Final Report: Knowledge Synthesis Grant

A Transdisciplinary Review of Research into Spatial Reasoning

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I. BRIEF SUMMARY

Spatial reasoning is proving to be of vital importance for people of all ages, and equips Canadian students to succeed in school and beyond. This assertion is perhaps most obviously realized in careers associated with sciences, technology, engineering, the arts, and mathematics (the STEAM disciplines) where strong correlations have been demonstrated among spatial reasoning abilities, academic success, and career choice. Despite growing awareness of the importance of spatial reasoning, the topic is scarcely addressed in grade school curricula. Among the many reasons for this blind spot, one particularly challenging issue is that research into the nature and development of spatial reasoning is typically confined by disciplinary boundaries.

The danger of this silo effect is a fractured understanding of spatial reasoning and its importance for school curricula and beyond. Due to the complex nature of spatial reasoning, deep understanding requires novel methods of research and analysis that synthesize these disparate bodies of knowledge. To that end, in this knowledge synthesis project we conducted a complex network analysis to identify where interaction across disciplines was occurring and not occurring as it relates to spatial reasoning. The project occurred over three phases, the third of which is still in progress. In Phase One, the research team completed an historical Knowledge Map that identified the seminal research activity related to spatial reasoning from 1900 to 2000. Phase Two involved completing a detailed SCOPUS search of citations, generating a database and illustrating the findings through a Heat Map and multiple Network Maps as part of a complex network analysis method. In Phase Three, the search process was further refined to verify the work of Phases One and Two. This work is still underway. Findings to date include the identification of a body of researchers across disciplines that form an essential history of the study of spatial reasoning. This historical map has undergone five revisions over time as additional work is undertaken by the research team. The study has also revealed gaps in communication between disciplines. In particular it appears that there are strong communication links for the domain of spatial reasoning between Psychology, Neuroscience, and Medicine, however there are very limited links to and from Education. The methods of this analysis are being documented in detail for replication by other researchers interested in communication links. The research team has also delved into five case studies where the missing connections to and from education are acute. One of the five cases, focused on perspective taking, is included in this report as an illustrative example.

Members of the study team for this Knowledge Synthesis Grant have developed and implemented a robust and varied knowledge mobilization strategy, which is fully detailed in the report and includes media outputs, peer reviewed researcher and practitioner publications, video messages, websites, and social media outreach.

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II. EXECUTIVE SUMMARY

Goals of the Project: The central purposes of the project were to conduct a complex network analysis that: (i) synthesizes current knowledge of spatial reasoning across the disciplines; (ii) identifies disparities and exactly where the disciplines are talking to one another or not talking to one another; and, (iii) creates an evidence-based agenda for future work in the area of spatial reasoning. The knowledge mobilization "products" generated through this synthesis project are multi-layered to respond to a range of practice and research needs.

Knowledge Synthesis Grant Fit - Theme 1: Identifying knowledge and learning outcomes required within the Canadian education system in order to support and sustain an innovative, resilient, and diverse society. Related question: *What innovative and collective approaches to learning, teaching, and research are being developed by educational institutions (particularly universities, colleges, and institutes) and what learning outcomes have been identified to date?*

Research Team: Bruce, Davis & Sinclair; Mulligan & Okamoto; and the Spatial Reasoning Study Group
A group of diverse researchers (mathematicians, mathematics educators, network analysis experts, and psychologists working together across three nations, to study and further communicate the research and importance of spatial reasoning in the early years of schooling (K-3 in particular) and beyond.

The Problem: Mathematics is an excellent predictor of school and career success. It is proving to be a better predictor of reading than reading itself, it predicts credit accumulation, and overall school success. Geometry and Spatial Reasoning is an untapped area of mathematics learning that enables students to access complex ideas in non-traditional ways. School math usually focuses on computation, memorization, and repetition. What we are learning from our research is that spatial reasoning opens the doors to other ways of engaging in mathematics. We describe this movement as 'Spatializing the Mathematics Curriculum'. Spatial reasoning is how we make sense of objects and space; i.e., how we mentally insert ourselves into a situation to solve a problem. However, spatial reasoning is not well understood or recognized for its importance in the role of learning and careers. Further, there is an apparent lack of communication among various education related disciplines, as well as between education and other disciplines such as medicine, psychology, and neuroscience that are studying spatial reasoning.

Research Questions: The following research questions have grounded the work of the Spatial Reasoning Study Group (SRSG) collaborating on this knowledge synthesis project.

(i) What do we already know? (Extending a current synthesis of research on spatial reasoning beyond education and psychology, to incorporate studies and applications across academic domains that take it up as a research topic);
(ii) Who is talking to whom and what are they saying? (Developing a cross-disciplinary lexicon, foregrounding commonalities, and divergences in vocabularies among disciplines);
(iii) What methodology can help? (Applying complex Network Analysis to refine a research methodology for supporting knowledge synthesis across multiple disciplines that are working on the same, complementary, and/or parallel areas of research);
(iv) How do we get the word out? (Developing a knowledge mobilization strategy to communicate the extreme importance of spatial reasoning for all learners, which is essential to the sustainability of innovation and STEAM leadership in Canada).

Activity of the Group: The SRSG began meeting prior to the knowledge synthesis grant. They have met 4 times through IOSTEM (University of Calgary) funding in Banff, Calgary (twice) and Palm Springs. The group was able to meet a fifth time in Vancouver thanks to this SSRHC Knowledge Synthesis Grant. At these meetings, the group has shared current research and related "products", co-written a range of resources and publications, and for this Knowledge Synthesis Grant, engaged in a network analysis research process.

Summary of Knowledge Synthesis Work:

Phase 1: Historical Knowledge Map

In phase one of the project, the SRSG identified seminal researchers/thinkers in spatial reasoning and important dates for their work. These notations were compiled by decade and mapped onto a large historical Knowledge Map with attention to the range of disciplines interested in spatial reasoning. This map was then revised on 5 occasions as the team furthered their analysis.

Phase 2: Complex Network Analysis

Phase two involved conducting a comprehensive SCOPUS search for key words that are used in spatial reasoning research. The six selected terms (e.g., "spatial visualization") were each entered into the SCOPUS database to find the top Modal Disciplines using this term. The researchers found the most cited paper in each Modal Discipline and used that most-cited paper to identify the top ten disciplines that this paper cited. These cited papers were counted and totals were entered into the database by discipline. There were 16 Modal Disciplines that used the six selected spatial reasoning terms. Matrix data were then subjected to a process of software-based analysis in Ucinet (Borgatti, 2012: Borgatti, Everett & Freeman, 2002) to produce a suite of graphical representations, weighted by degree (number of connections). This provided a visual overview or snapshot of the structure of the interconnectivity of the disciplines under

examination, with nodes (circles and squares) connected by lines (edges). The map was then studied to identify where connections between disciplines were strong and where they were limited. Essentially, the Network Map revealed that there are strong communication links for the domain of spatial reasoning between Psychology, Neuroscience, and Medicine (for example), however there are very limited links to and from Education, suggesting there is work to be done in this area.

Phase 3: Validation

In this stage of analysis, search parameters have been further tightened and the goal is to validate the work of phases one and two. In this phase, we have begun with the original key words and then expanded the search for key words using an iterative process. We have now identified 100+ keywords across 25 disciplines using 50,000 citations over the past 10 years. We are now compiling the specific terms by discipline and can describe the different fields of research and overlaps based on the key words. As we move forward, the key word search will also allow us to repeat our refined citation analysis and network analysis. This step will confirm and extend the identification of seminal research and highly influential authors in the field (enabling a 6th revision of the historical Knowledge Map) and the key publications across disciplines (enabling additional Heat Maps and Network Maps for comparison).

Related Knowledge Mobilization Strategy

The Knowledge Synthesis Grant has enabled the development of the following key products: 1 full draft of a research paper on network analysis methods for education-related constructs, with spatial reasoning as the illustrative example; 1 full draft of a research paper on the findings from the network analysis with illustrative case studies of how different disciplines are working together and where disciplines are working in isolation; 1 website (www.spatialresearch.org); 1 historical Knowledge Map of spatial reasoning from 1900's onward; 1 draft of symposium for NCTM 2016; and, 1 proposal to initiate an AERA special interest group on spatial reasoning. Direct work with educators has also ensued to bridge research and practice, including working with over 40 teachers and 450 students in 3 nations in collaborative research projects focused on spatial reasoning.