The present study examines a number of cognitive factors that may predict creative ability in mathematics. The study was conducted among 359 elementary school students in Cyprus, using four different instruments. The results revealed that students’ mathematical creativity may be predicted only by students’ mathematical abilities. In particular, the ability of students to solve inductive and deductive reasoning problems as well as the ability to process similarities and differences in mathematics contribute to the prediction of creative potential in this content. Intelligence, working memory, speed and control of processing, were not found to predict mathematical creativity.

**Keywords:** Mathematical creativity, mathematical abilities, cognitive factors.

**INTRODUCTION**

Contemporary curricula emphasize the development of students’ creative thinking in order to be congruous with the continuous changes and advance challenges of current society (Lamon, 2003). Therefore, several attempts have been made to determine the factors that influence general creative ability in order to enhance individuals’ creative potential. Intelligence (Sternberg & O’Hara, 1999), prior knowledge (Sheffield, 2009), memory (Geary & Brown, 1991) and information processing (Sternberg & O’Hara, 1999) are some of the factors that have been investigated in combination with general creative abilities.

The present study purports to examine which of the abovementioned cognitive factors may predict creative ability in mathematics. In particular, we firstly aim to confirm that students’ content knowledge may predict mathematical creativity, whereas intelligence, working memory, speed and control of processing have no predictive value. Secondly, we intend to investigate which types of mathematical abilities contribute to the prediction of creative potential in mathematics.

**THEORETICAL BACKGROUND**

Numerous studies have reached conflicting results about the relationship between intelligence and creativity. Several studies suggested that intelligence constitutes a superset of which creativity is a subtest (e.g. Gardner, 1993) while others considered intelligence to be a subset of creativity (e.g. Sternberg & Lubart, 1995). Other investigated intelligence and creativity as overlapping sets (e.g. Sternberg, 1985) or even as disjoint sets (e.g. Torrance, 1975). Due to these contradicting results regarding the relationship between intelligence and creativity, the issue remains unsolved (Sternberg & O’ Hara, 1999).

Moreover, creativity was found to depend on the amount of available ideas that can be recombined. Particularly, content knowledge is essential for the creative individual, in order to make connections between different concepts and types of information (Sheffield, 2009). Likewise, prior knowledge consitutes the backbone on which new information will be organised and determines the extent to which these information will be explored and developed (Sheffield, 2009).

In addition to content knowledge, Guilford (1962, in Mann, 2006) stressed the importance of organizing, retrieving and applying information where appropriate, in an effort to emphasize the importance of memory in creative thinking. Finally, information processing has been proposed to characterize creative thinkers, given that it involves flexibility on switching between conceptual systems (Sternberg & O’Hara, 1999).

Despite the number of studies on cognitive factors that influence general creativity, there is a lack of corresponding research on domain specific creativity, such as mathematical creativity. Moreover, the relationship between several cognitive factors and creativity have
been studied in isolation and no attempt has been made to ascertain the effect of all these cognitive factors on mathematical creativity. Therefore, the first aim of the study is to assess whether a theoretically driven model, in regard to the cognitive factors that may predict creative ability in mathematics, fit to the data. The second aim of the study is to investigate which of the mathematical abilities predict mathematical creativity.

**METHOD**

The sample consisted of 359 4th, 5th and 6th grade elementary school students in Cyprus. Students worked individually in the laboratory of their school in order to complete the instruments. The administration time ranged from 80 to 120 minutes.

Four different instruments were used: mathematical abilities instrument, memory-processing instrument, intelligence instrument and mathematical creativity instrument. All the instruments were given in electronic form, except from the intelligence instrument which was given as a paper-and-pencil test. The mathematical instrument consisted of 29 tasks measuring the following abilities: manipulation of quantities, causal relationships, visualization and spatial reasoning, processing of similarities and differences, inductive/deductive reasoning. The working memory and processing instrument included two activities. The first activity measured an individual’s ability to remember a figure when it appears on the screen for a short period of time and to distinguish it among other similar figures. In the second activity the individual had to focus on the form of stimuli presented and press the correct keyboard button according to the stimuli. The items that the stimuli appeared in the same direction as the keyboard button that had to be pressed, measured speed of processing. The items for which the keyboard arrow to press was inconsistent with the part of the screen that the stimuli appeared, measured control of processing. Furthermore, fluid intelligence was measured with the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999). Finally, the creativity instrument included five items. The assessment of students’ creativity was based on the distinction of students’ fluency (number of right answers), flexibility (number of approaches that are observed in a solution) and originality (new and unique ideas) (Torrance, 1974).

Data analysis aimed to explore the cognitive factors that predict mathematical creativity and to investigate the relationship between specific mathematical abilities and creativity. Confirmatory factor analysis (CFA) was conducted to test for model fitting, using the statistical modeling program MPLUS (Muthen & Muthen, 2007). Three fit indices were calculated, before evaluating model fit: The comparative fit index (CFI), the ratio of chi-square to its degree of freedom ($\chi^2/df$) and the root mean-square error of approximation (RMSEA). According to Marcoulides and Schumacker (1996), for the model to be confirmed, the values for CFI should be higher than 0.90, the observed values for $\chi^2/df$ should be less than 2 and the RMSEA values should be close to or lower than 0.08.

**RESULTS**

The results of the analysis revealed that the theoretical model matched the data set of the present study and determined the “goodness of fit” of the factor model (CFI=0.990, $\chi^2=53.945$, df=43, $\chi^2/df=1.254$, RMSEA=0.027). Figure 1 presents the structural equation model with the variables and their indicators.

According to the model, mathematical creativity consists of fluency ($r=0.835$, $p<0.05$), flexibility ($r=0.926$, $p<0.05$) and originality ($r=0.790$, $p<0.05$) and could be predicted only by mathematical ability ($r=0.547$, $p<0.05$). Regarding the latter, five distinct components constitute mathematical ability and therefore contribute to the prediction of mathematical creativity: (a) spatial ability ($r=0.327$, $p<0.05$), (b) quantitative ability ($r=0.673$, $p<0.05$), (c) qualitative ability. The data suggest that intelligence, working memory, control and speed of processing did not predict mathematical creativity.
Due to the fact that mathematical ability was found to predict mathematical creativity, a second CFA was conducted in order to examine which mathematical abilities contribute more to mathematical creativity. The data of the present study verified the theoretical model, as it is presented in Figure 2 (CFI=0.9911, $\chi^2$=16.845, df=10, $\chi^2$/df=1.684, RMSEA=0.044).

The statistically significant loadings of spatial ability ($r=0.141$, $p<.05$), quantitative ability ($r=0.115$, $p<.05$), qualitative ability ($r=0.185$, $p<.05$), causal ability ($r=0.112$, $p<.05$) and inductive/deductive ability ($r=0.233$, $p<.05$) show that these abilities may predict mathematical creativity. The ability to solve inductive and deductive reasoning problems, as well as the ability to process similarities and differences in mathematics, which we named qualitative ability contribute more to the prediction of creative ability in mathematics.

**DISCUSSION**

Data analysis revealed that mathematical ability is the most fundamental of the components under investigation for predicting mathematical creativity. Since creativity depends on the amount of ideas that are available for recombination (Sheffield, 2009), if an individual has a limited domain knowledge then he/she will have fewer resources to draw from and to form new ideas. In contrast, general psychological factors as working memory, intelligence, speed and control of processing are not valid predictors of mathematical creativity.

Additionally, the findings confirmed that the ability to solve inductive and deductive reasoning problems as well as the ability to process similarities and differences in
mathematics could better predict mathematical creativity. The first ability is incorporated in the definition of mathematical creativity given by Ervynck (1991), while the second ability has been included in the description of mathematical creative individuals, as proposed by Haylock (1987). As Ervynck (1991) stated “mathematical creativity is the ability to solve problems … taking account of the peculiar logico-deductive nature of the discipline” (p.47). At the same time Haylock (1987) proposed that “creativity includes the ability to see new relationships … and to make associations between possible unrelated ideas” (p. 60).

According to Pehkonen (1997), creativity should be an essential element for the accomplishment of the idea “mathematics for all”. For this reason, teachers and educators may use the proposed models as guidance as to which abilities predict mathematical creativity and invest on these abilities.

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