# XCOLONY EDUCATIONAL ACTIVITIES ENHANCE SPATIAL REASONING IN MIDDLE SCHOOL STUDENTS

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*This study aims to measure the effectiveness of the manipulative learning tool XColony KDK for developing spatial intelligence as a component of mathematical creativity in students. Our study engaged two groups of 5th grade students: the target group followed through a KDK program of 8 weekly sessions of 1 hour per week; the control group followed a similar educational program, except that the 1 hour session was focused on standard topics instead of KDK. Students in both groups were tested with specially designed tests at the beginning and at the end of the KDK program. Target group data was calibrated based on the control group measurements to eliminate biases induced by curricular learning, variability in difficulty level across test problems and other external factors. We found that in the target group XColony KDK activities lead to a significant 26% increase in spatial reasoning and to 17% increase in a global score for comprehension, problem solving and reasoning.*

*Key words: creativity, manipulatives, spatial intelligence, XColony KDK*

## INTRODUCTION

The mathematics community widely accepts the idea that the essence of mathematics is not limited to problem solving but it also includes the creative thinking process that led to finding the solution (Dreyfus & Eisenberg, 1996; Ginsburg, 1996; Mann, 2006). Consequently, promotion and development of creative mathematical thinking in school becomes a necessity (Leikin & Pitta-Pantazi, 2013).

In many countries, this necessity is included in the education policies. The Romanian National Curricula for secondary school recommends the development of "open and creative thinking". (MECI, 2009). In the USA, similar actions are recommended by the NCTM Standards (NCTM, 2000). On the other hand, teachers perceive the existence of some "barriers" in organizing creative mathematical activities in school (Kattou, Kontoyianni & Christou, 2009).

*What activities could teachers use for developing creativity in students?*

A recent study (Kell, Lubinski, Benbow, & Steiger, 2013) shows that spatial intuition predicts innovations in STEM (science, technology, engineering, mathematics) domains. Problem solving and problem posing were found to foster creativity (Pehkonen, 1997; Silver, 1997) and the use of manipulatives (Brunkalla, 2009) and virtual manipulatives (Bos & Lee, 2014) develops students' creativity in geometry.

We focus on the following questions: *How can we incorporate manipulatives into mathematical classroom activities, in order to promote understanding, foster creativity, and support other curricular areas?*

Our empirical study is based on the classroom use of the educational resource called the *Knowledge and Discovery Kit* (KDK) - a series of XColony construction games consisting in mathematical manipulatives and educational activities (Alexe, Voica & Voica, 2014). The KDK was introduced to the mathematical teaching community through a series of workshops presented in international conferences, including EPC - TKS 2013, Sinaia, Romania and The 8th International MCG Conference – Denver, Colorado, USA, 2014.

Our study follows up on the research questions raised during the MCG 2014 conference, by investigating whether manipulative activities such as XColony KDK are able to encourage the development of students' creativity in mathematics and to promote understanding.

The results of our study confirm these hypotheses and show in a case-control experiment that XColony KDK activities lead to a significant increase by 26% in spatial reasoning, and to an increase by 17% in a global score for comprehension, problem solving and reasoning.

## METHOD

### XColony KDK

The KDK is a series of modular construction games. Starting from elements planar chains of regular hexagons (Fig. 1a), one can assemble basic and complex modules (Fig. 1b, 1c).

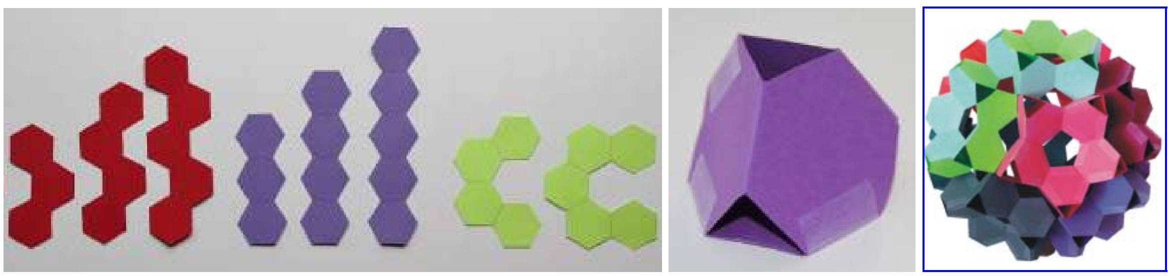


Figure 1. a. 2D Elements b. Module T c. Complex building

The modules display physical facets of hexagonal form, and co-facets (virtual faces). Two modules can be connected resulting in a more complex module; repeating operations of this kind leads to the construction of buildings of gradually increased complexity.

### Sample and procedure

Our study was designed as a case-control experiment in agreement with the standard practice (Vandenbroucke & Pearce, 2012) to evaluate the effect of XColony KDK activities in enhancing the geometric reasoning and creativity in 5th grade students from the *Herastrau Middle School*, Bucharest, Romania. A target group of 28 students and a control group of 17 students with similar curricular background were selected.

### Students in the target group

Students in the target group participated in the XColony KDK program for 8 weeks, in sessions of 1 hour per week, as part of their optional class offered through the school curriculum. During this period students in target group performed several activities:

A. they carried out tasks related to the construction of spatial structures presented in documentation and movies, and introduced by the teacher

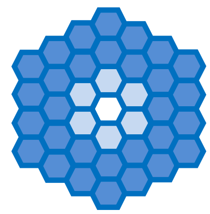
B. they were challenged to propose and ask questions like: a. How else would you designate the construction you just made? b. How can you use this construction? c. What other constructions do you think are possible to be obtained?

The questions in part B were meant to detect the development in student comprehension, reasoning and imagination.

Students in the control group followed a similar curricular training program as the training group, except that the topics for the optional class were different: instead of XColony KDK sessions they had standard mathematics topics like divisibility and prime numbers.

## Data collection

Both the target and control groups were given the same 2 tests: one at the beginning and one at the end of the XColony program (see Appendix). Each of the two tests consisted of 3 questions aimed to evaluate features as: spatial intelligence (Q1, Q2, Q3), geometric measurements and estimations (Q2, Q3), and composing/decomposing of geometric shapes (Q1,Q3). For illustration, a question included in the final test is described below:



> **Q2(final)**: *Andy would like to make an exterior frame for the picture in the image shown on the right. He wants to use hexagonal pieces of the same shape and size as the elements of the picture itself. How many pieces does he need? Explain your reasoning.*

Both tests were administered by the students' math teacher within a time range of 50 minutes. The target and control groups took the tests simultaneously. The final test was intended to be harder than the initial one, in order to increase the sensitivity of evaluation.

We expected that test data might include small amounts of noise due to local conditions: although target and control groups are coming from the same school and they are having the same curriculum, they are not sharing the same teachers. We used the control group for the purpose of minimizing the noise induced by such external factors, by calibrating the target group data.

## Data analysis

The results of the initial and final tests were analyzed along 3 coordinates: comprehension, solution/problem solving, and argumentation/reasoning. Each question received a binary score 0 or 1 for each coordinate; the score assignment rules were defined in advance in a consistent way for both control and target groups. As an example, for the question Q2(final), the following scoring rules were defined and applied:

***Comprehension* (C)***:* the student shows (using words or drawings) that he/she realize that the frame is exterior to the picture, made of regular hexagons that have to be arrange around the picture in a "circular" shape

***Solution/ Problem Solving* (S)***:* the student writes the correct answer: 24 pieces are needed

***Argumentation/Reasoning* (A)***:* the student draws the additional pieces, and based on the drawing he/she formulate the answer. Alternatively, the student provides reasoning based on estimation/approximation or explain his/her answer (even if not correct).

A **global score (CSA)** was defined as the average of the C, S and A scores.

All precautions were taken in order to eliminate any subjectivity in scoring. The results of the final and initial tests applied to the target and control groups were consistent and comparable.

The effect of the XColony KDK activities in enhancing geometric reasoning, problem solving and learning abilities in the target group was evaluated based on a comparative analysis of the C, S, A and CSA scores in the final vs initial test. The control group was used to evaluate the effect of external factors – other than XColony KDK activities - that account for performance differences in the final vs initial test (e.g., variance in the grade of difficulty across problems, curricular learning in-between the tests, etc.)

We hypothesized that the performance changes for the target group are explained through the additive effect of XColony KDK activities and the effect of external factors evaluated in the Control group: **ΔTarget.Group = XColony Effect + ΔControl.Group**, where Δ denotes performance changes in final vs. initial tests. Therefore the effect of XColony KDK activities was computed based on the score changes in the target group after **calibration with the control group**. Calibration was performed by subtracting from each C, S, A or global CSA score in the target group the average of the corresponding score in the control group.

The results of the target group in the final test were then compared for compatibility with the scholar grades for performance in curricular mathematics.

## Results

We present the results of this study in two categories: qualitative and quantitative.

### Qualitative analysis

A holistic analysis of students' answers in the initial and final test reveals several interesting aspects:

*Communication.* The target group improves the communication skills: in the final test, the majority of the students could provide coherent reasoning on how they got the results, and what choices have been made. The students in the control group do not show a similar development.

*Argumentation/Reasoning.* In the final test, students in the target group provide more variants for reasoning, vs. their initial test and to the final test of the control group. For instance, while solving Q2(final), the reasons are based on completing the missing hexagons (drawn or sketched) and then counting them; other approaches try to identify a recursion for the subsequent layers based on the rules observed for adding new pieces.

*Intuition.* The students in the target group show improved skills in the recognition of geometric patterns and forms. Initially, many students mistook the Hc3 element to a set of 3 hexagons, each one adjacent to the other two. Errors of this type are much fewer in the final test of the target group. Many students in the control group have difficulties with understanding the form of the element Hc5: they recognize the global pattern, but fail to understand the local structure.

## Quantitative analysis

The test scores obtained by students in the control and target groups are provided in Supplementary Tables S1 and S2. The changes in the C, S, A and global CSA test scores are depicted in Supplementary Figures S3, S4 and S5. The positive correlations between CSA global test scores and curricular math grade scores are illustrated in Supplementary Figure S6. The negative differences between scores in final vs initial non-calibrated tests support that **the Final test was more difficult than the Initial test.**

Calibrated target data was investigated for significant differences in C,S,A and CSA scores in the final vs initial tests based on 2 tailed t-test with the P-value cut-off 0.05 (Stockburger, 2013). Figure 2 depicts boxplots for target group scores in the initial and final test, along with their differences (delta scores). The changes in argumentation/reasoning (26% increase) and in the global comprehension, problem solving and reasoning score (17% increase) were significant (P-value: 0.004 and 0.02, respectively.)

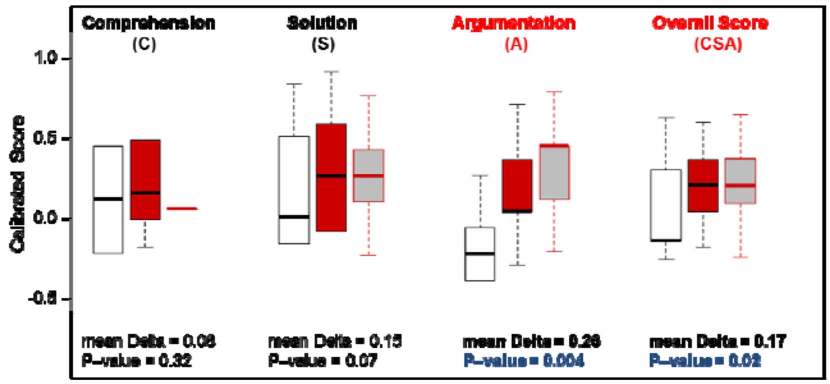



Figure 2. Comparative analysis of C, S, A and global CSA scores changes in the final vs. initial tests based on calibrated target data. White/red boxplots present scores assigned in the initial/final tests; gray boxplots present difference (Delta) scores for final vs initial tests.

## CONCLUSIONS

The paper reports an empirical case-control research with forty-five 5th grade students. The study is based on the systematic use of XColony KDK for optional class activities, and on comparing the results of target and control groups in two final vs. initial tests. Our study found that XColony KDK activities lead to enhanced spatial intelligence and overall problem solving abilities in the target group students.

**Student's score in our tests is also predictor for his/her performances in curricular math.** The scores in the initial and final tests of the students in the target group are highly correlated (0.67 and 0.68, respectively) with students standard math grades in school.

**XColony activities promote understanding of mathematical concepts.** The adjusted scores of the students in the target group show 26% increase in spatial reasoning, 15% in solution finding, and 7% in comprehension.

**XColony activities enhance students' creativity.** The results of the study indicate significant development of spatial intuition (i.e., skills required to mentally manipulate 2D and 3D objects) in students in the target group, thus confirming previous research (Alexe, Voica & Voica, 2014).

We plan to extend our research with new studies across various cultural environments (region, curriculum, level of education) in order to obtain larger amounts of diverse data that will increase the accuracy of the results.

**Acknowledgements.** The authors gratefully thank Aurelia Grigorescu, Angela Newberry, and Wai Leng Lye for their involvement, support and feedback in this research.

**Appendix.** Additional details (initial and final tests, tables and pictures) about this study are available in the Appendix: www.x-colony.com/MCG9_Appendix.pdf.

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