Problem Decomposition in Introductory Computer Science and Spatial Reasoning

Thitaree Tanprasert
Harvey Mudd College
Claremont, California
ttanprasert@hmc.edu

Ka Ki Fung
Claremont McKenna College
Claremont, California
kfung20@cmc.edu

ABSTRACT

Previous research has documented correlations between spatial reasoning ability and success in STEM fields [7–9]. While connection between spatial reasoning and other STEM fields like physics and calculus may seem obvious, there are no theories to explain this correlation of CS (computer science) performance and spatial reasoning. [5, 7, 8] We aim to better understand this correlation, specifically between CS performance in an introductory course and spatial reasoning by observing the common characteristics between students' strategies in solving CS and spatial reasoning problems. We conducted interviews with eight students who have prior experience in CS but have taken only two introductory CS courses. In the interview, we asked the participants to solve a total of four problems; two CS problems and two spatial reasoning problems. [1, 6] The CS problems were code-reading problems in Python, which focus on basic programming concepts, including nested loops and functions. We observed the participants' problem-solving strategies and asked participants to explain their strategies as well as other opinions regarding each problem. We observed that, for both types of problem, participants appeared to first observe the problem for its fundamental structures then decomposes the problem into smaller sub-problems. From this observation, we conjecture that problem decomposition may be a required skill to solve both CS problems and spatial reasoning problems, and thus, it could be a possible factor that contributes to the correlation between these two fields. Further study into utilization of problem decomposition in computer programming and spatial reasoning may provide more insights into the correlation between spatial reasoning ability and success in computer programming.

CCS CONCEPTS

• **Social and professional topics → Computer science education**;

KEYWORDS

Computer science education, spatial reasoning, problem decomposition

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1 PROBLEM AND MOTIVATION

While connection between spatial reasoning and other STEM fields like physics and calculus may seem obvious, there are no theories to explain the correlation of CS performance and spatial reasoning. Previous research has found a correlation between performance in CS and spatial reasoning [5, 7, 8]. We believe that it is important to explore this correlation because understanding the mechanism that produces this correlation could help improve pedagogy. Our preliminary observation shows that problem decomposition appeared to be a required step in solving both CS and spatial reasoning problems. With further analysis, we gain deeper and more detailed understanding into how problem decomposition bridge these two fields. We also hope that this research could provide a basis and hypothesis for additional research related to this correlation.

2 BACKGROUND AND RELATED WORK

There have been decades of research investigating the importance of spatial ability in educational pursuits in STEM(science, technology, engineering, and mathematics) domains [9]. One study had 400,000 participants who were tracked for 11+ years and their longitude findings were aligned with historical findings. They found that for decades, spatial ability were "salient psychological attribute among those adolescents who subsequently go on to achieve advanced educational credentials and occupations in STEM." Such quantitative research are the motivation of our research, proving the existence of a robust correlation between STEM performance and spatial reasoning, in which we could investigate and explore.

Particularly in the field of CS, there have been attempts to find the reason or cause of this correlation. Tai, Tu, Lai, and Lin [8] study the effects of spatial ability in promoting logical thinking abilities of students with regard to programming language. They found that there is a significant difference in logical thinking ability between students with high and low spatial ability. Using tests from Computer-Assisted Learning (CAL) courseware, they found that those with higher scores had significantly better achievements in CS than those with lower scores. This provides a starting point for further exploration in the exact correlation between CS and spatial reasoning. Although there are many researches that suggest possible factors that contribute to the correlation between CS performance and spatial reasoning, none of them provides supporting evidence or analysis to their hypothesizes. There are potentially more insights to uncover, particularly about the similar problem solving methods in CS and spatial reasoning problems.

One of the most important skills for solving CS problem is problem decomposition [2]. Problem decomposition is the ability to divide the problem into multiple, organized components and tackle each component, independently, before combining them to create

the final solution for the problem. Problem decomposition may be an important component of computational thinking, including, but not limited to CS. In the context of CS, it is used for factoring, breaking a complex problem or system into parts that are easier to conceive, understand, program, and maintain. For example the factoring of objects, methods, and functions, as well as overseeing the order of operations [2]. Computational Thinking is an emerging term in educational research and is believed to be a deterministic characteristic for children's competency in STEM education [4]. This research suggests that we may gain insights into the contributing factors of the development of CS performance through problem decomposition skill.

3 APPROACH AND UNIQUENESS

Although previous research has documented a correlation between CS performance and spatial reasoning [3, 5, 7], we found no research that makes a connection between spatial reasoning and problem decomposition skill, which is shown to be a very significant skill for programming. [2] Based upon these existing literature and our observation from our research interviews, we explore the relationship between CS performance and spatial reasoning focusing on the presence of problem decomposition skill in novice programmers' problem-solving schemes. To better understand the correlation between CS performance and spatial reasoning, we observe the common characteristics between students' strategies in solving CS and spatial reasoning problems. We conducted interviews with eight students who have prior experience in CS but have never taken more than two introductory-leveled CS courses in undergraduate school. In the interview, we asked the participants to solve a total of four problems; two CS performance problems and two spatial reasoning problems. The CS performance problems were code-reading problems in Python, which focus on basic programming concepts, including nested loops and functions. We observed the participants' problem-solving strategies and asked participants to explain their strategies as well as other opinions regarding each problem. Then, we analyzed the participants' explanations in connection to our observation of their problem-solving process and their scratch work seen in Figure 1.

4 RESULTS AND CONTRIBUTIONS

Based on our interviews, we hypothesize that participants' ability to problem decomposition may explain correlations found in previous research between intro CS performance and spatial reasoning. We analyzed the participants' scratch work and transcription of their explanation in detail and observed that, for both types of problem, participants appeared to first observe the problem for its fundamental structures then decomposes the problem into smaller sub-problems.

Figure 1 (left) is a scan of a scratch work of one of the CS problems in the interview, which involves tracing iterations and output of for loops in Python. The participant looked at the range of each loop parameter first. Then, he traced the values that were printed. These processes allowed him to recognize the patterns of the output. We conjecture that he separated his method into two parts: finding patterns and using patterns. Upon recognizing the pattern,

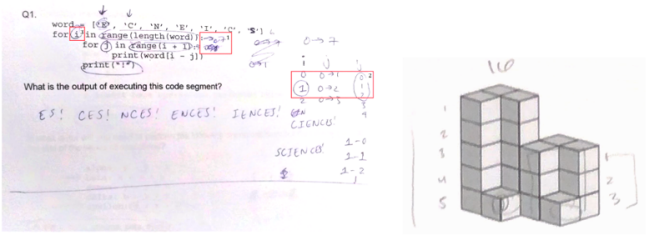

Figure 1: Scan of a participant's scratch work on (left) a CS problem and (right) a spatial reasoning problem.

he stopped his tracing process and could solve the problem successfully based on the initial tracing of the problem he constructed in the beginning.

Figure 1 (right) is a scan of a scratch work of one of the spatial reasoning in the interview, which involves determining the number of blocks shown in the figure[1]. Instead of counting each block individually, the participants divided the structure into two "towers" of height 5 and 3 before adding 2 "extra" cubes in the front. He was able to solve the problem by using this pattern as a reference. By decomposing the problem up into sub-parts, he could keep track of the blocks and reach the solution more efficiently.

By observing similar examples to above, we found that, when presented with these problems, participants first observed the problem for its fundamental structures then decomposed the problem into smaller sub-problems to reach the solution and also to reach it more efficiently. From this observation, we conjecture that problem decomposition may be a required skill to solve both CS and spatial reasoning problems, and thus, it could be a possible factor that contributes to the correlation between these two fields. The primary contribution is proposing that problem decomposition may be a foundation for both solving introductory CS problems and spatial reasoning tasks.

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