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New Tools for Spatial Intelligence Education: the X-Colony Knowledge Discovery Kit

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Abstract. This study introduces a new framework for developing spatial education programs based on a geometric language and manipulation of ensembles of polyhedra, called *X-Colony Knowledge Discovery Kit* (KDK). The KDK main goals are to develop spatial intelligence, creativity, strategic planning, forecasting skills, abstract reasoning, self-confidence, and social skills. Landmark studies document that spatial education plays a central role in driving performance in science, technology, engineering and mathematics (STEM) occupations, yet spatial education is under-studied and the infrastructure for research on spatial learning is at the beginning. KDK introduces a novel geometric language that allows visual communication and develops spatial abilities by engaging students to perform creative paper folding and various mental spatial transformations. KDK is organized in program sessions consisting of cooperative open-end paper construction activities that engage students to build modular constructions of gradual complexity and to explore various strategies for combining the constructs into novel configurations. KDK supports the Core Math Standard and Science curricula and provides students the opportunity to discover connections between mathematics, science and various other disciplines. A pilot case-control study conducted with fifth grade students indicates an average increase of 17% in geometric reasoning after 8 hours of KDK activities.

Keywords: Spatial Intelligence; Creativity; Geometric Language; Knowledge Discovery Kit KDK; Modular Paper Constructions

JEL Classification: I250

1. Introduction

Landmark research studies document that spatial education at early age plays a central role in achieving performance in school and in Science, Technology, Engineering and Mathematics (STEM) occupations in the information age (Frick, et al., 2014; Jirout, et al., 2015; Newcombe, 2010; Kell, et

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al., 2013; Lubinski, 2010; Wai, et al., 2009). Despite the increased interest in training spatial abilities the infrastructure for research on spatial education is at the beginning and spatial education is under-studied. Current approaches for developing spatial learning tools and educational programs involve the use of puzzles, real or virtual manipulatives, and games like Lego, Rubik' s Cube, Tetris, Chess, Origami.

Hereby we present the *X-Colony Knowledge Discovery Kit* (KDK), a systematic, flexible and dynamic expandable platform for developing spatial education tools based on a new "geometric language" and manipulation of ensembles of polyhedra which was invented by Sorin Alexe (Alexe, 2012).

KDK was developed as a collection of open end paper construction activities which provides students the opportunity to unleash their imagination in assembling geometric modules of gradual complexity and to discover connections between mathematics and various other disciplines, from history of ancient Egypt, to aquatic life-forms, geology of planets in the Solar System, and possible life styles in the near future.

KDK main goals are to develop spatial intelligence, creativity, strategic planning and forecasting, abstract reasoning, and to enhance fine motor skills, focus, self-confidence and social skills. KDK programs support the Core Math Standard curriculum and and are designed to be used in after-school programs, math clubs and summer camps.

In a first phase, the KDK programs were evaluated on culturally diverse 2-8 grade students, in several places worldwide: after-school programs (Hulstrom K8, Northglenn, Colorado, USA; National Junior College, Singapore; Middle School Herastrau, Bucharest, Romania, 2014), summer camps (Romania, 2012-2013). The KDK effect in fostering spatial abilities was evaluated in a pilot study with 5th grade students at Herastrau Middle School, Romania.

The evaluation results indicate that students enjoyed the KDK programs, became engaged and eager for new discoveries within ad-hoc brainstorming actions, gained more confidence, became more focused, recognized geometric forms with increased precision, and increased their performance in geometric reasoning. Overall the results suggest that the KDK educational activities are effective in educating spatial abilities for middle school students.

2. The KDK Educational Platform

2.1. KDK Basic Polyhedra

The KDK geometric language is defined over a universe of *states* described as *geometric configurations* which are built with a set of *basic polyhedral modules*. The geometric configurations evolve gradually based on *polyhedral operations* applied to states in a sequential manner.

KDK Basic Polyhedra are obtained by truncating the three Platonic bodies: regular *tetrahedron* (*T*), regular *octahedron* (*O*) and regular *icosahedron* (*I*), in such a way that all the faces of the truncated bodies are regular *hexagons*. The basic polyhedra *T*, *O* and *I* are shown in **Figure 1**. The hexagonal faces created by cutting the corners of the Platonic bodies are called *facets*. The empty shapes associated to each corner are called *cofacets*. Cofacets are module-specific: triangles for the *T* module, squares for the *O* module and pentagons for the *I* module.

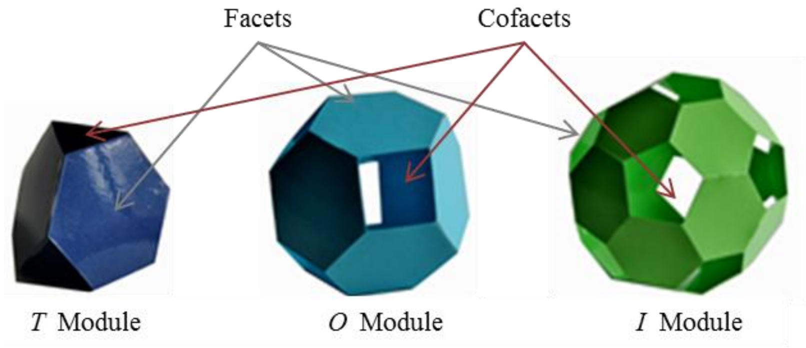


Figure 1. The three KDK basic polyhedra: T, O, I.

2.2. KDK Polyhedral Operations

KDK Polyhedral Operations are polyhedral *connections*, *rigid rotations* and *paper folding*. The KDK *connection* operations join two geometric configurations by *juxtaposition* of either facets or cofacets of equal shape, and are denoted *Delta*, *Gamma* and *Nabla*. The *rigid rotations* are performed along the edges of the juxtaposed facets or cofacets, by 60^o for hexagonal facets and by 120^o, 90^o, 72^o for *T*, *O*, *I* cofacets, respectively. The *folding operations* are used for compression, expansion, and for creating “dual” configurations. The connection operations applied to pairs of basic polyhedra are depicted in **Figure 2**.

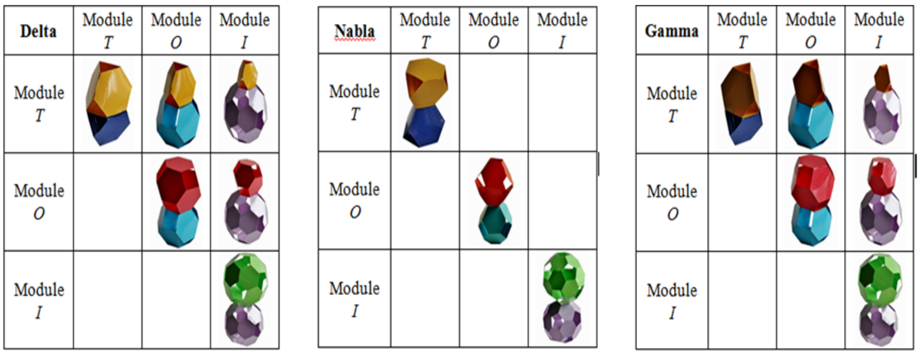


Figure 2. KDK connecting operations: *Delta*, *Nabla*, *Gamma*

2.3. KDK Geometric Configurations

KDK Geometric Configurations are described by “geometric expressions” created based on the basic modules *T*, *O*, *I* and sequential polyhedral operations. The operations are applied sequentially, by first connecting the basic modules *T*, *O*, *I* and then by creating configurations of increasing complexity. For instance, **Figure 3** illustrates the operation *Nabla* applied 5 times to *T* modules. Other complex geometrical expressions obtained by applying join operations to 60 *T* modules and 22 *O* modules are shown in **Figure 4**.

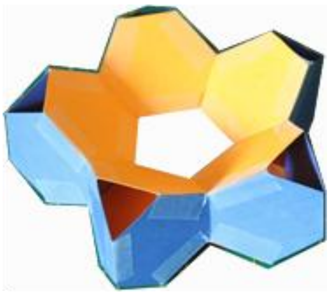


Figure 3. ***Nabla(T,T,T,T,T)***

(a) 60 *T* modules (b) 22 *O* modules

Figure 4. KDK geometrical expressions built with 60 T modules and 22 O modules.

3. KDK Euclidean Representation Rules

KDK Euclidean Representation Rules validate the feasibility of the geometric representation in the 3D Euclidean space. For example, while *Nabla* (*T*,*T*,*T*,*T*,*T*) in **Figure 3** can be built by sequentially applying *Nabla* to five *T* modules, an additional module *T* cannot be connected to extend this expression.

3.1. The KDK Educational Program

KDK implements an effective interdisciplinary type of *learning through playing* for after-school programs, clubs and summer camps, which is focused on fostering spatial intelligence, creativity, strategic thinking, and stimulates the students to discover multiple connections between math, science and arts. Instructors can use KDK programs as "research labs" in which students can practice through hands-on paper construction activities for various topics learnt in math, science and other subjects.

A typical *KDK session* unfolds in groups of 4-6 students and starts with a short presentation of the objective, materials and instructions. Students understand the objectives, analyze the documentation and proceed with developing optimal strategies for achieving the target. The constructions are built incrementally by combining simpler modules into objects of higher complexity. The modular objects are investigated at each step for their geometric, kinetic and aesthetic properties. The construction activity can be interrupted at any time and continued from that point in the next session. At the end of the program sessions the modular constructions can be displayed on stands in classrooms and school exhibitions.

Figures 5 and 6 illustrate examples of KDK constructions realized by students at Herastrau Middle School in Romania, in a series of 8 after-school KDK sessions of 1hour/week. Students had access to documentation and movies, and were challenged to propose new tasks and to answer questions meant to evaluate the progress in enhancing comprehension, reasoning and geometric creativity, e.g.: *How else would you designate the construction you just made? How can you use this construction? What other constructions do you think are possible to be obtained with the same set of basic modular polyhedra?*

(a) Progressive KDK modular constructions (b) Students in a KDK session

Figure 5. Examples of KDK progressive modular constructions realized by 5 grade students.

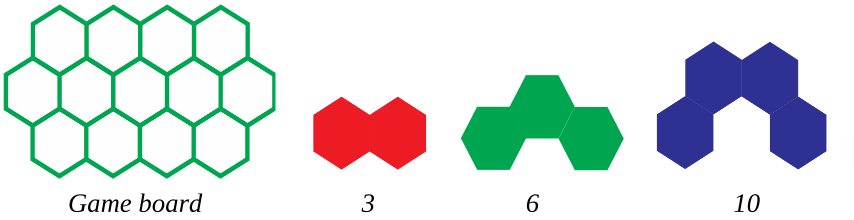
Figure 6. Various geometric configurations realized in KDK after-school and optional sessions.

4. KDK Evaluation

The effect of the KDK programs on enhancing spatial abilities and the performance in learning Geometry was tested in a pilot study at Middle School Herastrau, Romania. The 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 math 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.

The problems were selected to evaluate several Core Math Standards items for Geometry: spatial intuition, estimations in a geometrical context, composing/ decomposing geometrical shapes.[1] A problem of the final test is shown below as an example.

The game HEX requires you to place pieces inside the game board without overlapping. The board and the pieces are shown next, and for placing one piece on the board you receive the number of points listed below each piece:



What is the maximum number of points you can get if you have at your disposal as many pieces as you want of each kind? How do you place the pieces in order to get that score?

Each test problem was scored for comprehension, solution finding and reasoning with 0, 1, 2, 3 points. **Figure 7** 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.)

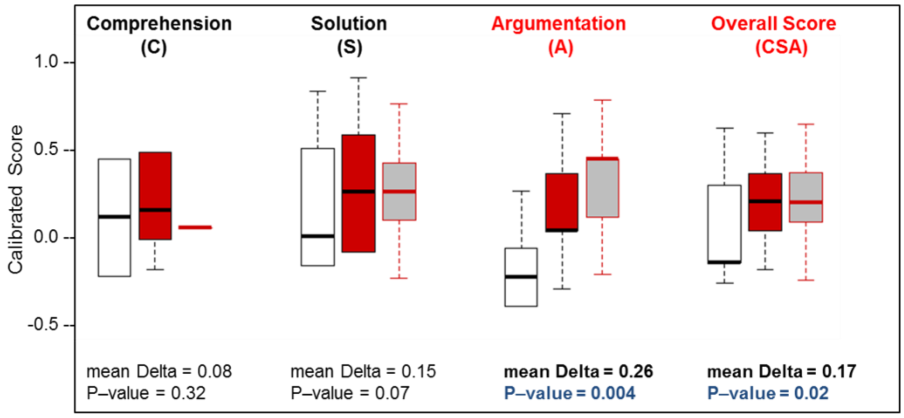


Figure 7. Comparative analysis of score changes in the final vs. initial tests in calibrated data. White/red boxplots present scores assigned in the initial/final tests; gray boxplots present difference (Delta) scores for final vs initial tests.

[1] See www.x-colony.com/MCG9_Appendix.pdf.

5. Conclusions and Future Research

The KDK programs fosters spatial abilities and contributes to the identification of comprehensive relationships between spatial education, geometric creativity and general performance in school. From a practical point of view, KDK is able to provide a flexible, personalized educational platform for fostering spatial abilities and strategic reasoning.

Future research will focus on validating the hypothesis that KDK activities improve students' spatial abilities. We plan to conduct extended studies with an increased number of participants from various cultural environments, and to employ focused scoring methods as described in (Harris et al., 2013). Overall we plan to study if KDK effects are durable and if they are able to reduce any differences in spatial abilities related to gender or social-economic status (Levine et al., 2005). We also plan to test if the effects of KDK translate in improving students' performance in various STEM disciplines and Arts.

6. Acknowledgements

The authors gratefully thank Dileep Bhattacharya for his involvement, support and feedback in this research.

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