to the PC, E, and R concepts are given in Tables 4–6, respectively.

As shown in Table 4, the analysis of the PC score data indicated no significant overall intervention effects, controlling for pretest [$F(1, 34) = .658$, $p > .05$]. Regarding the PC score, students in the experimental groups benefited significantly more than those in the control groups (*mean difference* $= .150$, $p > .05$). From the results of the pairwise test, it can be stated that CAT was more effective than traditional teaching methods in remedying students' misconceptions regarding the concept PC. However, there was no

Table 1
The rubric developed for the Misconception Test (MT).

Comprehension Levels	Explanation	Score	Assessment Criteria (1st-2nd Phase)	Sample Response
Correct Justification	Answers that encompass all aspects of the valid justification	3	Correct Answer-Correct Justification	R[a] 1. It has a pattern as in choice "c" thus not so convincing, successive outcomes of T or H as in choice "b" is also not convincing. Thus, choice "a" is more realistic. Because it has mixed outcomes. E[b] 3. Choice "a", because the number of cases resulting in a sum of 7 are more than those resulting in 3 or 11.  For example, 2+1=3, 2+5=7, 6+1=7 and 6+5=11.
		2	Incorrect Answer Correct Justification	E[b] 1. Choice "a", because the number of 4-person families that Mehmet can visit are less, *P* (M) = 24/36 and *P* (Ş) = 60/90. R[a] 3. Choice "a", because half of the numbers on a dice are even and the other half are odd. Indeed, the sum of odd and even numbers are equal.
Partially Correct Justification	Answers that do not encompass all aspects of the valid justification	2	Correct Answer - Partially Correct Justification	E[b] 3. Choice "a", because the distribution is not expected to be normal and in choice "a" 3,7,11 is not normal. PC[c] 1. Choice "b", there are 8 cases that yield a sum of 7 and there are 4 cases that yield a sum of 5. R[a] 4. Choice "b", because it's most logical.
		1	Incorrect Answer Partially Correct Justification	PC[c] 4. May be 16, 11 or 6. Therefore choice "c". E[b] 3. Choice "b", because the amount of the numbers 2+1=3, 1+6=7, 6+5=11 and 1, 2, 5 and 6 are equal.
Wrong Justification	Answers that contain incorrect knowledge	1	Correct Answer - Wrong Justification	PC[c] 3. Choice "c", yet Emre's dice is more likely to come even. Because half of the numbers on the dice are even. E[b] 4. It seems like choice "c", but the player should be in her lucky day. R[a] 3. All are possible but "c" is more realistic because the outcomes are respectively T and H.
		0	Incorrect Answer Wrong Justification	PC[c] 1. The sum of the outcomes of the dices is more likely to be 5. Because there are more 5 on the dices and no 7. E[b] 4. I would turn spinner A, because fewer people turned it. PC[c] 3. Burak wins. Because each toss would yield an even outcome.
No Justification	Correct, incorrect or blank answers with no justifications written.	1	Correct Answer-No Justification	---
		0	Incorrect Answer-No Justification	---
		0	No Answer-No Justification	---

[a] Representativeness, [b] Equiprobability, [c] Probability Comparisons

Table 2
Descriptive statistics.

Measure	Variable	Group	*n*	*M*	*SD*
Pretest	Probability comparisons (PC)	Control	19	1.81	.55
		Experimental	18	1.80	.76
	Representativeness (R)	Control	19	1.02	.44
		Experimental	18	.93	.57
	Equiprobability (E)	Control	19	1.76	.67
		Experimental	18	1.62	.68
Post-test	Probability comparisons (PC)	Control	19	2.19	.60
		Experimental	18	2.34	.49
	Representativeness (R)	Control	19	1.31	.65
		Experimental	18	2.31	.77
	Equiprobability (E)	Control	19	2.07	.66
		Experimental	18	2.48	.46

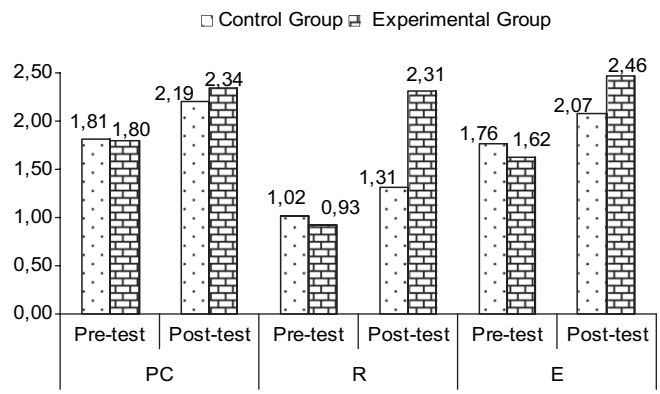


Fig. 1. Pretest and post-test results of the groups related with the concepts of PC, E and R.

significant difference between groups in terms of the concept PC, and this can be associated with the fact that both textbooks and teachers emphasized the teaching of this concept. In this part, students' answers to the questions PC 1, PC 3, and PC 4 were examined briefly.

It was found that the students who had misconceptions regarding question PC 1 had different justifications for their wrong answers. For example, "*It depends on chance so no comment can be made*," "*Choice C, because the probability to obtain 5 or 7 are equal because there are only odd numbers on one dice and only even numbers on the other. Therefore the probabilities are equal,*" and "*Choice A, because 5 is a very special and beautiful number for me*." These statements reveal that they thought that any event naturally depends on chance and therefore has an equal probability. Amir and Williams (1999), Baker and Chick (2007), Batanero and Serrano (1999), Fischbein et al. (1991), Lecoutre (1992), Nilsson (2007), and Pratt (2000) reported similar conclusions in their studies. Moreover, it is understood that students' justifications are affected by their individual learning, experiences, cultures, and beliefs. Amir and Williams (1999), Fischbein et al. (1991), Sharma (2006), Shaughnessy (1993), and Tatsis et al. (2008) reported similar results in their studies.

It was also observed that a few students gave correct answers to question PC 1 based on incorrect justifications. For example, "*The sum would be more likely 7. Because we use all the numbers to obtain 7*," "*7 is more likely. Because 7 is bigger than 5*," "*7 is more likely. Because in order to obtain 5, (3, 2), (2, 3) and (1, 4), (4, 1). In order to obtain 7, (3, 4), (4, 3), (2,5), (5,2) and (1,6), (6,1)*," and "*(22 4444) and the sum of the first dice 6 and (33 5555) the sum of the second dice 8. The mean of 6 and 8 is 7. So, 7 is more likely.*" These kinds of answers revealing some misconceptions of students can be argued to stem from the students' lack of sufficient knowledge in the sample space concept. In parallel, Baker and Chick (2007), Chernoff (2009), Fischbein et al. (1991), Gürbüz (2007, 2010), Keren (1984), Nilsson (2007), and Polaki (2002) showed in their studies that students' knowledge about the sample space concept played an important role in their answers to questions related to the subject of probability.

It was found that the students who had misconceptions regarding question PC 2 gave different justifications for their wrong answers. For example, "*When four tosses resulted in heads, the next toss would more likely yield tails* (Negative recency)," "*Choice B, because tails should be expected. Otherwise, a normal distribution can not be obtained* (Positive recency)," "*These questions are very different, but in my opinion HHHH is not likely. HTHT or HHTT are more likely*," "*This is related to chance. In another experiment the results may be HHHH*," "*Depends on the ability of the player*," and "*It depends on where the money is tossed. For example, the result will be different when the coin falls on concrete ground or in mud*." However, it can be suggested that these misconceptions considerably disappeared in the post-test. The students were found to give different justifications for their correct answers to this question. For example, "*A coin has two sides. Thus, the result may be heads or tails*," "*When no cheat is made, then both are likely to come out*," "*The outcome of a toss does not affect the outcomes of the following tosses. The result may be heads or tails*."

It is suggested that question PC 3 is the one for which the students showed the least number of misconceptions. The students were found to give answers to this question showing misconceptions based on a number of different reasons. For example, "*Choice A, because Emre's dice is designed as (111 444)*," and "*Choice B, because there are more even numbers on Fatih's dice, namely 1, 2, 3, 4, 5, 6, 7, 8,…*." It was also observed that a few students gave correct answers to question PC 1 based on incorrect justifications. For example, "*Choice C, because when a dice is rolled the result can not be foreseen*," and "*Both are equal, since both competitors are male*."

The question PC 4 can be argued to be the question for which the students revealed the highest number of misconceptions. For example, "*Choice A, because the two spinners are turned at the same time and would yield the same result. 3+3 = 6*," "*The probability of obtaining 6 is 1/2 x 1/2 = 1/4 and the probability of obtaining 11 is 1/2 x 1/2 = 1/4. In other words, choice C*," "*Choice B, because it is always*

Table 3
Results of the pretest of the groups related to the concept of PC, R and E.

Variable	Group	*n*	*M*	*SD*	*df*	*t*	*p*
Probability comparisons (PC)	Control	19	1.81	.55	35	.047	.963
	Experimental	18	1.80	.76			
Representativeness (R)	Control	19	1.02	.44	35	.567	.574
	Experimental	18	.93	.57			
Equiprobability (E)	Control	19	1.76	.67	35	.617	.541
	Experimental	18	1.62	.68			

Table 4
A comparison of post-test scores of groups on misconceptions related to the concept of probability comparisons using ANCOVA.

Variable	Group	M^a	Std. error	Mean difference	*df*	*F*	*p*	Partial eta squared (η^2)
Probability comparisons (PC)	Experimental	2.347	.129	.150	1–34	.658	.423	.019
	Control	2.197	.132					

[a] Estimated marginal means for post-test.

easier to obtain the bigger outcome," and "*Both are not my lucky number so the answer is choice C.*" These misconceptions stem from the fact that students perceive these cases as independent, they are lacking in sufficient knowledge about the concept of sample space, and they think that the results obtained from the experiments depend on chance. In parallel, Amir and Williams (1999), Baker and Chick (2007), Batanero and Serrano (1999), Fischbein et al. (1991), Gürbüz et al. (2010), Lecoutre (1992), and Nilsson (2007) reported similar conclusions in their studies.

As seen in Table 5, the analysis of the R score data indicated significant overall intervention effects, controlling for pretest [F (1, 34) = 20.074, $p < .01$]. Regarding the R score, students in the experimental groups benefited significantly more from the CAT method than those in the control groups (*mean difference* = 1.036, $p < .01$). From the results of the pairwise test, it can be stated that CAT was more effective than traditional teaching methods in remedying students' misconceptions regarding the concept of R. Effect sizes (*partial eta squared*) calculated were .371 for R. If these effects should be evaluated according to Cohen (1988), it can be stated that the CAT had a very high effect on R. Likewise, Chang and Chien (1996), Huang et al. (2008), Lee (1988), Liu et al. (2010), Özdener (2008), and Zydney (2010) showed in their studies that CAT is effective in remedying misconceptions.

In this study, it was determined that some students have misconceptions regarding question R1, but based on different reasons. For example, "*If the coin is tossed 10 times, then the chances of heads and tails are equal. Therefore the outcome will be 5 times heads and 5 times tails. The answer is C,*" "*All three choices have equal probability*," "*Obtaining the same result repeatedly is not likely. But mixed outcomes are more likely. So choice A or B*," and "*When a coin is tossed, the outcome does not yield H repeatedly 5 times. It may be at most 2 or 3 times.*" For this question, the students concentrated on choice *C*. As in the concept of PC, the students concentrated on this question generally on the chance factor and the appearance of the choices.

It was also found that some students have misconceptions related to question R2, generally based on the same reasons, and they found difficulty with this question. For example, "*Choice C, because 2/3=200/300*," "*Since the ratios of the answers are the same, the answer is C*," "*The increase in the number of tosses does not affect the results*," "*Choice C, because the difference in two cases is the zeros added to 2 and 3. Zeros have no value*," and "*The probability increases as the number of experiments increase*." Most students gave irrelevant justifications or no justifications at all. It was found that students who gave correct answers to this question had difficulty in providing justifications. Some correct justifications stated by the students were these: "*It is less likely to obtain 200 heads 200 out of 300 tosses*," "*As the number of tosses increase, the probability to obtain heads or coins increase*," "*The probability to obtain 2 heads out of 3 tosses is higher*," and "*As the number of tosses increases, the probability of the expected outcome decreases*." As stated by Kahneman (2003), it can be argued that these students made logical judgments.

Similarly, it was determined that students who had misconception related to question R3 either did not understand the question well or understood it wrong. For example, "*The probability that Erdem wins is 3/6 and it is impossible for Burak. So Erdem wins*," "*Erdem wins, because there are more even numbers (even + even = even)*," and "*Burak wins, because Burak = 6/6 + 6/6 = 12/12 even and Erdem = 3/6 + 3/6 = 6/12 odd*." Some students concentrated on the chance factor in this question, too. For example, "*The person in her luck day will win*," and "*Since the dice are changed, Burak seems to have more chance*." Besides these, some students gave correct answers to question R3 based on incorrect justifications. For example, "*Choice C, because when a dice is rolled everything is possible,*" "*Erdem or Burak, both can win. Because, the structures of the dices were changed*," and "*Both may win, because, I do not know them*."

Question R4 can be suggested to be the one for which the students showed the highest number of misconceptions. The students who gave wrong answers to this question concentrated on choice "*A*" and generally abstained from writing a justification. For example, "*Because all outcomes will occur equally,*" "*Because the dice is in a cubic form and all the outcomes have equal probability,*" and "*Theoretically, the answer should be choice A.*" This is referred to as *equiprobability* in the literature. Indeed, Morsanyi et al. (2009) determined that university students had similar misconceptions. It was found that students who gave correct answers to this question had difficulty in giving justifications. For example, "*Choice B. Because, in experimental probability the outcomes cannot be foreseen*."

As shown in Table 6, the analysis of the E score data indicated significant overall intervention effects, controlling for pretest [F (1, 34) = 5.915, $p < .05$]. Regarding the scores for E, students in the experimental groups benefited significantly more from CAT than those in the control groups (*mean difference* = .446, $p < .05$). From the results of the pairwise test, it can be stated that CAT was more effective than traditional teaching methods in remedying students' misconceptions regarding the concept E. Effect sizes (*partial eta squared*) calculated were .148 for E. If these effects are evaluated according to Cohen (1988), it can be stated that CAT had a very high effect on E. Similarly, Chang and Chien (1996), Huang et al. (2008), Lee (1988), Liu et al. (2010), Özdener (2008), and Zydney (2010) revealed in their studies that CAT is effective in remedying misconceptions.

Table 5
A comparison of post-test scores of groups on misconceptions related to the concept of representativeness using ANCOVA.

Variable	Group	M^a	Std. error	Mean difference	*df*	*F*	*p*	Partial eta squared (η^2)
Representativeness (R)	Experimental	2.236	.165	1.036	1–34	20.74	.000	.371
	Control	1.300	.161					

[a] Estimated marginal means for post-test.

Table 6
A comparison of post-test scores of groups on misconceptions related to the concept of equiprobability using ANCOVA.

Variable	Group	M[a]	Std. error	Mean difference	df	F	p	Partial eta squared (η^2)
Equiprobability (E)	Experimental	2.506	.131	.446	1–34	5.915	.020	.148
	Control	2.060	.127					

[a] Estimated marginal means for post-test.

Most of the students who had misconceptions related to question E1 preferred choice "*C*." Most of the students who preferred choice "*C*" presented justifications such as this: "*It does not matter, Mr. Mehmet or Ms. Sule, because the probabilities are equal.*" The students who had misconceptions regarding choice "*B*" wrote different justifications. For example, "*Choice B, because Mr. Mehmet 36-24=12; Ms. Sule 90-60=30, i.e., P(M)=24/36; P(S)=90/60.*" For all students who had misconceptions, the size of the sampling was not important. Most of the students who gave correct answers to this question gave justifications such as "*As the sample space grew larger, the sought probability decreased.*" As suggested by Kahneman (2003), students who gave correct answers can be argued to have used correct reasoning.

In this study, most of the students who had misconceptions related to question E2 preferred spinner B without making any calculations and by using only informal calculation strategies and visual intuitions. Kahneman (2003) referred to these approaches as flawed intuitions. Some of the students having this kind of misconception gave justifications such as these: "*Red color is more dominant on spinner B*" and "*Since there are more red areas on spinner B, therefore the probability to stop on red is higher after each turning.*" Few students selected choice "*A*" based on justifications such as "*On spinner A two cherries are received on red, so it will finish earlier.*"

The question E3 can be suggested to be the one for which the students showed misconceptions most frequently. As stated by Kahneman (2003), Gürbüz (2007) and Gürbüz et al. (2010), students are observed to give their answers based on their visual intuitions rather than on their logical reasoning. It was determined that students were giving wrong answers to this question based on different reasons. For example, "*Choice B. Because the probabilities of 3, 7 and 11 are equal*" and "*Because the odd and even numbers are equal on the dices, the answer is choice B.*" Similarly, some students focused only on the magnitude such as in these responses: "*Choice C. Because the sum of two numbers is always bigger*," and "*As the number of tosses increases, the outcome will be larger. So, choice C.*" In addition, it was also found that some students gave correct answers based on wrong reasons. For example, "*Since the distribution will be disorderly, the answer is choice A*," and "*Choice A, because the distribution will not come out as shown in choices B and C.*"

It was also found that students have misconception related to question E 4 based on different reasons. For example, "*I would choose spinner A. Because it is highly probable that the spinner stop at the color where it began*," "*I would choose spinner A, because fewer people turned it*," and "*Choice A, because the arrow stopped exactly in the middle on spinner A.*" It was also found that some students gave correct answers to this question based on wrong reasons. For example, "*An outcome such as green in A does not affect B, as well as an outcome such as blue in B does not affect A. Because A and B are mutual events. Therefore, choice C.*" Besides these, some students gave correct answers to this question based on different reasons. For example, "*A and B spinners are all the same because the probability is equal in both,*" "*The probability to win is ½ in both. The answer is C,*" and "*Choice C, because the number of winners is not important. What is important is the probability, i.e., both have a probability of 50 %.*"

These findings can be summarized in the following way: CAT showed a positive impact on remedying students' misconceptions regarding the subject of probability and enabled conceptual learning. These positive effects are thought to be obtained by computer-assisted teaching materials accompanied by a student-centered learning environment. Since teaching in Turkey is very teacher-dominated and heavily dependent on textbooks during the lessons, it serves to encourage rote and rule-based learning rather than conceptual learning. Thus, students are compelled to memorize the topics and regurgitate answers when asked questions on exams. Therefore, students are probably unable to develop a scientific understanding of key concepts, i.e., probability concepts, or to represent their understanding when required in daily life or in scientific situations.

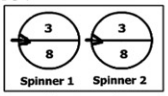
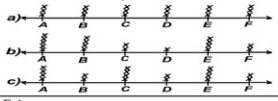
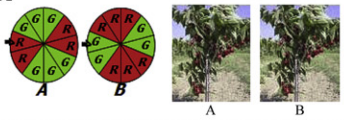
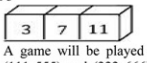
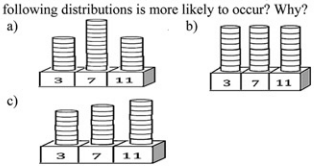
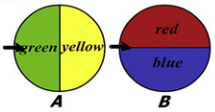
4. Conclusions and implications

As a result of this study, it can be suggested that post-test scores regarding the concepts of PC, E, and R showed a significant increase when compared to pretest results. Thus, both instructional methods can be argued to improve students' learning and reduce their misconceptions. Yet, when the improvements in the groups are compared, it can be said that the intervention in the experimental group was more effective in remedying the misconceptions. Several factors are thought to be effective in this result: students construct their own knowledge in CAT environment, misconceptions regarding probability can be remedied by doing the exercises on the materials, the problems used in this process are taken from real life, and this process increases student motivation.

The concepts of probability seem to be much more complex, in many respects, than are usually considered. If one intends to develop by instruction a strong, correct, coherent, formal, and intuitive background for probabilistic reasoning, one has to cope with a large variety of misunderstandings, misconceptions, biases, and emotional tendencies. Such distortions may be caused by linguistic difficulties, by a lack of logical abilities, by the difficulty of extracting the mathematical structure from the practical embodiment, or by the difficulty of accepting that chance events may be analyzed from a deterministic-predictive point of view. Similar difficulties were previously reported by Jones, Langrall, Thornton, and Mogill (1997) and Gürbüz (2007, 2010).

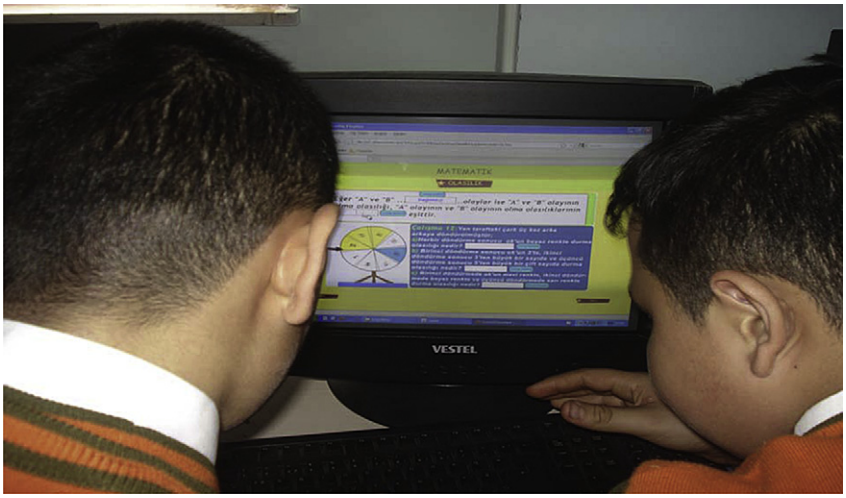
In traditional learning settings, mathematics instruction is carried out mostly by a teacher-centered approach and by adhering to an official textbook. This approach is not sufficiently effective in remedying the misconceptions of the students (Kajander & Lovric, 2009; Manage & Scariano, 2010). In fact, instructional strategies like the CAT one described in this paper should be adopted in addition to textbooks in order to remedy students' misconceptions in mathematics education. The materials used in this study can also be applied in conjunction with several other instructional tasks, and the effects of these materials on students' conceptual development on the subject of probability can then be investigated. Moreover, the effects of CAT and activity-assisted teaching on remedying the misconceptions of probability subject can be compared.

Appendix 1. Question items used in Misconception Test

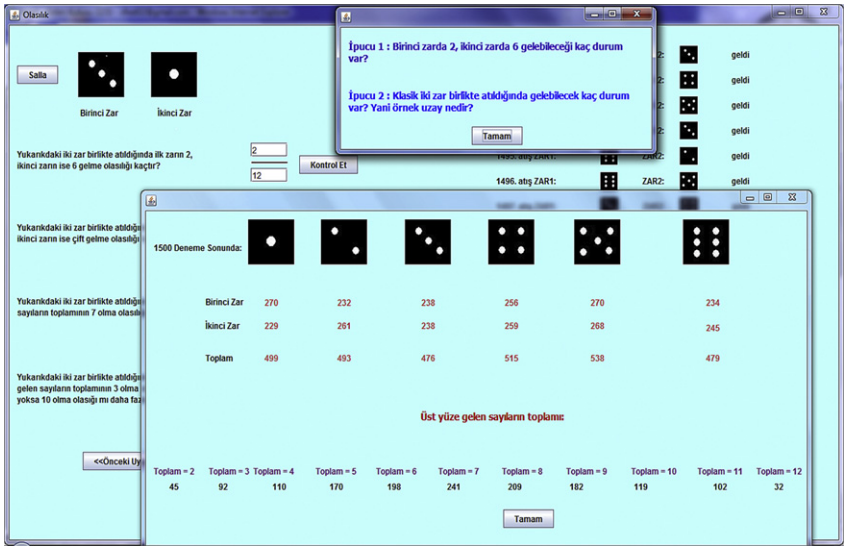
Probability Comparisons (PC)	PC[c] 1 Two dice are designed such as (22 4444) and (33 5555). When these dice are rolled together; which is more likely to get as a sum on the upper faces of the dices, 5 or 7? Why? a) 5 is more likely. b) 7 is more likely. c) The probabilities of 5 or 7 are equal.	PC 2 A coin is tossed four times and the results are HHHH. What is more likely for the next toss, Heads or Tails? Why? (T= Tails, H=Heads) a) H is more likely. b) T is more likely. c) The probabilities are equal.	PC 3 Emre plays by using a dice designed such as (111 444), Fatih plays by using a normal dice. When both players roll their dice, which of the following cases are more probable? Why? a) It is more likely that Emre's dice yield an even outcome. b) It is more likely that Fatih's dice yield an even outcome. c) The probability of obtaining an even outcome is equal for both dice.	PC 4  Two spinners as shown above have numbers 3 and 8 written on the equivalent halves. When these spinners are turned, the sum of the outcomes will be more likely 6 or 11? Why? a) 6 is more likely b) 11 is more likely c) The probabilities of 6 or 11 are equal.
Representativeness (R)	R[a] 1 A coin is tossed ten times. As a result of these tosses, which of the following sequences of outcomes is most likely? Why? (T = Tails, H= Heads) a) HTHHTHTHHT b) TTTTTHHHHH c) THTHTHTHTH	R 2 Which is more likely; obtaining 2 heads when a coin is tossed three times or obtaining 200 heads when a coin is tossed 300 times? Why? a) The probability of obtaining 2 heads out of 3 tosses is higher. b) The probability of obtaining 200 heads out of 300 tosses is higher. c) The probabilities are equal in both cases.	R 3 Erdem and Burak will play a game by using toy cars on a 10 step long road. Each player will roll the two dice designed such as (333 444) and (222 666) at the same time. If the sum of the outcomes is even, Erdem will move his toy car one step further. If the sum of the outcomes is odd, then Burak will do the same. The one who completes the 10-step long road earlier will win. In your opinion, who wins the game? Why? a) Erdem wins. b) Burak wins. c) Erdem and Burak have equal chances.	R 4 A dice on whose sides the letters A, B, C, D, E, and F are written is rolled 18 times. Which of the following results is more realistical? Why? 
Equiprobability (E)	E[b] 1 Mr. Mehmet is assigned to Site A and Ms. Şule is to Site B in order to carry out the census in a region. In 24 of 36 flats in Site A, and in 60 of 90 flats in Site B, 4-person families are residing. According to this, who is more likely to visit a 4-person family, Mr. Mehmet or Ms. Şule? Why? a) Mr Mehmet b) Ms Şule c) There is no difference	E 2  You and your friend will play a game using the spinner A and B shown above and the cherry trees A and B which have 10 cherries each. The rule of the game dictates that if the spinner stops on red, 2 cherries and if it stops on green 1 cherry will be taken. The player who finishes the cherries will win the game. Which spinner would bring more chance? Why? a) Spinner A b) Spinner B c) Both Spinners A or B are the same	E 3  A game will be played using two dice designed such as (111 555) and (222 666). When these two dice are rolled together, the sum of the numbers on the upper faces of the dice are read and then a piece will be added to the block with the same number. As a result of 24 rolls, which of the following distributions is more likely to occur? Why?  	E 4  The rule of the game is that when the spinners above are turned, if they stop at yellow or blue areas, an MP3 player is won by the player. There are 50 players in the competition and the first 3 three players turned the spinner A and it stopped each time at yellow area. The next 5 people turned spinner B and it stopped each time at blue area. If it were you, which spinner would you choose? Why? a) Spinner A b) Spinner B c) Both Spinners A or B are the same

[a] Representativeness, [b] Equiprobability, [c] Probability Comparisons

Appendix 2. A sample interface from the developed computer-assisted teaching material-I



Appendix 3. A sample interface from the developed computer-assisted teaching material-II



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