# UNDERSTANDING AND IMPROVING STUDENTS' COGNITIVE NAVIGATION AND PROGRAMMING ABILITIES

by

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A DISSERTATION

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfilment of Requirements

For the Degree of Doctor of Philosophy

Major: Computer Science

Under the Supervision of Professor Stephen Cooper

Lincoln, Nebraska

May, 2022

UNDERSTANDING AND IMPROVING STUDENTS' COGNITIVE NAVIGATION AND PROGRAMMING ABILITIES

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University of Nebraska, 2022

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Spatial skills have been shown to play an import role in most STEM field. Studies have showed that students' spatial skills (primarily students' mental rotation abilities) are correlated to their programming ability and that with the use of a spatial skills intervention, focused on 3D mental rotations, students' spatial skills and programming abilities improve. It makes sense that a person's ability to mentally rotate objects it correlated to their success in other STEM degrees, but it makes less sense why there is any connections to students' programming abilities. In my research I aimed to further explore new spatial skills, primarily cognitive navigational abilities, and their role in computing. We did so by conducting a two-year study investigating the relationship between students' navigational abilities and their programming abilities in multiple introductory computing courses. Our results showed that there is a correlation between students' map reading ability and their programming ability. We also found that with the use of a map reading intervention using an augmented reality sandbox both students' map reading skills and programming abilities increased compared to students who did not participate in the intervention.

# DEDICATION

To Jeff and Kelly, my parents, and Glen and Carol, my grandparents, for teaching me the value of education and hard work and supporting me. No matter where I went, I always knew that I had a place to call home.

# ACKNOWLEDGMENTS

I want to express my appreciation and gratitude to my advisor Dr. Stephen Cooper. He has been a great mentor, and I am truly fortunate to have had the opportunity to work with him. His consistent guidance and invaluable support have made this a rewarding journey. I want to express my sincere thanks to my committee members: Dr. Leen-Kiat Soh, Dr. Justin Olmanson, and Dr. Mindi Searls. Each one of them has greatly influenced this work. Their feedback and suggestions helped improve the quality of this work. I also want to express my sincere gratitude to my friends and fellow graduate students who helped and support me throughout my PhD.

# GRANT INFORMATION

This material is based upon work supported by the National Science Foundation under Grant Numbers 1711780, 1711830, 1712331. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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# Chapter 1

# INTRODUCTION

In this chapter we first describe the problem that we would like to solve in Section 1. Then in Section 2, we discuss the motivation behind the studies that we want to conduct. In Section 3 we discuss the contributions of our research work and outline the results we have found so far. Section 4 provides an outline for the rest of the dissertation.

## 1.1 Problem

Computer science has one of the highest dropout rates for any bachelor's degree. In 2013 a study conducted by the U.S Department of Education found that when looking at all STEM degrees, the degree with the highest attrition rate for bachelor's candidates was in computer/information sciences [4]. When investigating attrition rates even further, Guzdial and Soloway found that attrition rates in introductory computing courses can be as high as 30% and by year two attrition rates can be uapproaching 60% [5]. Work has been done to combat student attrition in introductory computing courses over the years, but there is still more work that needs to be done.

## 1.2 Motivation

Recent studies have shown that students' spatial skills are a good predictor to their success in obtaining a STEM degree. Those studies showed that students' spatial skills are better at predicting their success than their SAT-Math and SAT-Verbal scores [6].

Spatial skills/spatial ability research dates to the 1800's when Sir Frances Galton focused on discovering how people differ in their "mental disposition" through the use of mental imagery [7]. In general, spatial skills may be defined as, the capacity to understand, reason, and remember the spatial relations among objects or space. There are several different types of spatial skills including: paper folding, map reading/way-finding, and embedded figures. The most study spatial skill is mental rotation, or the ability to perform mental rotations on an object. Figure 1.1. shows an example problem from the Purdue Spatial Visualization Test: Rotations. This test is designed to gauge a person's mental rotation ability.

The motivation for our work derives from previous studies that Sorby et al. and Cooper et al. have done. Their studies showed that a person's spatial skill is an important factor to their success in STEM and in particular computing [8, 9]. When exploring how spatial skills are related to computing, Cooper et al. found that there is a correlation between students' spatial skills and their ability to program. They also showed that with the use of a spatial skills intervention, students had a higher degree of success in their given field of study than those students who did not participate in the intervention.

While administering spatial skills interventions in introductory computing courses showed promising results with increasing students' programming abilities, these studies only considered students' 3D mental rotation abilities. Clearly there

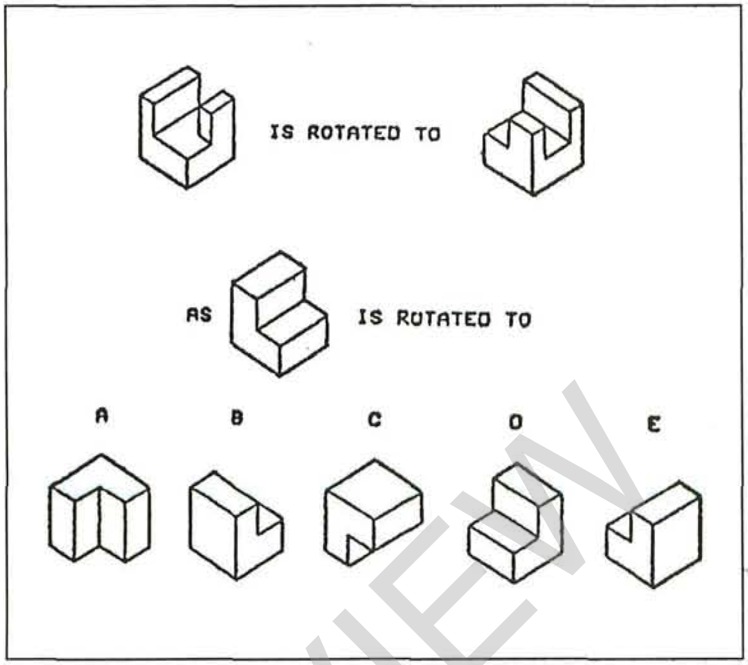


Figure 1.1: Sample Problem from the PSVT:R

are some links between 3D mental rotations and higher-level of thinking and reasoning that are essential to programming. However, we believe that mental rotation is not the most directly related spatial skill to programming. We wanted to explore some of these other types of spatial skills in greater detail. Is there another type of spatial ability that is more directly tied to the thought processes behind programming?

Cox et al. considers program comprehension as the process of developing a cognitive map, or what they call codespace [10]. A cognitive map is defined as a mental model of spatial information [11]. Fisher et al. defines codespace as "a programmer's mental model of source code with respect to the perceived spatial attributes of entities identified within the code" [12]. In both Cox's and Fisher's studies, they suggest that "Source-code navigation is not a trivial activity occurring while we develop complex domain models of a software system. Instead, the

perspective suggests that we are developing highly effective route and survey maps to navigate the system's codespace. Without these navigation skills, maintainers would be unable to locate the source-code fragments associated with a domain concept." From the results of these studies, we believe that a person's navigational abilities are directly related to their ability to program and understand source code.

In our research, we aim to increases students' programming abilities. We hope to decrease student attrition in introductory computing courses by (1) confirming that spatial skills are correlated to programming abilities, (2) testing whether running a spatial skills intervention (primarily mental rotations as done in previous studies) increases students' programming abilities, then (3) exploring how student's navigational ability are related to their programming ability and (4) creating and administering a spatial navigating intervention to see if the intervention is correlated with improved students' programming abilities.



## 1.3 Contributions

The research presented in this dissertation focuses on the work that we have done over the past several years investigating how students' spatial skills, both mental rotations and map reading abilities, impact their programming abilities.

### 1.3.1 Creation and Validation of the SCS1R

The first goal of our study was to replicate Cooper et al.'s study that investigated students' spatial skills and programming abilities [9]. However, there were a few things different from that study to ours. The first main difference was that we conducted our study at larger scale. We ran our study across several sections

of an introductory computing course at three different universities. The original study was conducted on a single set of high school students all being taught in the same programming language, Java. Because of the scale difference, we needed an instrument that gauged students' programming aptitudes across different programming languages. In Chapter 3 we discuss our work in the creation and validation of the Second Computer Science 1 exam Revised (SCS1R).

We needed to create a new version of the Second Computer Science 1 exam (SCS1) [13] called the SCS1R. The original SCS1 consisted of 27 questions and took around two hours to complete. However, the length of the SCS1 was too long for our purpose. We reduced the number of questions to 9 out of the original 27 questions of the SCS1. This new version took around 30 minutes to complete. After altering the exam, we went through the process of re-validating the instrument using Item Response Theory.

We later revised the SCS1R by removing one of the questions and then adding in several questions from the CS AP exam. Work is currently being conducted to validate the new version of the instrument. We have named this version of the SCS1R the SCS1Rv2.



### 1.3.2 Computing Attitudes Instrument

In Chapter 4 we discuss our work creating and validating a computing attitudes instrument that we wanted to use to collect more information regarding students' attitudes towards computing and computing related issues. We did so by combining two computing attitudes instruments and adding several questions of our own. The first was a validated instrument created by Dorn and Tew [14] called the Computing Attitudes Survey version 4 (CASv4), and the second instrument was created by Wiebe [15] and included questions regarding attitudes towards gender

related issues in computing. This new instrument was validated using Exploratory Factor Analysis and was validated at the same time as we validated the SCS1R.

### 1.3.3 Replication Study

Chapter 5 discusses our replication study examining the relationship between students' spatial skills and their success in learning to program. We conducted our intervention across three different universities in a pre-post format. Like Cooper et al.'s study, we saw a correlation between student's spatial skills and their success in learning to program. More significantly, we saw that after applying an intervention to teach spatial skills, students demonstrated improved performance both on a standard spatial skills assessment as well as on a CS content instrument. We also saw a correlation between students' enjoyment in computing and improved performance both on a standard spatial skills assessment and on a CS content instrument.



### 1.3.4 Spatial Skills Predictions

Chapter 6 discusses our study investigation into the extent to which the data we collected could predict students' success in an introductory computing course. Previous studies have found that students' spatial skills are a good predictor of student of their success in college [6]. During this study we used a multinomial logistic regression to create a predictive model to predict students' introductory programming abilities at the end of the semester. The highest model accuracy was obtained when accounting for students' prior programming abilities, prior spatial skills, socioeconomic status, and three factors regarding students' attitudes towards computing. It was also found that when looking at the predictability of each

individual variable, students' prior spatial ability had the highest predictability when compared to all other variables.

### 1.3.5 Navigation and Map Reading

In the first four major chapters we focused primarily on students' mental rotation abilities. We wanted to investigate the extent that which students' navigational abilities are related to their programming abilities. We believe that students' navigational abilities are more closely related to their programming abilities as compared to their mental rotation abilities.

There has been little work done investigating the relationship between students' navigational abilities and their programming abilities. In preliminary testing we investigated the relationship between students' active navigational ability (gauged by how well they did at successfully navigated a virtual maze) and their programming ability (based on the SCS1R). However, we did not find any correlation. We believed this was because the navigational task used gauged a person's active ability to navigate while the SCS1R is a multiple-choice test that does not measure a person's active code writing ability but does gauge their code reading and code comprehension ability.

We decided to investigate students' map reading abilities, a subset of navigational abilities. Chapter 7 discusses our study investigating the correlation between students' map reading ability and their ability to program. In this study we used the Topographic Map Assessment (TMA) [16] and the SCS1R [17]. The TMA is an assessment that was designed to test a person's ability to read and understand topographic maps. These topics included: route planning, cross section, 2D to 3D visualization, and orientation.

We collected data from students in multiple sections of an introductory comput-

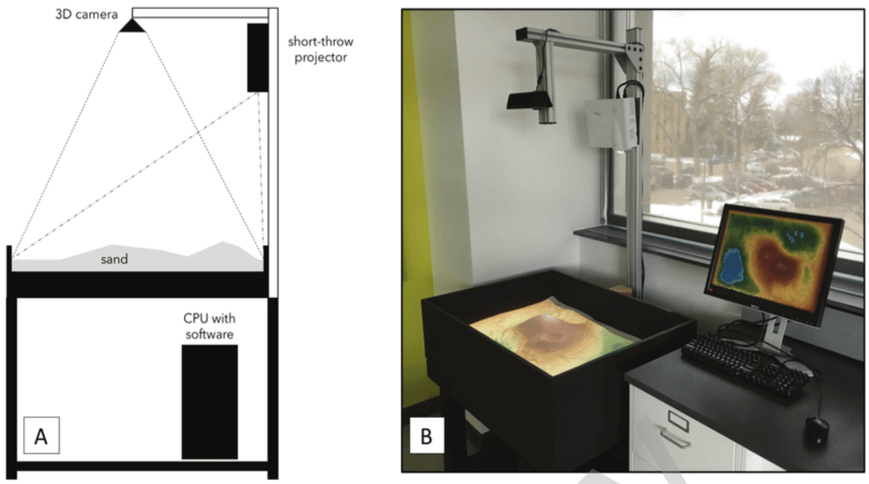


Figure 1.2: Example AR-Sandbox [1]

ing course in a pre-post format using the TMA and SCS1. Our results showed that there is a correlation between students' map reading ability and their programming abilities.

### 1.3.6 AR-Sandbox

After finding a correlation between students' map reading ability and their programming ability, we then wanted to create a map reading intervention. In creating material for the navigational skills intervention, we modified an augmented reality (AR) sandbox [18]. The original AR-sandbox was used to teach simple understanding how topographic maps worked (Figure 2.2). We wanted to expand the capability of the AR-sandbox to fit the need of our intervention. Chapter 8 discusses the work we did to modify an AR-sandbox to teach more advance map reading topics for the use of our intervention.

### 1.3.7 Map reading intervention

Chapter 9 details our study administering a map reading intervention. This study targeted students enrolled in an introductory computing course and had students participate in a map reading intervention centered around material for use with our AR-sandbox. The study was conducted over the course of a semester and administered in a pre-post format.

Our results showed that students who participated in the intervention had increased map reading abilities after the intervention. Our results also showed that students who participated in the intervention also had higher post programming abilities. However, our results were inconclusive to whether students that participated in the intervention had higher learning gains compared to students who did not participate. This was because the students in the different groups had different prior programming knowledge.

## 1.4 Overview

The rest of this dissertation is organized as follows. Chapter 2 discusses the related work that is associated with our studies throughout this dissertation. Chapter 3 discusses the creation and validation of the SCS1R. Chapter 4 discusses the creation and validation of a new computing attitudes instrument. Chapter 5 details our study replicating Cooper et al.'s study. Chapter 6 investigates the predictability of student success based on their spatial skills and other variables we collected. Chapter 7 details our study investigating the correlation between students' map reading ability and their ability to program. Chapter 8 discusses the current modification we made to the AR-Sandbox. Chapter 9 discusses the results of our map reading intervention and Chapter 10 concludes the dissertation.