Graduate Research Plan Statement

Background: Success in computer science strongly correlates with socioeconomic status [3]. Computer science also struggles to attract and retain female students. While it is likely that many factors drive these correlations, one probable component is discrepancies in **spatial ability**. Defined as an individual's capacity to mentally manipulate objects, common spatial tasks include reading a map or mentally rotating a 3D object. Studies have found that spatial ability is often the single biggest predictor of student success in both computer science and STEM in general [4].

Unfortunately, gender and socioeconomic status strongly correlate with undergraduates' initial spatial ability. In fact, a recent study found that, compared to access to computing, lower spatial ability better explains the under-performance of low-socioeconomic computer science students [3]. I believe a key reason behind this is that spatial ability endows students with a set of general problem solving skills, giving some students an advantage in introductory programming.

On the upside, spatial ability can be improved through training: A meta-analysis [6] found that **spatial training** can increase performance on a variety of tasks that share the same brain regions. There is reason to believe programming is a spatially-intensive activity. In particular, a recent paper from my research group determined that "data structure and spatial operations use the same focal regions of the brain but to different degrees" [1]. Furthermore, research has found that spatial training improves (transfers to) student outcomes for select engineering courses [5]. These prior results give confidence that spatial training may transfer to programming outcomes.

Proposal: Given that spatial ability is predictive of success in computer science and that spatial skills can be taught, my primary question is: *Does spatial training actually transfer to computer science, causing gains in programming ability and program comprehension?* That is, does spatial training allow novice programmers to become experts *faster?* I am particularly interested in the effects of training on women and other underrepresented groups in computer science.

I propose a longitudinal study investigating the effects of spatial training on computer science performance. I will recruit a large (~100) and diverse group of undergraduates from Michigan's introductory computer science class. Participants will be given a battery of programming and spatial ability tests curated to both align with previous work and tease out the spatial components of programming. A subgroup will also be subjected to medical imaging while taking the tests (my lab has fNIRS access). I will then randomly assign participants to a control and treatment group, each with two hours of training per week. The treatment group will receive spatial skills training while the control will receive a different active task, such as reading technical reports or additional programming practice. I will also ask participants to report time engaging in spatially-intensive activities. After a semester, participants will retake the programming, spatial, and imaging tests as applicable. I will also periodically retest participants to study skill retention.

Evaluation: The efficacy of the spatial training intervention will be measured using a rigorous statistical evaluation examining differences in programming and spatial skills between the treatment and control groups. Should I find a statistically-significant improvement in programming ability in the treatment group as compared to the control, then I will conclude that the spatial training transferred to programming. I will also analyze the medical imaging data to check for functional network connectivity or brain efficiency changes that differ between the two groups. Although this proposed evaluation is ambitious, I am well positioned to carry it out effectively; I will build on the qualitative and quantitative research methods demonstrated in my two peer-reviewed publications with human subjects, as well as my lab's imaging experience.

Planned Extensions: While I will target psychology journals that accept negative results along with traditional software engineering venues, if I find transfer of spatial training to programming, I will extend the work by studying which programming language paradigms are most spatially intensive and what software tools best support low spatial skills students. I will also continue discussions with Michigan faculty about integrating spatial training into the computer science curriculum. In the case of a negative result, I will investigate cognitive differences between comprehension of visual and text-based programming languages to better understand how developers mentally model programs. Overall, my research will improve the design of language features and software development environments for both pedagogical and industrial settings.

Intellectual Merit: To the best of my knowledge, I am proposing the first controlled evaluation of spatial training transfer to computer science. While previous studies have assessed transfer to other domains [6], or proposed untested theoretical models [2], this is the first to target spatial training transfer to undergraduate programmers. This proposal brings together rigorous statistical techniques, psychology methodologies, and medical imaging. To complete the research in this proposal, I will curate programming tests that are easy enough for introductory students, difficult enough to assess computing knowledge, and capture spatial programming features. Ambitious and time consuming, longitudinal studies are rare in software engineering: there were only two in ICSE 2019. However, a longitudinal study is the best way to assess spatial training transfer. With a human-factors research background, I am equipped to carry out the work despite its challenges.

Broader Impacts: The research described in this proposal could provide actionable suggestions for closing socioeconomic and gender performance gaps in computer science. Researchers have found that spatial reasoning is a stronger mediating variable for the correlation between socioeconomic status and computer science achievement than computing access [3]. Therefore, if I find spatial training transfers to programming, then it is possible that adding spatial training to computer science courses could decrease the socioeconomic performance gap. While not specific to computer science, such interventions have been successful in general engineering [4], [5].

This study would also contribute to the understanding of the usefulness of cognitively grounded theories in computer science pedagogy. The use of medical imaging in software engineering is relatively new: The first software engineering paper using fMRI was published in 2014. Medical imaging papers have suggested that their technique could one day "help us understand the reported productivity gap between experienced and novice programmers" [1]. By using medical imaging to enhance the evaluation of transfer training, my work would be the first to show the practical use of medical imaging for influencing computer science practice.

References:
[1] Yu Huang et al.. 2019. Distilling neural representations of data structure manipulation using fMRI and fNIRS. In 41st International Conference on Software Engineering. 396-407. [2] Lauren Margulieux. 2019. Spatial Encoding Strategy Theory: The Relationship between Spatial Skill and STEM Achievement. International Computing Education Research. 81-90. [3] Miranda Parker et al.. 2018. Socioeconomic Status and Computer Science Achievement: Spatial Ability as a Mediating Variable in a Novel Model of Understanding. In Proceedings of the 2018 ACM Conference on International Computing Education Research. 97-105. [4] Sheryl Sorby. 2009. Educational research in developing 3-D spatial skills for engineering students. International Journal of Science Education 31, 3 (2009), 459–480. [5] Sheryl Sorby, et al.. 2018. Does spatial skills instruction improve STEM outcomes? The answer is 'yes'. Learning and Individual Differences, 67, (2018), 209-222. [6] David Uttal et. al.. The malleability of spatial skills: A meta-analysis of training studies. Psychological Bulletin, 139(2), 352-402.