Investigating the Influence of Spatial Thinking in Problem Solving

Christos Charcharos Margarita Kokla Eleni Tomai

School of Rural and Surveying Engineering
National Technical University of Athens
H. Polytechniou Str. 9, 15780 Zografos Campus
Athens, Greece
chchar@central.ntua.gr, mkokla@survey.ntua.gr, etomai@mail.ntua.gr

Abstract

Spatial thinking has been acknowledged as an important interdisciplinary ability relevant to many aspects of everyday life, workplace, and science. Recently, researchers begun to explore the relation between spatial thinking and other high-level skills and its capacity to constitute a new approach to learning (learn-to-learn), differing from the more established auditory-sequential type of learning. The present paper explores whether spatial thinking is associated with another high-level cognitive skill: problem-solving. The aim is to design an experiment that will determine the relation (if any) between these skills. Eligible participants for this experiment are both males and females under 25 years old. The participants' spatial thinking (including both small and large scale factors) and problem-solving skills (including analytic and interactive) will be estimated through various questionnaires, such as from the Spatial Thinking Ability Test (STAT), the Programme for International Student Assessment (PISA), and the Programme for the International Assessment of Adult Competencies (PIAAC Project). Regarding the statistical analysis of the results, firstly, the normality of the collected data will be calculated and depending on the results, the appropriate methods will be used to estimate the kind of correlation (positive or negative) between spatial thinking and problem-solving skills. Moreover, a stepwise multiple regression analysis will be conducted to determine the relative contribution of age and spatial thinking to problem-solving.

Keywords: Spatial thinking, problem-solving skills, correlation.

1 Introduction

During the past decades, many scientists have expressed an increasing interest about spatial thinking, a kind of thinking that deals with space and its concepts (location, direction, orientation, scale, shape, size etc.). Spatial thinking has been acknowledged as an important ability for everyday life, workplace, and science. Also, it has been characterized as crucial for increasing participation and achieving innovation in STEM disciplines, as well as highly relevant to social sciences, humanities [11], and education [2].

Spatial thinking is a constructive combination of three components [22]: (a) concepts of space, (b) tools of representation, and (c) processes of reasoning. For example, in order to find suitable areas for constructing a winery based on various criteria (altitude, distance from towns, rivers, and protected areas), someone should:

- grasp spatial concepts such as location, distance, proximity, area of influence, and elevation,
- use representation tools such as maps and terrain modelling, and
- be able to perform reasoning processes, such as combining maps and evaluating multiple criteria to draw inferences about the potential areas.

Spatial thinking uses the properties of space as a means of solving problems, finding answers, and expressing solutions [ibid.]. In other words, it uses space for structuring problems, seeking answers, and formulating possible solutions associated with space. It also includes the ability to analyse space, which is essential for decision-making. Spatial notions such as scale, generalization, and pattern cross-cut education subjects; thus spatial thinking overcomes the boundaries of relevant sciences and is considered as a very important new approach to learning (learn-to-learn), differing from the more established auditory-sequential type of learning.

Just as spatial thinking is classified as a high-level cognitive process so is problem-solving. Problem-solving helps humans find useful and original solutions in order to achieve specified goals, when they have not faced any similar problem in the past. Problem-solving is divided into two sub-categories, analytic and interactive problem-solving; analytic problems provide a single choice and have all the information disclosed at the outset; while interactive problems provide multiple choices thus solvers must uncover some of the information needed [10].

Problem-solving is accomplished in two phases, problem representation and problem solution [19]. Spatial thinking may substantially contribute to both phases because at representation phase, someone should create a mental representation of the problem to fully understand it and at solution phase, someone could spatially represent the problem's answer using graphs for example [ibid.]. Hence, a question worth pursuing is whether spatial thinking is associated with other cognitive abilities such as problem-solving, either for simple everyday activities (e.g. finding the way in a shopping mall) or for more advanced activities (e.g. assembling furniture) and various kinds of problems (e.g. information, verbal, mathematical etc.) that have space as a testbed.

According to a report of U.S. National Research Council regarding Discipline-Based Education Research, the use of spatial thinking and more specific, visual representations can promote conceptual understanding and problem-solving in various disciplines (physics, chemistry, biology and of course Geosciences) [21].

The main purpose of the paper is twofold: (a) to explore the existing work on spatial thinking and problem-solving and (b) to design an experiment that could provide evidence whether spatial thinking is actually related to problem-solving skills. The establishment of such link allows more research to be conducted on this field, as for example to examine if the enhancement of one skill leads to the improvement of the other.

2 Related Research

Extended research has been conducted in order to establish a relation between problem-solving skills and various other skills, mostly thinking skills, such as critical thinking skills [15], reflective thinking skills [8], motivation and innovation skills [18], metacognition skills [4], and coping skills[1] [7]. All these research studies have proven that problem-solving skills are positively related with these skills; the increase of the former leads to the improvement of the latter.

Boonen et al. [5] examined the relation of visual representation type, spatial ability, and reading comprehension in verbal problem-solving and found out that reading comprehension and mainly spatial ability increases the chance of solving a verbal problem successfully. On the other hand, Mohring et al. [20] investigated pre-schoolers' ability to locate targets and to reason about proportions. The results showed that proportional reasoning (reasoning can be part of problem-solving [9]) and spatial thinking are highly correlated abilities.

Spatial thinking may be cultivated with substantial results. Spatial skills are malleable which means that with the appropriate training individuals' spatial reasoning can be empowered [12, 30, 31]. For example, spatial ability of young children could be enhanced through puzzle-type games or video games and the use of spatial language and gestures by parents or teachers [23]. Consequently, spatial training programs could have an essential role in education.

The above studies provide promising indications of the influence of spatial thinking in problem-solving skills. In this context, the present paper presents an experimental framework to examine this link. The verification of this link would provide an alternative direction for cultivating problem-solving in education.

3 Proposed Experimental Framework

In this section, the proposed experimental framework is analyzed, in terms of the selection of the participants, the materials that could be used and the statistical analysis which will be performed on the data.

[1] Coping is the effort to solve personal/interpersonal problems and to seek ways to master and minimize stress or conflict.

3.1 Research Questions

The main research questions, that the experiment will try to answer are:

1. What is the relationship (if any) between spatial thinking and problem-solving?
2. Can age and level of spatial thinking predict the level of problem-solving?

3.2 Participants

Participants should be both male and female and the age range should vary from young people to young adults (ages between 13-19 and 20-25), thus inclusion criteria are two: age and gender. The sample of the experiment should be as large as possible because as this increases, the confidence in the estimation increases, uncertainty decreases, and a greater precision will be achieved.

3.3 Material

In this experimental framework, questionnaires that assess participants' spatial thinking and problem-solving skills will be used. Spatial thinking questionnaires should evaluate both small scale factors (spatial perception, mental rotation, flexibility of closure etc.) and large scale factors (navigation, learning the layout of a new environment, pointing to unseen location in a familiar environment) while problem-solving questionnaires should evaluate both analytic and interactive problems.

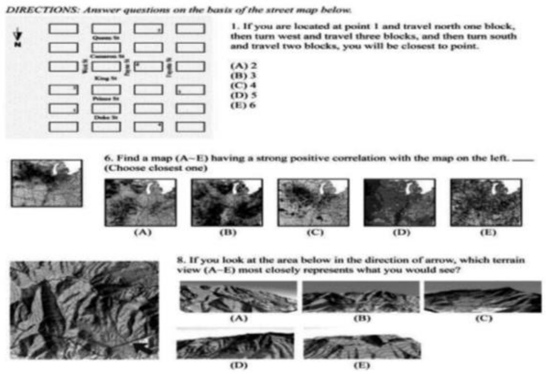
Regarding spatial thinking questionnaires and more specific small scale factors, the Spatial Thinking Ability Test (STAT) or the Spatial Ability Test (SAT) can be used. STAT is a revised edition of Spatial Skills Test (SST)[2], and was created to assess how students develop spatial thinking related to the fact that teachers started to use the Teacher's Guide to Modern Geography [1], which helped them to incorporate spatial thinking skills into their classes. Aspects of spatial thinking abilities covered by STAT are shown in Figure 1 and include [16]:

- comprehending orientation and direction,
- correlating spatially distributed phenomena,
- mentally visualizing 3-D images based on 2-D information,
- overlaying and dissolving maps.

On the other hand, SAT has been created in order to assess four basic factors of spatial thinking (spatial visualization, perception, orientation, and manipulation) of Myanmar's students, using Paper Folding test, Paper Formboard test, Figure Rotation test, and Block Rotation test respectively [14]. For example, the Paper Form Board Test consists of five figures one of which is displayed in disarranged parts. The participant has to decide which of the figures displays the pieces joined together.

[2] SST was created to investigate the possible effects of GIS learning on college students' spatial thinking ability [17].

Figure 1: Selected items form STAT



Source: Lee et al., 2012 [16]

Regarding large scale spatial thinking questionnaire, the Santa Barbara Sense of Direction (SBSOD) [13] or Sense of Direction questionnaire [29] could be used. SBSOD was developed to measure participants' ability in various environmental tasks such as wayfinding, orientation, learning layouts and using maps to navigate. It is a self-reported questionnaire and the researcher does not get involved in the completion process. Participants could choose from a scale 1 (strongly agree) to 5 (strongly disagree) what they think more appropriate. For example, some indicative questions (quoting the SBSOD) are presented below.

- I am very good at giving directions.
- I am very good at judging distances.

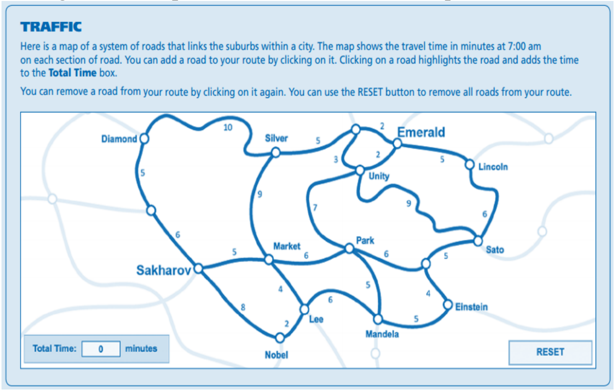
It should be taken into consideration that self-report data is suggestive and needs follow up with more objective testing. Alternative, due to the fact that there aren't questionnaires which examine more than two components simultaneously, a new questionnaire should be created based on several individual tests [6] such as the previously-mentioned questionnaires or the experiment made by Hegarty et al. for navigation in real and virtual spaces [28] etc.

Concerning problem-solving questionnaires, suitable questionnaires that assess problem-solving skills of 15-years-olds students, have been developed by the Programme for International Student Assessment (PISA Project). The questionnaires focus on general cognitive processes involved in problem-solving, rather than on the ability to solve problems in particular school subjects.

PISA 2012 focuses on literacy in mathematics, while PISA 2015 focuses on literacy in sciences and introduced Collaborative Problem Solving (CPS) for the first time. The 42 items of PISA's 2012 questionnaire are classified into four clusters with 16 units in total (assessing both analytic and interactive problem-solving skills) [25]. The most recent PISA questionnaire contains 35 problem-solving items and 44 CPS items [26]. Selected items from PISA's questionnaire are shown in Figure 2 and 3.

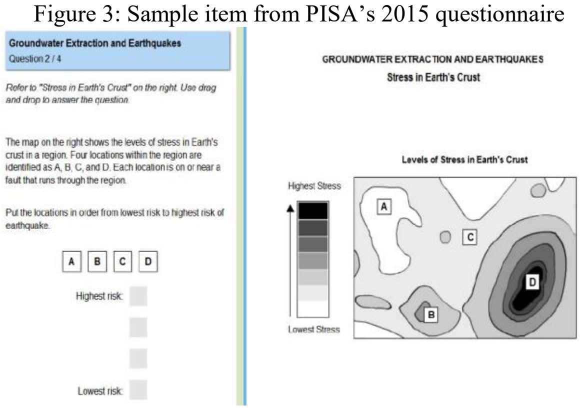
Other problem-solving questionnaires have been developed by Adult Literacy and Lifeskills Survey (ALL survey) [24] and the Programme for the International Assessment of Adult Competencies (PIAAC Project) [27]. The ALL survey consists of two 30-minutes assessment sets of tasks and addresses subjects 16 to 65 years old. The PIACC Project includes a questionnaire, which focuses on problem-solving in technology-rich environments and consists of 16 items (that involve a number of sub-tasks such as searching through simulated websites for relevant information). Items from each questionnaire are shown in Figure 4 and 5, respectively.

Figure 2: Sample item from PISA's 2012 questionnaire



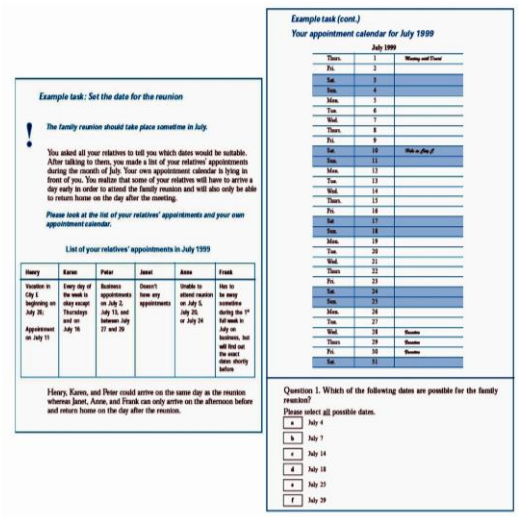
Source: OECD, 2014 [25]

Figure 3: Sample item from PISA's 2015 questionnaire



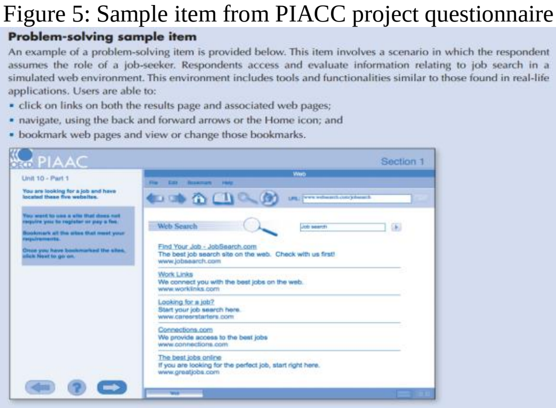
Source: OECD, 2015 [26]

Figure 4: Sample item from ALL survey questionnaire



Source: OECD, 2005 [24]

Figure 5: Sample item from PIACC project questionnaire



Source: OECD, 2012 [27]

At this point, it should be taken into account that the questionnaires, if necessary, must be adapted to the country's specific needs. Usually spatial thinking tests are characterized as non-verbal, but this does not indicate that they are also culture-fair tests [3].

3.4 Statistical Analysis

After the participants fill in the questionnaires, a total score for each one will be calculated and analyzed using the statistical package SPSS 22.0. Initially, adherence to the normal distribution of the total sample will be examined. Depending on the sample size of the experiment the appropriate test will be used. More specifically, if the sample of the experiment is greater than 50 then the Kolmogorov-Smirnov should be used, otherwise the Shapiro-Wilk is more suitable.

After that, some descriptive statistics concerning the total sample, as well as partitions concerning gender and age will be analyzed. Variables that will not normally distributed, will be presented as P50 (P25-P75), otherwise will be presented as mean ± sd. After controlling for the normality of the distribution, parametric or non-parametric tests will be used to give evidence regarding the research questions.

The main research question is whether spatial thinking is associated with problem-solving skills. Therefore, in order to study whether such a relation exists, Pearson correlation coefficient should be used (for normal distributed data) or Spearman's rank correlation coefficient (for non-normal distributed data). In addition, the above-mentioned correlation coefficients will determine if these variables are associated in a positive or negative way.

Once the relation between spatial thinking and problem-solving is analysed, other statistical analyses can be conducted to examine the relative contribution of both small and large scale spatial thinking factors and probably age to problem-solving. In particular, a stepwise multiple regression analysis can be conducted considering as dependent variable the problem-solving skills and as independent variables the two spatial thinking factors, and age. Through this procedure, the influence of each variable to formulating the ability to solve problems can be explored.

4 Conclusions

The present paper describes a framework for designing an experiment that will give insights to the relation between problem-solving and spatial thinking. Participants will fill in questionnaires that assess spatial thinking and problem-solving in a holistic way and then statistical analysis will be performed on the results. Significant outcome from this research is the establishment of a link (if any) between these skills. If the results confirm the existence of such a relation another outcome will be the relative contribution of each factor to problem-solving skills.

The modern societies demand individuals who can find answer regarding non-routine problems. Hence, it is of highly importance to equip students with skills that help them to overcome complex, non-routine problems. In addition, a shift is observed from traditional to lifelong education: students are transformed into lifelong learners who are asked to face unfamiliar situations and to solve non-routine problems when they have not a ready-made strategy.

Therefore, the establishment of a link between spatial thinking and problem-solving points to the possibility that spatial skills could be harnessed to foster an advanced understanding of everyday non-routine problems and also provides the grounding for enhancing both skills, spatial thinking and problem-solving in formal learning settings with the aim of educating the future skilled students.

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