Learning Progressions for Maps, Geospatial Technology, and Spatial Thinking

A Research Handbook

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GeoProgressions

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A Research Handbook

Edited by
Michael Solem, Niem Tu Huynh, and Richard G. Boehm

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Preface

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Michael Solem, Niem Tu Huynh, Richard G. Boehm

Understanding the World in Spatial Terms: A Call for Research and Action

From etchings on clay tablets dating to Ancient Babylonia, to maps sketched on paper napkins in roadside diners, to the digital mapping apps and virtual globes of the 21st century, it is clear that humans have always had a cartographic impulse for survival, enlightenment, exploration, navigation, communication, recreation and discovery. Yet despite this long and rich cartographic history, a fundamental puzzle remains unsolved: how do people develop the capacity for spatial thinking and geographic understanding?

As geography educators, we are especially interested in how the human ability to think spatially and acquire geographical knowledge can be groomed through purposeful instruction. Although there is a rich tradition of research in spatial cognition, much of that work was not explicitly investigated in the context of standards for K-12 education. Given the current "geospatial revolution" of literally boundless and pervasive amounts of digital data on space and place (Downs 2014), more than ever we need research to identify and interpret the factors and conditions shaping how students come to understand the world through spatial thinking and the role of geographic information, tools, and technologies in fostering geographic learning and spatial thinking abilities.

There is an extensive body of work in geography and spatial cognition that can inform future studies on geographic learning and spatial thinking in schools. Equally important will be building capacity to do systematic, large-scale, and strategic research in geography education. During the past 20 years a number of reports have characterized the state of geography education research in rather bleak terms (Butt 2010; Segall and Helfenbein, 2008; Bednarz, Downs, and Vender 2003, Forsyth 1995). They paint a portrait of a field that is generally disconnected from educational research in other disciplines and overrun by studies that, while often interesting, are mainly descriptive and anecdotal accounts of classroom practices. Geography education has few longitudinal studies and research designs that lend themselves to replication and theory-building. Compared with educational research in mathematics and science, discipline-specific findings are few, and there is little consensus on ways to enact reforms in teaching, teacher preparation, curriculum development, assessment, and other educational practices. The need for geography education researchers who understand sample selection, hypothesis formation, data quality, statistical analysis, reporting requirements and research ethics has been a longstanding need (Downs 1994; Williams 1996).

In recent years, attempts have been made to formulate a framework for improving and doing research in geography education, one that draws on precedents in science, technology, engineering, and mathematics (STEM) education. The National Research Council's *A Framework for K–12 Science Education* (National Research Council 2012) organizes the content and process of science around three dimensions: (1) practices including the cognitive, investigative and social factors involved with "doing" science; (2) crosscutting concepts and ideas that have wide application across a variety of subfields; and (3) core ideas of disciplines. The framework emphasizes learning with core ideas and using appropriate content-based practices, while considering the thematic features of the discipline represented by the cross-cutting concepts. Additionally, the framework focuses on what students must do to develop understanding of particular core ideas.

With regard to the practices, crosscutting concepts, and core ideas of geography, these were codified for educators in a landmark document introducing national standards for K-12 geography in the U.S.: *Geography for Life: National Geography Standards* (Geography Education Standards Project 1994). The U.S. national geography standards, which were updated in 2012 (Heffron and Downs 2012), specify what a geographically-informed person should know and be able to do by the 4th, 8th, and 12th grades. As the standards were developed, there was a sense among the writers of a need for research that could potentially refine the expectations for learning through evidence of how students think geographically and develop geographic ideas and skills as they advance in their cognitive capabilities. In the interim period between the 1994 and 2012 editions of *Geography for Life*, researchers at the Grosvenor Center for Geographic Education at Texas State University published a "scope and sequence" and related teacher's guide (Grosvenor Center for Geographic Education 2000, 2001) that responded to a need for a grade-by-grade "content map" for geography; provided teachers with sample lesson ideas; called out for a more research-based set of standards (standards informed by learning progressions); and looked at science and math standards to get a comparative perspective on how standards were being structured and sequenced.

On the heels of the second edition of *Geography for Life*, the National Geographic Society's Road Map for 21st Century Geography Education project issued a report that uses the national geography standards to anchor a research agenda on geographic concepts, ideas and practices that emphasize inquiry, analysis and communication (Bednarz, Heffron, and Huynh 2013). The report by the Road Map Geography Education Research Committee (GERC) points out how core ideas between science and geography education overlap across multiple concepts dealing with patterns, similarity and diversity; cause and effect; scale, proportion and quantity; systems and system models; energy and matter (flows, cycles and conservation); structure and function; and stability and change. Given these relationships, the GERC report calls for closer alignments and linkages with the systematic approaches taken in STEM education as a strategy for improving learning and proficiency in geography. This leads directly to the present interest in building capacity for learning progressions research in geography.

Researching learning progressions in geography education

The Road Map GERC report recommended systematic efforts to identify learning progressions in geography both within and across grade bands as a means of attaining broad-based improvements in geography teaching and learning. A learning progression is a description of "the successively more sophisticated ways of thinking about a topic that can follow one another as children learn about and investigate a topic over a broad span of time" (National Research Council 2007, 219). Qualitative change and development in learning can be measured on a continuum along a hypothesized progression, or trajectory, of what students ought to know about a target topic at a specific grade or age (Duncan and Hmelo-Silver 2009).

Developing a learning progression is an iterative process as the progression is written and revised based on the findings of formative assessments of students' thinking and understanding about a concept (Alonzo and Steedle 2009). The main goal of developing a learning progression is to acquire empirical data to test hypotheses about how students' thinking develops and is organized in their minds as they learn (Mosher 2011; Duncan and Hmelo-Silver 2009). The resulting predictions about learning can potentially inform teaching practices and the design of curriculum standards, assessment resources and teacher professional development programs for different academic subjects. Empirical research may well reveal the eclectic nature of student populations, alternative value systems, and how students' thinking develops and is organized in their minds as they learn (Mosher 2011; Maloney, Nguyen, and Confrey 2014) .

After an extensive review, the Road Map GERC report found no systematic attempts in the U.S. to research learning progressions in the context of geography education at any level. This research handbook aspires to catalyze such research activity in school geography education, focusing initially on three national geography standards that set goals for teaching and learning with maps, geospatial technology and spatial thinking. These three standards appear collectively in *Geography for Life: National Geography Standards, Second Edition* (Heffron and Downs 2012) under the heading Essential Element 1: The World in Spatial Terms:

Geography Standard 1: How to use maps and other geographic representations, geospatial technologies, and spatial thinking to understand and communicate information.

Geography Standard 2: How to use mental maps to organize information about people, places, and environments in a spatial context.

Geography Standard 3: How to analyze the spatial organization of people, places, and environments on Earth's surface.

Each of these national geography standards is expounded in *Geography for Life* by detailed sets of knowledge and performance statements. Knowledge statements are introduced by the phrase "The student knows and understands …", whereas performance statements are introduced by the phrase "Therefore, the student is able to …”. Performance statements are further illustrated through the use of exemplars that provide educators with ideas for learning activities. All three standards and their respective knowledge and performance statements are reproduced in the Appendix to this handbook.

Although the second edition of *Geography for Life* drew upon research literatures and was subjected to extensive peer review, the scope and sequencing of the national geography standards largely rests on conventional wisdom and the insights accumulated over decades of classroom teaching experiences. This is not unusual and indeed reflects the nature of other STEM curriculum standards. One of the potential values of learning progressions research is to acquire evidence of learning, comprehension and understanding within and between grade bands. Corcoran, Mosher, and Rogat (2009) assert that, “Progressions can make the interactions between content and practices explicit in a way that current standards and assessment often do not.” Such evidence might be used to refine and strengthen the quality of the national geography standards in future editions of *Geography for Life*.

An Initial Focus on Maps, Geospatial Technology, and Spatial Thinking

The geography standards composing Essential Element 1 were chosen as a starting point for learning progressions research in geography education for several reasons. Ever since the publication of the National Science Education Standards (National Academy of Sciences 1995), a concerted and evolving movement has gathered momentum to make STEM-based learning more inquiry-oriented. The importance of spatial thinking for promoting inquiry and learning is cited throughout STEM education standards and frameworks, including *Geography for Life: National Geography Standards 2nd Edition* (Heffron and Downs 2012), the *Next Generation Science Standards* (Achieve 2013), the *Common Core State Standards for Mathematics* (National Governors Association Center for Best Practices and Council of Chief State School Officers 2010), and *The College, Career, and Civic Life (C3) Framework for Inquiry in Social Studies State Standards* (National Council for the Social Studies 2013).

Essential Element 1 of *Geography for Life* is closely tied to expectations for student performance in mathematics and science. For example, the mathematics standards expect students to specify locations and describe spatial relationships using coordinate geometry (e.g., coordinate systems in maps). The link between Essential Element 1 and science education spans multiple topics found in the Next Generation Science Standards, such as the ability to interpret and analyze data from maps to describe patterns on the Earth’s surface and to use models such as maps and globes to explain climate change as a function of atmospheric and oceanic circulation. The common thread among these standards is the use of maps, spatial thinking and geospatial technologies for analyzing phenomena from a geographic and spatial perspective (National Research Council 2006).

Maps and other forms of geospatial data and technology enable people to think spatially at geographic or “geospatial” scales (e.g., neighborhood, biome, region, national, global) that are beyond an individual’s purview, and thus are considered to be useful for enhancing spatial thinking in STEM education. Researchers are increasingly interested in studying how competency and understanding in the uses of maps and geospatial technology may be related to the learning of core geographical and spatial concepts such as location, scale and pattern (Kim and Bednarz 2013; Lee and Bednarz 2012). The integrated connections between spatial thinking and standards for math and science provide opportunities to improve learning in STEM through the development of learning progressions based on Essential Element 1. The cross-cutting nature of the discipline creates a fascinating research context for exploring any number of connections among geographic learning, spatial thinking, geometric measurement, other modes of cognition and learning in STEM education.

For these reasons the Road Map GERC advocated for learning progressions as a means of unpacking the mysteries of how children learn and develop fundamental geographic and spatial concepts. The GERC report recommends connecting the relatively small community of geographers and others who conduct research in geography education with the broader community of scholars from the learning sciences, education, STEM and related fields. This cooperation and collaboration has potential to inform, assist and enable more generative activities such as developing a suite of assessments that can be used in geography and other fields. It might also encourage studies that align to key research questions; are situated in a problem context; focus on the core ideas, knowledge, skills and practices of geography; draw from research about crosscutting themes and foundational concepts from other disciplines; and use common tasks, measures and assessments.

Drawing on the Road Map GERC report’s recommendations, this handbook stresses capacity building through the training of graduate students, early career scholars and faculty of all ranks in methodologies of educational research. The focus of the book is on preparing the next generation of education researchers to carry out research on geography learning progressions. Ultimately, we hope to see attempts at developing learning progressions for the other geography standards dealing with places and regions, physical and human systems, nature and society, and the uses of geography. Such work would probably require researchers to adopt different perspectives from the learning sciences, social sciences and humanities, and perhaps less so from the spatial cognition literatures that are the foundation for spatial thinking and learning with maps and geospatial technologies. This is because the geography standards composing Essential Elements 2-6 overlap more with traditions of geographic thought that draw on a wider range of epistemologies, from cultural studies and the humanities to social theory, political ecology, globalization, global citizenship, among many other contemporary philosophies dealing with the fundamental nature of geography's twin sisters, space and place.

On that point, we wish to acknowledge the risk of losing sight of the *geography* that underpins the skills and practices of Essential Element 1 (an issue that Michael Solem and David Lambert critically examine in the concluding chapter). By developing this handbook to support research on learning progressions for maps, geospatial technology and spatial thinking, our purpose is to begin a process that has potential to improve the quality of geography teaching and learning in the broadest sense. That means valuing and appreciating geographic knowledge and the richly diverse perspectives on society and the environment that geography offers.

Geography for Life is an integrated set of educational standards for geographical knowledge, skills and practices. It is therefore important to remember that Essential Element 1 was never intended to act as a standalone set of standards for spatial thinking. *Geography for Life* makes clear that maps, geospatial technology and spatial thinking are conduits for learning geography. The related learning progressions, then, should be constructed for the purpose of helping more students become geographically informed and knowledgeable about people, places and environments, whether that learning occurs in a "geography" class or in a different STEM context. This also focuses the purpose closely upon the development of teachers' pedagogical content knowledge, promoting improved instruction in geography across a range of disciplinary studies and within its own right.

Organization of this handbook

This research handbook was developed to serve three purposes. First, the book is designed to provide researchers with an introduction to learning progressions and the methodologies that have been developed to create and test learning progressions, using examples from math and science education. Second, the book is intended as a reference for coordinating future efforts for independent and collaborative studies that generate empirical data grounded in replicable design. A third aim of the book is to build capacity not only within the geography community, but also among education researchers in STEM with interests in spatial thinking and geographic learning with maps and geospatial technologies.

In Chapter 1, Niem Tu Huynh and Amelia Wenk Gotwals provide an introductory overview of learning progressions. The authors discuss the ways education researchers have defined learning progressions and describe the research literatures where this work originated. They also explore some of the major areas of debate surrounding learning progressions and illustrate how different approaches to research can yield different forms of evidence that, in turn, can contribute to the development of a learning progression. The authors conclude the chapter with a discussion of how prior work in learning progressions in math and science has implications for geography education, specifically to thinking and learning with maps and geospatial technologies.

Chapter 2, by Lindsey Mohan, Audrey Mohan, and David Uttal, provides a review of research that is most closely related to the goal of developing learning progressions based on Essential Element 1. Successfully building capacity for learning progressions research in geography will require researchers to consider and draw upon relevant literature in geography teaching and learning. Within the field of geography education and fields such as spatial cognition, there is some basic research to guide the development of learning progressions related to spatial thinking, maps and geospatial technology. The authors consider this prior work as they assess the state of knowledge on how students acquire and communicate information through the use of spatial thinking, maps, geographic information systems and other geographic representations.

The book's third and fourth chapters, prepared by learning progressions experts Jeffrey E. Barrett, Shawn Stevens, Hui Jin, and Amelia Wenk Gotwals, provide readers with a comparison of quantitative and qualitative research methodologies and the reasons why a researcher might choose one approach over an alternative. The authors present detailed case studies of a math learning trajectory and a science learning progression and illustrate how each was developed, researched and modified using evidence of student learning and comprehension of the subject matter. The authors also include a general discussion of issues such as budgeting and confidentiality assurances and protections for human subjects participating in learning progressions research.

The final chapter offers a critical yet constructive perspective on the aims of learning progressions research and its potential impacts on educational purpose and practice. Michael Solem and David Lambert focus on the assumptions about progress and sophistication that seem to underlie learning progressions as presently understood and practiced. They question whether the findings generated by learning progressions research on spatial thinking, and the concurrent emphasis on Essential Element 1, might have unintended consequences when applied to geography assessment, curriculum making or teacher professional development. Solem and Lambert wonder, for instance, whether learning progressions might lead to a narrowing of curriculum content to fit what emerging evidence suggests students are capable of knowing and doing, without considering the complex nuances of geographic context and the possibility of unknown but potentially equally valid alternative pathways to understanding and comprehension of geographical topics and concepts.

Acknowledgements

We hope this book inspires you to take on the considerable challenge of researching learning progressions in geography. Whether you are just beginning a thesis or dissertation, are an experienced educational researcher, or primarily think of yourself as a geographer, geoscientist, or other STEM researcher, this book was created to assist you in undertaking research of a nature that, we believe, can address and potentially clarify some of the most fundamental questions pertaining to geographic learning and spatial thinking. We therefore wish to begin our acknowledgements by thanking you, the reader, for your interest in this topic.

Of course, a research handbook alone cannot fulfill the considerable challenges facing us in terms of building research capacity in geography education. This is why the Association of American Geographers and Texas State University have created a National Center for Research in Geography Education (NCRGE) to provide an emerging network of researchers with a stable resource for data sharing, reporting, and dissemination. We invite you to contact the NCRGE (www.ncrge.org) so that we can help connect you to an interdisciplinary community of scholars who are researching learning progressions for geography in schools.

Finally, we are very grateful for the support we have received from key organizations and individuals. This research handbook, and related capacity building efforts were the outcomes of the GeoProgressions project funded by the National Science Foundation through its Education and Human Resources Core Research program (Award DRL-1347859). The National Geographic Society and National Council for Geographic Education provided much in the way of in-kind support and outreach to key stakeholder communities.

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Sincerely,

Michael Solem, Association of American Geographers

Niem Tu Huynh, Association of American Geographers

Richard G. Boehm, Texas State University

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Biographies

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Michael Solem is Director of Educational Research and Programs for the Association of American Geographers. Michael is principal investigator on several large-scale, federally funded projects spanning geography at all levels of education, focusing on professional development, internationalization, global education, and teacher preparation. His publications include articles in the *Annals of the Association of American Geographers, The Professional Geographer, Research in Higher Education, Education About Asia, The Geography Teacher,* the *Journal of Geography in Higher Education*, and the edited books *Aspiring Academics, Teaching College Geography,* and *Practicing Geography.* Michael currently serves as co-Director of the National Center for Research in Geography Education and is Treasurer for the International Geographical Union's Commission on Geographical Education. He is a member of the editorial board for the *Journal of Geography in Higher Education, Review of International Geographical Education Online,* and the *Journal of Research and Didactics in Geography.* Michael has twice received the *Journal of Geography in Higher Education's* award for promoting excellence in teaching and learning for his research on faculty development and graduate education in geography. He is the 2015 recipient of AAG Gilbert Grosvenor Honors in Geographic Education

Niem Tu Huynh is a Research Fellow at the Association of American Geographers (AAG). She has worked closely with inner city high school teachers in D.C. and parts of Maryland, as part of the My Community Our Earth - Global Connections and Exchange program, to introduce mapping and geospatial technologies as tools for data analysis and communication in science. This experience dovetails with her research interest of geography education, specifically using geospatial tools. Niem serves as an internal evaluator for several education projects. She was the research coordinator and co-editor of *Road map for 21st century geography education: Geography education research*, a report to improve research in geography education. She has won the Journal of Geography Award, Geography Program Development, from the National Council for Geographic Education in 2012 and 2014.

Richard G. Boehm presently holds the Jesse H. Jones Distinguished Chair in Geographic Education at Texas State University. He is also the Director of the Gilbert M. Grosvenor Center for Geographic Education and Co-Director of the newly formed National Center for Research in Geography Education. He has received numerous awards for his work including "Distinguished Geography Educator" by the National Geographic Society, the George J Miller Award for Distinguished Service by the National Council for Geographic Education (NCGE) and Grosvenor Honors in Geographic Education by the Association of American Geographers. Dr. Boehm is the Executive Editor for the scholarly journal *Research in Geographic Education,* and has authored several best-selling geography and social studies books for grades K-12. He was a co-author of *Guidelines for Geographic Education* (1984) and *Geography for Life: National Standards in Geography* (1994). Recently he has worked closely with Carmen Brysch, Grosvenor Scholar at the National Geographic Society, to develop the Learning Cluster Method, a hybrid online professional development system for teachers. He has also worked recently with Dr. Michael Solem on three NSF applications; (1) Geospatial Technology in STEM Teacher Training, (2) Assessment in Introductory Geography Courses, and (3) Developing Materials to Improve Workforce Success for Geography/Geoscience Students.

About the Authors

Jeffrey E. Barrett is *Professor of Mathematics Education* and also serves as an *Associate Director* of the Center for Mathematics, Science and Technology at Illinois State University. His research interests include the learning and teaching of the mathematics of measurement, geometric reasoning, the use of computer software to model mathematical ideas, and the professional development of teachers engaged in teaching elementary and middle-school level mathematics. Dr. Barrett is currently Principal Investigator of a four-year project, *Learning Trajectories to Support the Growth of Measurement Knowledge: Pre-K through Middle*

School in collaboration with Douglas Clements and Julie Sarama at the University of Denver and Craig Cullen, a colleague at Illinois State University. This work extends the project, *Children's Measurement*, an examination of learning trajectories on children's development of spatial measurement knowledge from prekindergarten through Grade 5 (with NSF funding from 2007 and 2011). Barrett recently served as the Principal Investigator for an Illinois Math Science Partnership project funded by the Illinois State Board of Education (2010 through 2013) to support professional development of elementary teachers in using measurement learning trajectories as a basis for formative assessment: *Formative Assessment Improving Teachers' Instructional Practices.*

Amelia Wenk Gotwals has a BA in Biology from Brown University and an MS in Ecology and Evolutionary Biology, MS in Educational Studies, and a Ph.D. in Science Education from the University of Michigan. She is currently an associate professor in the Department of Teacher Education at Michigan State University. Her research interests are focused around the learning progressions that K-12 students take when learning science, the trajectories that teachers follow when developing expertise in teaching, and the interaction of these two in the classroom. In particular, she is interested in: (1) the development and evaluation of learning progressions for how students learn to utilize science practices (specifically, formulating evidence-based explanations and arguments) to reason about disciplinary core ideas (especially in ecology); (2) the design and validation of assessments to gather evidence of students' developing understandings; and (3) the characterization of how teachers develop more sophisticated formative-assessment teaching practices.

Hui Jin is an assistant professor at The Ohio State University. She received her PhD in Curriculum, Teaching, and Educational Policy from Michigan State University in 2010. Her dissertation research focused on the development of a learning progression for energy and causal reasoning in socio-ecological systems. During her career, Jin has pursued interests in learning progressions, conceptual change, climate change education, and secondary science teaching. Her current research involves the development of an instruction-assisted learning progression for argumentation, investigation of teachers' understanding and use of learning progressions, and video analysis of classroom teaching. She is also part of a research team that develops learning progressions for matter and energy in social-ecological systems.

David Lambert was a secondary school geography teacher for 12 years. He joined the Institute of Education (IOE) in 1986-7 as a teacher educator, becoming Assistant Dean for Initial Teacher Education (research) in 1999. He played a leading role in introducing the innovative Master of Teaching (MTeach) course at the Institute which now has over 200 students. In 2002 he left the IoE to become full-time Chief Executive of the Geographical Association, helping to guide its transformation into a significant provider of CPD and a leader in funded curriculum development activity, including the £4m Action Plan for Geography funded by the government (2006-11). From September 2007-12 he combined this role with a return to the IOE as Professor of Geography Education (finally returning full time in 2012). Recent publications include "*Geography 11-19: a conceptual approach*", co-written with John Morgan (2010), *Debates in Geography Education* co-edited with Mark Jones (2013) and *Knowledge and the Future School: curriculum and social justice* with Michael Young (2014). His overarching career goal is to advance understanding of the goals and purposes of geography in schools, not least its role in helping young people grasp the significance of the Anthropocene.

Audrey Mohan joined BSCS as a Research Associate in December 2012. Her expertise is in the design of instructional materials and professional development for K-12 teachers, and she also conducts research and evaluation studies related to teacher and student learning in science. Prior to joining BSCS, Audrey worked in a number of roles (high school teacher, professor, researcher director, university staff) in geography, social studies, and STEM education. She is particularly interested in the design of professional development and curriculum materials in geography and environmental studies. She is also interested in studying how domestic and international travel experiences influence the knowledge, teaching practice, and worldview of geography and environmental science teachers. Audrey has a B.A. in History from the University of Notre Dame, an M.Ed. with emphasis on special education from University of Texas-Austin, and a Ph.D. in Geography with emphasis in geography education from Texas State University-San Marcos. She lives in Colorado Springs and spends her free time hiking, camping, or skiing with her husband and two year old son.

Lindsay Mohan is a middle school earth science teacher at Burnet CISD in Texas and an education consultant in science and geography education. Her work focuses on the design of innovative instructional resources and effective teaching programs. Lindsey was a lead writer on the instructional materials and professional development report for *A Roadmap for 21st Century Geography Education*. She also co-produced a report titled *Spatial thinking about maps: Development of concepts and skills across the early years* for National Geographic Education Programs. Prior to returning to the middle school classroom, she worked on the development of learning progressions in science as a post-doctoral researcher and research scientist on the Environmental Literacy Project at Michigan State University. Lindsey also directed the development of the *Environmental Literacy Teacher Guide Series* in her role as Climate Education Manager at National Geographic Society. She completed a B.A. in Psychology from the University of Notre Dame, and a Ph.D. in Educational Psychology and Educational Technology from Michigan State University.

Shawn Stevens is an assistant research scientist in the School of Education at the University of Michigan where her work focuses on assessing and improving learning in formal and informal environments. Her current research efforts include developing and empirically testing learning progressions for a variety of disciplines and developing interdisciplinary high school curriculum materials to help students understand electromagnetic interactions and their role in the structure, function and behavior of matter. She co-authored a book to support secondary teachers' incorporation of nanotechnology into the classroom. She was a member of the design team for that defined drafted learning progressions for the core ideas of physical science for grade K-12 learners for the *Framework for K-12 Science Education.* She received her AB in chemistry from the University of Chicago and her PhD in chemistry from the University of Michigan.

David Uttal is Professor of Psychology and of Education at Northwestern University. His research focuses on cognitive development and learning, particularly spatial and symbolic thinking. He also studies how these factors contribute to STEM learning. Uttal is a Fellow of both the American Psychological Association and the Association for Psychological Science. His meta-analysis of studies of spatial training won the George Miller Award for Outstanding Recent Article on General Psychology.

Chapter 1

What are Learning Progressions?

Niem Tu Huynh, Amelia Wenk Gotwals

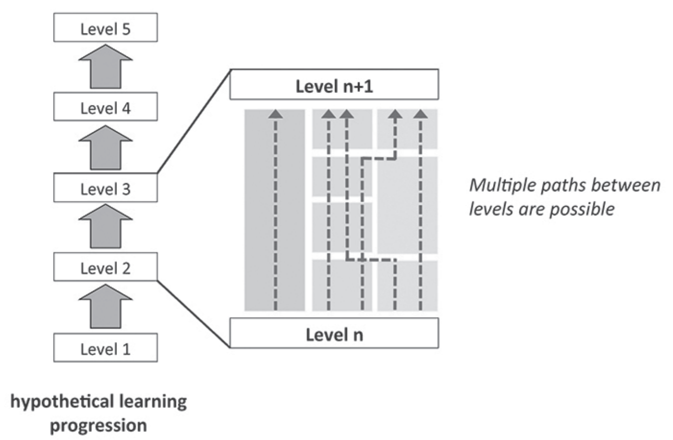
Since the mid-2000s, the mathematics and science education communities have accelerated efforts to explore learning progressions (LPs) and learning trajectories (LTs) as frameworks to help support student learning over time. LPs, in science, are defined as "descriptions of the successively more sophisticated ways of thinking about a topic that can follow one another as children learn about and investigate a topic over a broad span of time (e.g., 6 to 8 years). They are crucially dependent on instructional practices if they are to occur" (NRC 2007, 219). Similarly, LTs in mathematics have been defined as

> …empirically supported hypotheses about the levels or waypoints of thinking, knowledge, and skill in using knowledge, that students are likely to go through as they learn mathematics and, one hopes, reach or exceed the common goals set for their learning. Trajectories involve hypotheses both about the order and nature of the steps in the growth of students' mathematical understanding, and about the nature of the instructional experiences that might support them in moving step by step toward the goals of school mathematics. (Daro, Mosher, and Corcoran 2011, 12)

LPs and LTs shift the focus from end point mastery to understanding how ideas build upon one another as students develop desired knowledge, skills, and practices in a discipline. By providing a coherent description of how to build more sophisticated understanding of core ideas or skills of a discipline, LPs and LTs provide a framework to align content (desired knowledge and skills), curriculum, instruction and assessment. The possibility of having this type of coherence that builds on the ways in which students learn is exciting for the field. Researchers involved in this work have opportunities to re-think how to conceptualize student learning such that all levels of education (i.e., from national standards to classroom assessment) are aligned.

While LPs and LTs provide frameworks for how ideas build over time, they are not meant to imply that there is a single path through the progression. It is likely that there are multiple paths students can follow from one level to the next as they experience different instructional strategies (Figure 1).

Figure 1: Diagram of how learners might progress along a LP



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Generally, the terms *learning progressions* and *learning trajectories* are used to represent similar ideas in science education and mathematics education, respectively. However, when the latter term (i.e., LTs) is used in science education, it sometimes also refers to LPs that have a more narrow time span and grain size and explicitly include instructional sequences (e.g., an LP based on a unit on buoyancy; Kennedy and Wilson

2007) (Duschl, Maeng, and Sezen 2011). Internationally, research is also being conducted on frameworks to represent student learning. In Australia, these frameworks are often referred to as progress maps, whereas in the United Kingdom, similarly to the U.S., they are referred to as learning progressions. The purpose of this chapter is to introduce LP research in mathematics and science education. Following Chapter 2's discussion of learning progressions in the context of spatial thinking research, Chapters 3 and 4 will build on the concepts discussed here and examples will be provided.

Learning Progression Components

While LPs may differ in some aspects, most current research considers the same essential features of LPs and LTs: (1) the learning goal or upper anchor; (2) the developmental progressions of thinking and learning in which students might engage; (3) assessments; and sometimes (4) learning activities or sequences of instructional tasks (Clements and Sarama 2004; Simon 1995; Corcoran, Mosher, and Rogat 2009). Below we discuss each of these features.

1. The Learning Goal *(also known as learning targets, end points, or upper anchors)*

Learning goals are based on knowledge, skills, and abilities needed to participate in society or that are needed for making the next step in understanding. Depending on the scope of the LP, the upper anchor may be knowledge that is needed to move to middle school (for example a LP that spans K-8) or understanding that a high school graduate should possess in order to be a literate citizen in the given discipline (e.g., geography). These learning targets result from a deliberative process that includes an understanding of the core disciplinary ideas and practices, social aspirations for citizens, and research about students' understandings after instruction. These learning targets are often defined as educational standards for a given discipline. For example, the standards within *Geography for Life* (Heffron and Downs 2012; e.g., Standard 1: "students use maps and other geographic representations, geospatial technologies, and spatial thinking to understand and communicate information") may be reframed as upper anchors.

2. Hypothesized Developmental Progressions of Thinking and Learning *(sometimes called Progress Variables)*

Developmental progressions are the hypothesized pathways that students take en route to the upper anchor. The development of these progressions is an iterative process as they are derived partly from theories about how disciplinary knowledge and practice are organized (top-down) and partly from empirical research on student learning (bottom-up). These developmental progressions often represent learning in terms of levels. The development of levels is based partly on research about what constitutes higher and lower levels of performance and partly on data about students' actual performance. Using empirical findings of student reasoning is critical for LP research because LPs do not impose normative models of disciplinary understanding on student learning. Rather, LPs are based on how students learn the discipline (which may differ greatly to how a disciplinary expert might deconstruct ideas). Table 1 describes four levels of a hypothesized LP on map use, grounded in findings from the literature. For an in-depth discussion of this research, see Chapter 2.

Table 1: How to use maps and other geographic representations, geospatial technologies, and spatial thinking to understand and communicate information.

Level	Description
4	Students understand that there are spatial relationships and connections between phenomena at the local to national to global scale. Communication of patterns is supported by analytic tools (e.g., computation of spatial analysis) to answer and ask questions.
3	Students can map a variety of spatial data collected from observations (e.g., fieldwork in the community) and external sources. They begin to use the map as a model to understand patterns and the connection(s) of the phenomenon to the surrounding area.
2	Students can use their body to measure and understand distances (e.g., 1 foot size equals 1 foot on the ground). The measurements provide a foundation to understanding different scale formats.
1	Students can match landmarks from a familiar environment (e.g., classroom or bedroom) to symbols on a large-scale map. The symbols used are iconic such that they resemble the landmark being mapped (e.g., green patches for grass).
0	No evidence of understanding

3. Assessments

Assessments are tasks that allow students to reveal their reasoning about the levels in the LP. Identification of assessments that provide information about learning performances is critical as students' level of performance on assessment tasks should be relatively consistent. Initially, researchers attempt to match student responses to the framework and use these responses to help them iteratively refine the hypothetical progression. Once the LP has validity evidence underlying it, student responses to assessments can be used to place their performance at particular achievement levels, which can provide stakeholders (e.g., teachers, researchers, school administrators) with information about these students' understanding. *Geography for Life* (Heffron and Downs 2012) includes student knowledge and student performance statements that can be used as both upper anchors and as a guide for assessment development. For example, the upper anchor of Properties and Functions of Geographic Representations within Geography Standard 1 at grade 4 is "identify and describe properties and functions of geographic representations" (22), which could lead to the development of assessment tasks that measure students' understanding in relation to this goal. A related assessment task, for example, might require respondents to identify which map elements are represented by a point, line, or polygon.

4. Instructional Sequences

The role of instruction in LPs is both critical and complicated. Instruction plays a key role in helping children move through LPs; and in the absence of instruction, children may be unlikely to progress much beyond their naïve conceptions in the domain.

What children are capable of at a particular age is the result of a complex interplay among maturation, experience, and instruction. What is developmentally appropriate is not a simple function of age or grade, but rather is largely contingent on prior opportunities to learn. (NRC 2007, 2).

As discussed in the following chapters, instruction can play multiple roles in LP research. Instruction can be used to develop a LP by conducting teaching experiments in order to define levels (e.g., see Barrett et al. 2012 described in Chapter 4). Alternatively, some LPs are developed based on research of status-quo instruction and then instructional sequences and activities are designed to help students proceed along this learning progression (e.g., see Jin's example in Chapter 4).

Eventually LPs or LTs are tied back into the work of teachers in their classrooms, though the distance between research and classroom varies widely by research focus and context (Sztajn et al. 2012). LPs aim to improve student learning; however learning is mediated through instruction. The teacher cannot be removed from this analysis, thus the emphasis on actual classroom instruction.

The Origin of Learning Progressions Work

Research on LPs (in science) and LTs (in mathematics) have different developmental histories. In science, LPs began as a response to the critique that studies in science education did not produce the types of findings that could influence large-scale assessment or policy decisions, being too limited in duration and scope (e.g., NRC 2005; Smith et al. 2006). For example, studies often focused on student learning in a single unit with no connections across years or disciplinary core ideas, or research was conducted on a small population of students with limited possibilities for generalization. While these studies provided rich insights into how students learn, until recently there have been few efforts to find connections between studies in order to inform larger frameworks (Gotwals and Anderson, forthcoming). Thus a need arose for frameworks that could merge the findings from multiple domains to build a more powerful and coherent understanding of how students learn in the long term.

In order to meet the needs for longer-term frameworks, the NRC (2005; 2007) recommended that LPs bring together research on student learning from science education, developmental psychology, sociocultural theory, and other domains in order to develop frameworks that span six to eight years of instruction. While not all LPs work in science education follow this temporal guideline (e.g., Alonzo and Steedle 2009; Furtak 2012; Gotwals and Songer 2013; Songer, Kelcey, and Gotwals 2009), there is a push for LPs to make connections across grades in order to inform larger purposes (Gotwals 2012).

In mathematics, on the other hand, LTs often began with a focus on classroom instruction. Simon (1995) introduced LTs as a way to support teachers' use of student ideas in their instructional decision-making. Since that time, researchers have built upon this work to clarify and expand on the definition (e.g., Clements and Sarama 2004; 2009; Sarama and Clements 2009), but the main focus has remained on improving classroom instruction. In more recent years, Confrey and colleagues (e.g., Penuel, Confrey, Maloney, and Rupp 2011) have worked to inform the development of the Common Core State Standards Initiative through work on LTs. Thus, while math LTs often focus on design research around specific instructional programs or sequences, they have also conducted large scale-up studies to inform policy decisions such as standards setting and large-scale assessments.

These represent examples of LP and LT studies occurring in both disciplines at different levels and allowing for impacts on different aspects of the educational enterprise, including teacher learning, curriculum development, assessment development and standards setting. Clements (2007) has argued that curriculum development frameworks need to be in place to guard against claims that curricula are "research-based" when they have not been subjected to adequate standards for design, testing or generalization. LPs and LTs are a key element in an adequate and substantive criterion for educational research in STEM fields that are intended to improve teacher learning, curriculum development, assessment development and the development of standards.

The Role of Research in Developing Learning Progressions

Through the incorporation of both a top-down (the structure of the discipline) and bottom-up (what we know about how students learn) design process, LPs combine ideas from multiple disciplines to provide a coherent framework for describing the development of students' knowledge and practice (Gotwals and Alonzo 2012). As part of the top-down design of LPs, experts (e.g., geographers, geography educators) identify learning goals or upper anchors that consist of key ideas and skills based on the knowledge needed for productively engaging in society (as mentioned above, these are often standards). What separates LPs from other frameworks is that they also prioritize how students learn these concepts. A logical decomposition of the core ideas by experts may not necessarily represent the paths that students take as they learn the content. Thus LPs also include a bottom-up process based on empirical studies of students' sense-making processes and the nature of students' thinking as they develop more sophisticated understandings.

Therefore, research is critical for defining and empirically testing LPs at multiple levels. As noted above, learning targets or end points of LPs (also called "upper anchors" in some research groups) are generally defined (in a top-down approach) as the standards, which students should achieve at certain points in order to prepare them to be productive citizens. However, because standards are generally designed from this top down perspective, they may not be feasible or reasonable for students to attain. Thus, research is critically important to ensure that, with appropriate instruction, students are able to reach these upper anchors. If students are unable to reach the upper anchors, then those targets may need to be re-thought.

Research is also critical for defining and empirically testing the entry points into LPs (also known as "lower anchors"). Given that different students have many different experiences coming into school, discovering what they know and can do is critical for finding patterns in order to define lower anchors.

Another important research topic is the definition of the intermediate levels of LPs. Defining these levels tends to be "messy" (Gotwals and Songer 2010), in that students often do not demonstrate consistent patterns of understanding (see a more thorough description of the "messy middle" below). Research is needed on the ways in which students' grasp of the content develops along a LP. What types of instruction are needed in order for students to gain more sophisticated understandings of the key ideas? It is especially critical that teachers develop greater awareness of the intermediate levels between the lower and upper anchor knowledge and performance achievements. Teachers sometimes expect students to move directly from not knowing to knowing well, or correctly. This is a critical role of LPs, to convey to teachers that growth can include partially formed, or partially correct and partially incorrect middle stages of concepts and ideas.

Areas of Debate and Concern in Learning Progressions Work

By their nature, LPs must be research-based rather than simply a decomposition of the domain. Anderson (2008) states that in order to develop and gather validity evidence about LPs, researchers must consider three qualities. First, LPs must have *conceptual coherence*, or provide a logical story of how "initially naïve students [or teachers] can develop mastery in a domain" (3). Secondly, they must have *compatibility with current research* and build on findings about learning in the given domain. Finally, LPs must involve some process of *empirical validation* based on data from students or teachers. In this section, we would like to highlight some areas of debate and concerns in LP research, many of which stem from these three qualities that must be addressed by researchers in LP work.

Starting Points for Designing LPs

Where do you start in building a LP? The starting point for any given project will depend on the ultimate goal of the project, the expertise of the researcher or team of researchers on the project, and theories guiding the research. As will be discussed in future chapters, there are multiple possible starting points. Some researchers choose to examine the nature of student learning with "status-quo" instruction. This work often begins with cross-sectional research to examine the different levels of student understanding for a given area without specific intervention. Cross-sectional work such as this relies heavily on developing assessment tasks that can gather evidence of student understanding at multiple levels. Once the LP has been developed based on status-quo instruction, researchers often develop instructional materials to support student learning along the progression.

Alternatively, LP research may begin with targeted instructional activities (also known as teaching experiments) to determine what students are capable of learning with specific opportunities (e.g., see examples from Barrett, Gotwals, and Stevens in Chapters 3 and 4). The findings from this work, then, use students' learning in order to develop LP levels. In these cases, the LP and the instruction are not easily distinguished and movement along the LP is critically dependent on specific forms of instruction.

The Meaning of Learning Progression Levels

What does it mean for a student to be "at a level" on a LP? In the case of the UK, levels have been abolished but not the idea of progression, marking the end of a twenty-year journey of attempts to specify progression in the national curriculum (for a thorough discussion, see Appendix B). In the U.S., LPs are gaining traction in the research community and levels are used to measure progress. In order to determine how students are thinking, we must use their performance on assessment tasks (which can range from written assessments to interviews to careful observations of discourse or other practice). However, responses on a single assessment task cannot place a student at a certain level of achievement; there needs to be a series of assessment tasks that can provide information about the probability that students are at a given level. When students are given a series of assessment tasks, they may respond at different levels on different tasks. While it would be cleaner if a student could be placed at a specific level, student thinking is not as clean as levels may suggest. It is more likely that students exhibit a more prominent level than the other nearby levels, but students are typically going to perform at multiple levels at any given point in time.

In addition, sometimes student understanding often does not fit neatly into a given level. This is especially true for intermediate levels, which have been described as the "messy middle" (Gotwals and Songer 2010). In these situations, students may give different responses to tasks that seem to measure the same idea. For example, students may be better able to reason about certain types of food chains (Gotwals and Songer 2010) or apply concepts of force and motion differently for different situations (Steedle and Shavelson 2009). In this messy middle, students may have some, but not all, of the necessary pieces of knowledge and are thus able to respond to some assessment tasks but not to others. Moreover, these patterns of responses differ across students, creating multiple "messy middles." In such cases, defining a path, or paths, between the lower and upper anchors is tricky and the description of levels as an approximation of student learning may prove problematic.

Practical Concerns

The development and revision of a LP, from its hypothetical to validated form, vary in time commitment depending on the size of the LP (e.g, see Chapters 3 and 4 for examples of LPs with different scopes). Work on LPs benefits from funding for human power because of the range of expertise that can inform LP work (e.g., education experts, disciplinary experts, curriculum developers, psychometricians). Thus, the value of LPs has been questioned, partly due to the cost and time that needs to be invested. Debates have also arisen over their swift integration in educational policies despite the relatively short history of research on their effectiveness (e.g., Alonzo 2012; Krajcik 2012; Shavelson and Kurpius 2012). Despite these concerns, the potential for LPs to bring coherence to multiple aspects of geography education is encouraging.

In addition, more research is needed to disentangle some conceptual and methodological issues in LPs work. Some researchers are concerned that there are too few studies for a rigorous comparison of effective ways to implement LPs (Clements and Sarama 2004), although they have developed a framework for checking such claims. A "curriculum development framework" was created (Clements 2007) that offers a foundational set of three stages that might provide a common standard to guide LPs research. A comparison study in physics education by Steedle and Shavelson (2009) using two analysis methods (confirmatory and exploratory models) found that a LP was aligned with student performance only at the upper anchor, but it did not describe all students' understanding on the topic of force and motion. More importantly, we need to clarify the links between the LPs/LTs with the expected educational outcomes one might attribute to it prior to the implementation. For example, some outcomes might include improved teacher knowledge, student learning of concepts, student knowledge development over several years' time, or shifts in an educational system due to assessment structures or the application of learning standards across a district or region.

The diversity among LPs studies indicates how difficult it may be to produce the large-scale frameworks necessary for LPs to achieve their potential and serve as a "basis for dialogue" between various stakeholders in the education community (NRC 2007, 8-2).

Links between learning progressions research, geography, thinking and learning with maps, and geospatial technologies

To build capacity for LP research in geography, researchers will need to consider and draw upon relevant literature in geography teaching and learning. There is fairly robust research in geography education and spatial cognition to guide the development of LPs related to map interpretation, spatial reasoning processes, and geospatial technologies. Building upon prior research on student learning of big ideas across geography, math and science, Table 1 outlines a high level summary listing of the levels of a LP for map reading and interpretation. We acknowledge that the LP consists of a complex account, including some matters that are difficult to put on a page, about how children are reasoning, what came before, what comes next, and how to check for this level and how to move children on to the next level. The core ideas of this example, those that are continually developed upon in higher grades, include crosscutting concepts between science and geography (e.g., patterns, scale, proportion and quantity) and those more specific to geography (e.g., location identification, symbols and representation). Its conception draws from milestones found in Standard 1 of *Geography for Life: National Geography Standards, Second Edition* (Heffron and Downs 2012), as well as focused research on student map learning. Although the stated learning levels are known through research (e.g., Bednarz, Heffron, and Huynh 2013), there is currently no data that supports or provides alternative ways to explain student thinking on the target topic.

Conclusion

Formal education has the role of imparting to students knowledge, skills and practices. For educators, this task is partially accomplished by combining professional experience with research. Education research has focused on different facets of learning and teaching. The purpose of working on LPs is to aggregate disparate research findings to propose coherent frameworks representing student learning that are supported by empirical data. The process is a combination of research and instruction. The promise of developing, having and integrating LPs is to identify sequences of learning that can be anticipated and directly supported as a means to bridge informal, formal and fragmented learning experiences. This chapter serves as an introduction to the topic; the following chapters of the book provide in-depth discussion of integral pieces to the research process. Chapter 2 highlights research in the areas of geography education, cognitive science, learning science and other related fields that together provide an understanding of student learning related to Essential Element 1 of *Geography for Life*. Chapters 3 and 4 provide a broad and focused outline of the methods used to conduct LPs and LTs. Finally, Chapter 5 presents a constructive critique of learning progressions research that address philosophical issues LPs raise as well as some of the practical impacts of LPs on the curriculum, some of which may be unintended.

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Chapter 2

Research on Thinking and Learning with Maps and Geospatial Technologies

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Identifying the Knowledge Space: Spatial Thinking

When people think of geography, they often think of students memorizing names of state capitals, landforms, and oceans. To the contrary of this popular misconception, geography is a rich discipline of study that focuses on the characteristics, relationships, and spatial patterns of the human and natural worlds. Geography includes learning about cultures, geopolitics, natural systems, resource distribution and use, and mapping spatial data to better understand the world. As the U.S. national geography standards illustrate, a geographically informed person is someone who views the world ***spatially***. Understanding the way in which the world is organized spatially is critical to learning and doing geography.

The 18 national geography standards presented in *Geography for Life*, 2nd Edition (Heffron and Downs 2012) are organized under six Essential Elements: The World in Spatial Terms, Places and Regions, Physical Systems, Human Systems, Environment and Society, and the Uses of Geography. For the purpose of this chapter, we focus our review of the literature within Essential Element 1, *The World in Spatial Terms*, which includes three standards:

- How to use maps and other geographic representations, geospatial technologies, and spatial thinking to understand and communicate information.
- How to use mental maps to organize information about people, places, and environments in a spatial context.
- How to analyze the spatial organization of people, places, and environments on Earth's surface.

Together the three standards focus on a fundamental way of thinking *about* the world and *within* the world. **Spatial thinking** is a combination of knowing about spatial concepts and types of relationships and patterns that occur in the world; using tools, both internal and external, that represent spatial data; and being able to reason about or with spatial data or phenomena (National Research Council [NRC] 2006). Spatial thinking is a type of thinking that *all* people possess and use to greater or lesser extents in their everyday lives and careers. While not unique to geography, spatial thinking is a cornerstone of the discipline and essential to the teaching of geography to novice learners (Hanson 2004).

While there is almost fifty years of research on spatial thinking, it has been notably difficult to define and measure it, and arguably even more difficult to foster spatial thinking among students in actual classroom settings. There is a wealth of research on spatial thinking tasks (outside the regular classroom), especially studies that compare novices to experts and males to females. Overall, however, the body of literature is fragmented for several reasons. The research studies originate in many different fields of study (e.g., geography education, cognitive psychology, learning sciences, and neurosciences) and thus, emphasize different elements of spatial thinking. Researchers have used a wide variety of approaches to measure aspects of spatial thinking, but the spatial tasks that are utilized vary so greatly from study to study that comparison of the findings across multiple research studies can be problematic. In many cases, the specificity of the task and the context in which it was measured prevents findings from being generalized. This is especially true when trying to make sense of what happens across a developmental time span or in real-world settings, such as the classroom. For example, cognitive psychologists have focused their efforts on table-top and computer-generated tasks to better understand spatial visualization and orientation, while many geography education researchers focus on wayfinding and navigational tasks using spatial representations (e.g., maps). Neuroscientists tend to focus more closely of aspects of brain functionality as it relates to performing spatial thinking tasks.

All of these disciplines contribute significantly to our understanding of spatial thinking as a whole, somewhat like piecing together a giant jigsaw puzzle. Yet, even given the decades of research on the topic, our puzzle is far from complete. Many pieces have been assembled but there is a notable lack of systematic effort to make connection between the seemingly disjointed parts. Regardless of the disparities within the current body of literature, there is a great need for learning progressions research to better understand how and when spatial concepts, tools and processes of reasoning begin to emerge and evolve in young children into adulthood, and potentially how instructional materials and teaching strategies can better support students in more sophisticated ways of thinking spatially. While, individually, many of these research studies have certainly contributed significantly to our understanding of spatial thinking, as a combined body of literature, we lack the coherence needed to make use of this research to improve classroom practice.

The rest of this chapter takes a closer look at existing frameworks that communicate the concepts, tools and processes related to spatial thinking and how we might build from the frameworks to produce learning progressions. We look at how we might use the existing research to define the upper and lower anchors of a learning progression within the spatial thinking domain, and then how to determine measurable progress variables between these anchor points. We conclude with special considerations that may affect how one defines the Lower and Upper Anchors of a spatial thinking progression.

Defining the Domain of a Spatial Thinking Learning Progression

A major undertaking at the start of learning progressions research is to identify the domain of the progression. The broad expanse in which we can find spatial thinking complicates this process to some extent. As previously described, spatial thinking encompasses a wide variety of constructs and spatial practices. In this chapter we focus on spatial thinking as defined by NRC (2006), but also point to specific frameworks for spatial thinking developed within the geography education community. We chose the NRC Framework because it represents considerable consensus regarding the concepts, tools, and reasoning processes of spatial thinking, even though the limited systematic research into these concepts, tools and reasoning processes that make up the framework has been noted (Bednarz, Heffron, and Huynh 2013). There are several other equally valid frameworks that are important to consider, especially as many of these frameworks have been created by geographers with substantial experience in spatial thinking research (see Table 1). All of these frameworks capture the array of constructs and practices essential to spatial thinking, and thus, are useful tools to consult when defining the domain of a progression, and also situating the progression within the larger backdrop of spatial thinking as a whole.

Clearly articulating the domain of the progression can be useful for understanding what is and what is not being investigated and explained by the learning progression. Let us look at an example of why this process is important using spatial representations from the NRC framework. Spatial representations include both internal and external representations; internal representations being mental mapping and mental modeling, while external representations being a combination of concrete or technology-based maps and models. If one was interested in better understanding internal representations, like mental mapping, a learning progression would then target this construct. However, if one was interested in geospatial technologies, a learning progression might hone in on external representations like GIS mapping, or computer modeling. While both would investigate types of spatial representations, they would result in vastly different learning progression domains. To complicate matters further, a learning progression might focus on the "what" or substance of the representations, or a learning progression might focus on the process and skills for creating and/or using representations. So a learning progression could take the form of descriptions of how spatial representations themselves evolve, or as a description of how creating or using spatial representations evolve, or even a combination of the two. Within this example of spatial representations, there are many possible learning progressions to be developed. Consequently, situating the substance, or domain, of a progression becomes an important task at the outset of learning progression research.

Learning Progression Anchors and Progress Variables

Every learning progression has both a lower anchor and an upper anchor; the lower anchor represents the emerging knowledge students have as novice learners of a construct or practice, and the upper anchor is a depiction of what learners should know and be able to do after learning has occurred. The goal of the learning progression is to not only define the anchor points clearly, but more importantly to uncover the intermediate understandings that occur between them (Duschl, Schweingruber, and Shouse 2007).

Upper Anchor. The upper anchor is typically representative of societal expectations of learning a topic, and so it is naturally related to learning goals captured by national and/or state standards. The upper anchor of a learning progression does not necessarily have to replicate education standards, but it should depict the depth of knowledge that could reasonably be expected on a topic at given age levels. *Geography for Life, 2nd Edition* and documents such as the NRC (2006) report are important resources to guide development of the upper anchor. Yet, even more important to defining the upper anchor is the inclusion of expectations we may have for educating citizens, or for educating future experts in the field. Either way, there needs to be a consideration of what are the most essential constructs or practices that we would like *all* students to be able to know or use after they have learned about a topic. Sometimes the upper anchor might draw from several different education standards, or might bridge different subfields within the geography or spatial thinking disciplines.

Table 1. Spatial Concepts Frameworks. This table originally appeared in Mohan and Mohan (2013) and is reprinted here with permission from National Geographic.

Learning to Think Spatially, NRC 2006	Building on work by Golledge et al. 1995, 2002, 2008a; Adapted by Jo and Bednarz 2009	Gersmehl and Gersmehl 2009, 2007, 2006	Janelle and Goodchild 2011	Cognitive Psychology (general reference; see Bednarz and Lee 2011; Golledge, Doherty, and Bell 1995)
Concepts of Space Primitives of identity Spatial relations **Tools of Representation** Internal External **Processes of Reasoning** Extracting spatial structures Performing spatial transformation Drawing functional inferences	**Spatial Primitives** Identity/Name Location Magnitude Time/Duration **Simple Spatial Relationships** Distance Direction Connectivity and linkage Movement Transition Boundaries Region Shape Reference Frame Arrangement Adjacency Enclosure **Complex Relationships** Distribution Pattern Dispersion/ Clustering Density Diffusion Dominance Hierarchy/Network Association Overlay/Layer Gradient/Profile/Relief Scale Projection Buffer	**Location** Conditions Connections **Modes of Spatial Thinking** Comparison Aura Region Hierarchy Transition Analogy Pattern Spatial Association **Spatio-Temporal Thinking** Change Movement Diffusion (expansion or contraction) Spatial Models	Location Distance Neighborhood and Region Networks Overlays Scale Spatial Heterogeneity Spatial Dependence	**Visualization** Ability to mentally manipulate, rotate, twist or invert two- or three-dimensional visual stimuli. **Orientation** Ability to imagine how a configuration would appear if viewed from a different orientation or perspective. **Spatial Relations** Ability to estimate or reproduce distances, angles, linkages and connectivities; to develop spatial hierarchies in which nearest-neighbor effects are prominent; to remember sequence and order as in cues along a route; to segment or chunk routes into appropriately sized units that facilitate memorization and recall; to associate distributions or patterns in space; and to classify and cluster information into meaningful spatial units such as regions.

Importantly, the upper anchor is often a reflection of vision that geography educators have for student learning, and can be based on many years of working in the classroom and with other geography educators. It should set high expectations for learning, but also ones that are reasonable and achievable by students.

Lower Anchor. Existing literature in the field, however incomplete it may be, is a necessary resource for understanding the lower anchor.

Oftentimes, the emerging concepts and/or skills at the lower anchor that contribute to upper anchor understanding are not obviously connected and may only later be revealed to researchers once data is examined from novice learners. When looking across several studies it is possible to begin identifying patterns in student thinking with respect to a spatial thinking construct or practice. In science education, for example, Rosalind Driver and colleagues reviewed considerable literature on student learning of science concepts and then produced numerous books and articles to summarize what they found for the science education community. Their work helped to paint a picture of student ideas in different domains, which naturally lent itself to learning progressions work (e.g., Driver, Asoko, Leach, Scott, and Mortimer 1994; Driver, Squires, Rushworth, and Wood-Robinson 2013). While spatial thinking does not have similar resources available, the NRC (2006) report is an excellent place to start, along with other efforts to begin summarizing students' ideas about spatial thinking among young children (e.g., Liben 2006, 2002; Mohan and Mohan 2013; Newcombe and Huttenlocher 2000; Uttal 2000).

To add to spatial thinking's nebulous nature is the lack of consensus among researchers in the field regarding its temporal development, especially as it relates to very young pre-K and elementary age students. There is a notable debate about the capabilities of these very young children that is significant to consider in learning progressions research. The research literature on spatial thinking is complicated by two competing schools of thought regarding its development in young children. On one side, nativist researchers believe that spatial thinking develops innately within young children with little to no guidance from knowledgeable adults, and in some cases these children can engage with fairly sophisticated spatial tasks (see, for example, Newcombe and Huttenlocher 2000; Blaut 1997; Blaut and Stea 1974, 1971).

On the other side of the debate, constructivist researchers assert that while spatial thinking can develop early in life, full realization or mastery of this type of thinking cannot occur until later in life (see, for example, Liben and Downs 1993, 1989; Piaget and Inhelder 1967). The debate primarily stems from Piaget's Three Mountain Task, which demonstrated that students under nine or ten years old struggled with perspective-taking on spatial tasks, leading Piaget and colleagues to develop a topological to projective/Euclidean progression of spatial thinking from early childhood to upper elementary; however, similar perspective-taking tasks have shown that even three-year-olds have the ability to view locations of items from different perspectives (Newcombe and Huttenlocher 2000, 118-125). The Piagetian spatial tasks set the stage for researchers to question the spatial abilities children were truly capable of in their younger years, a debate that has not been resolved. Regardless, these two different camps within spatial thinking research, that is, the nativist and the constructivist, both suggest that spatial thinking is an innate ability that emerges in young children; however, constructivists believe that it cannot develop fully until a child has reach a certain level of cognitive maturity and has both formal and informal opportunities to learn to think spatially.

Within spatial thinking research, mapmaking and map reading boasts a great deal of research targeting the lower anchor of learning with substantial attention given to discovering the earliest appearances of making and using simple maps to locate objects. There is substantial debate regarding what young children can and cannot understand about maps. Many researchers (e.g, Blaut 1997; Blaut, Stea, Spencer and Blades 2003) have stressed that young children are capable of understanding aspects of maps from an early age. More recently, psychologists have demonstrated that children as young as 2.5years of age can use some of the spatial properties of very simple maps of locations of objects in a room (e.g, Winkler-Rhoads, Carry, and Spelke 2013).

However, some researchers have urged caution in over interpreting these findings (e.g., Liben and Downs 1993), suggesting that these demonstrations of early competence, although impressive and important, are not demonstrations of fully-fledged map-reading abilities (e.g., Liben 2002), Most of the psychological studies with young children have focused on single skills, such as detecting the relation between a map or model and the space that it represents. These studies do not consider map reading as a systematic activity involving many different cognitive abilities, but instead use a more reductionist approach that isolates individual abilities. Acquiring a deeper, more conceptual understanding of maps is a lengthy developmental phenomenon that depends on substantial learning and experience.

Mohan and Mohan (2013) reviewed the body of research on spatial thinking as it relates to mapmaking and map interpretation and found that while there were a great many efforts made to understand the lower anchor characteristics among young children, there still remained significant gaps in the research, both in terms of the substance of the findings and also with the methodology and spatial tasks utilized (discussed later in this chapter). Table 2 summarizes key findings on several spatial constructs with respect to very young, novice learners, and is one resource that can serve as a starting point when developing initial characteristics of lower anchor thinking.

Progress Variables. Simply defining the upper and lower anchor points, however, does not provide enough direction to dig into the meat of the learning progression—the design of assessments and curriculum that will help uncover the intermediate understandings between anchor points. After hypothesizing both the upper and lower Anchor points, a logical next step would be to figure out a way to measure the constructs or practices that are included. The measurable elements of a progression are usually termed progress variables. Ideally progress variables are chosen because they are 1) big ideas or key constructs and practices within the discipline, and also because 2) they can be operationalized to measure knowledge at both the novice and expert levels. Corcoran, Mosher, and Rogat summarize progress variables as "critical dimensions of understanding and skill that are being developed over time" (2009, 15).

In science education, for example, learning progressions might utilize scientific principles or cross-cutting concepts as progress variables, such as structure, function, matter, energy, change over time, scale, hierarchical organization, etc. Similarly, when spatial researchers are asked what it means to think spatially, they tend to explain it using a set of fundamental constructs and practices that encompass a great deal of spatial thinking more broadly (e.g., location, direction, distribution, scale, hierarchy; see Table 1). Identifying the potential progress variables within a progression is a matter of unpacking the upper anchor and tracing it back to emerging ideas from young children. What constructs might bridge between the two anchor points and is this construct measurable? If so, then it is likely a good candidate as a progress variable in the learning progression.

Table 2 summarizes a plausible list of progress variables that, while not named progress variables by researchers, have been utilized to examine spatial understanding at different age levels. When Mohan and Mohan (2013) mapped the existing literature onto the spatial frameworks outlined in Table 1, they were able to show the potential of spatial constructs serving as progress variables for a learning progression (see publication for full review). The potential progress variables are both enduring constructs in the field of spatial thinking, and they have demonstrated the ability to be operationalized and measured at different age levels.

The progression of concepts in Table 2 is based upon, in many cases, just one or two studies, but it allows researchers to consider the possible age levels to target in establishing upper and lower anchors for progress variables. For example, primitive spatial concepts, such as location, would likely have an age span from ages three to upper elementary while complex spatial concepts, such as overlay, might more appropriately be targeted between upper elementary through high school or adulthood. Golledge, Marsh, and Battersby (2008b) developed a table that shows what the research recommends in terms of introducing spatial concepts to young children. We have reproduced this table, with some adaptations, in Table 3. While the existing literature contains many gaps, using what research we have and geographers' best guesses we can make fairly good predictions at when children are primed to learn spatial concepts. The research tends to focus on very young children, so understanding learning in the upper elementary and middle grades is certainly an area in which learning progressions has great potential to illuminate.

Putting it Together: An Illustrative Case

In order to illustrate the development of upper and lower Anchors and progress variables, we will use a hypothetical learning progression we call *Spatial Aspects of Conflict* as an illustration of how this process might work. We are using this illustration simply as a way to think through the process of designing a hypothetical progression for spatial thinking, but it is clearly only representative of the initial stages in a much more complex iterative design process.

Let us say that we would like to develop a learning progression on student understanding of the spatial aspects of conflict. As geography educators we believe that understanding spatial elements of conflict is critical for 21st century citizenship but we would like to better understand how students' understanding of this construct can evolve to maturity before they leave high school.

For our upper anchor we state that all students graduating from high school need to be able to understand the role that resources, such as water, oil, and natural gas, play in conflicts around the world. We would like students to be able to understand news reports and newspaper articles on the topic of worldwide resource conflict once they leave K-12 education so that they can be knowledgeable citizens—not experts—on the topic.

Table 2. Synthesis of the progression of spatial concepts ages 3-12. Modified from Mohan and Mohan (2013). Reprinted with permission from National Geographic Society.

Spatial Concepts	**Student Understandings and Possible Misconceptions and Challenges**		
	Ages 3-6 (Pre-K through Grade 1)	**Ages 7-9 (Grades 2-4)**	**Ages 10-12 (Grades 5 and 6)**
Identity and Location	Students in this age group can typically identify places on maps, landscape features on maps and aerial photographs, and can locate familiar places on maps. While children at this age can identify places, they may be limited by vocabulary development. Students might also use landmarks as a way to identify where places or items are located on a map, but they can easily confuse locations on maps if the map is not well aligned to their real world. **Studies of Interest:** Blades and Spencer 1990; Blaut and Stea 1974, 1971; Blaut, Stea, Spencer, and Blades 2003; Bluestein and Acredolo 1979; Downs, Liben, and Daggs 1988; Huttenlocher, Newcombe, and Vasilyeva 1999; Liben 2008; Liben and Downs 1993; Presson 1982; Sowden, Stea, Blades, Spencer, and Blaut 1996	Students can accurately locate places and landscape features on a map, but perform better with familiar locales as opposed to foreign locales. Map alignment issues also improve at this age. However, students inconsistently use landmarks to verify locations. **Studies of Interest:** Blaut and Stea 1971; Golledge, Battersby, and Marsh 2008a; Kastens and Liben 2010, 2007	Students need to be primed to use all the resources available to determine locations, and encouraged self-explanation of decisions, to cue thinking more about landmarks, distances, and directions. Students do not readily use map scales, metric distances, or cardinal directions to help determine locations, but can do so if prompted during instruction. Accuracy on these tasks is better for familiar places and becomes less accurate for more foreign or large-scale tasks. **Studies of Interest:** Blaut and Stea 1971; Golledge and Stimson 1997; Liben 2008; Liben and Downs 1993; Tretter et al. 2006
Magnitude	Students seem to innately understand magnitude of objects (bigger, smaller), but they might confuse the size of an object with the number of objects (numerosity). **Studies of Interest:** Golledge, Battersby, and Marsh 2008a; Mix 1999; Rousselle, Palmers, and Noel 2004		
Distance and Direction	Understand relative distance, such as near, far, next to, and can begin using relative direction on maps, such as navigating mazes. Struggle with knowing which way to "hold a map" and easily get confused if it is not aligned to the real world; Students also do not intuitively think about distances without being prompted to do so. **Studies of Interest:** Blades, Sowden, and Spencer 1995; Blades and Spencer 1987; Liben 2008; Liben and Downs 1993; Rutland, Custance, and Campbell 1993	This is a transition period between topological (e.g., near, far) concepts of distance to metric measurements; by 4th grade, students should readily use metric distances. They will still need guidance to transition to metric measurements though. Students also frequently use landmarks and relative direction, but some ready to learn cardinal directions. **Studies of Interest:** Kastens and Liben 2010	
Frames of Reference and Perspective Taking	Children at this age view the world from an egocentric frame of reference (i.e., how they see the world rather than how another perspective might see it, such a bird flying over a house). **Studies of Interest:** Newcombe and Frick 2010; Newcombe and Huttenlocher 2000;	Students can begin to understand grid systems (coordinate system) and begin learning absolute location. Students might get distracted by features that are not useful and neglect useful features on maps. **Studies of Interest:** Bell 2000; Liben 2008; Kastens and Liben 2010; Newcombe and Frick 2010	
Scale	Students at this age can handle scale better using smaller, familiar spaces, such as a classroom. Students do not have a systematic way to handle scale- they cannot move between scales easily, such as the size of the school in real life v. the size of a school depicted on a map. **Studies of Interest:** Liben 2008; Uttal 2000		
Symbols	Abstract, unrelated symbols are not understood well at this age level. Students might also confuse the colors used on representations and expect those colors to be the same in the real-world (e.g., a red road on a map should be red in real life). **Studies of Interest:** Liben 2009, 2008; Myers and Liben 2008	During this age, students transition between iconic real-world symbols to abstract symbols, but they still make significant errors; explicit guidance needed on what symbols mean. **Studies of Interest:** Golledge, Battersby, and Marsh 2008a; Liben 2009, 2008; Myers and Liben 2008	Students can use abstract symbols and understand symbols do not always "look like" the referent. **Studies of Interest:** Golledge, Battersby, and Marsh 2008a; Liben 2009, 2008; Myers and Liben 2008
Hierarchies		Concept of hierarchy (or nesting) is not well established innately with this age group, but can possibly be introduced with close guidance. **Studies of Interest:** Lowes 2008	
Overlay and Other Complex Spatial Tasks			About half of all 6th grade students incidentally understand the concept of overlay without formal instruction Guidance using map overlays can likely improve student success. Students can also move onto complex spatial concepts such as distribution, patterns, overlays, and projection with support if mastery of the basic spatial concepts of location, distance, direction, boundaries, regions achieved. **Studies of Interest:** Battersby, Golledge, and Marsh 2006

Table 3. Spatial Thinking Concepts by Grade. Adapted from Golledge, Marsh, and Battersby 2008b, 98.

	Geospatial concept	Grade					
		K	1	2	3	4	5
Primitives	Identity/Name	X	X	X	X	X	X
	Location (Relative)	X	X	X	X	X	X
	Magnitude	X	X	X	X	X	X
Simple Spatial	Distance (Relative)		X	X	X	X	X
	Direction (Relative)		X	X	X	X	X
	Shape		X	X	X	X	X
	Symbol (Real-World)		X	X	X	X	X
	Boundary			X	X	X	X
	Connection			X	X	X	X
	Reference Frame/Coordinate Grid				X	X	X
	Distance (Metric Measurement)				X	X	X
	Direction (Cardinal Directions)				X	X	X
Complex Spatial	Network				X	X	X
	Hierarchy				X	X	X
	Distribution				X	X	X
	Pattern				X	X	X
	Symbol (Abstract)					X	X
	Map Projection						X
	Scale						X

While we have identified the goal for student learning and the upper age range for our progression (i.e., 12th grade), we have yet to hone in on what our learning progression will be about specifically, the concepts and skills the learning progression will encompass, and the lower age range of children we will investigate (and how this age was determined).

The next step would be to decide what elements of spatial thinking we believe will play the most significant role in understanding spatial aspects of conflict over resources. This list of concepts should be fluid across the iterative design process inherent in learning progression work, but needs to be initially hypothesized to give us a reasonable starting point. The conceptual frameworks in Table 1 are one useful resource for making decisions about these constructs, along with *Geography for Life*, 2nd Edition and NRC (2006).

After reviewing the literature on spatial aspects of conflict, we determine the most significant spatial concepts that ultimately contribute to understanding conflict over resources include 1) location, 2) boundaries, 3) settlement patterns and 4) movement of people. We might also suspect that 5) networks and 6) hierarchies become particularly important as students develop more sophisticated understanding. We have now identified six spatial concepts that we believe are critical in our hypothetical learning progression, are representative of big ideas in spatial thinking, and are also ones we can envision measuring in both a 12th grader and a younger age level of student. While six progress variables are possibly too many, the initial list will give us direction to design assessments and instructional resources.

Given the six constructs we have chosen, what age would make the most sense for the lower anchor of the progression? At this point the existing research literature with young learners becomes especially important. Tables 2 and 3 summarize what existing spatial thinking research says about the emergence and appropriateness of some spatial concepts at particular grade levels, but these tables are certainly not exhaustive. Given our hypothetical concepts it appears that we may be able to investigate students ideas about location as young as kindergarten age, but all concepts—location, boundaries, networks, etc.—are developing and/or emerging by upper elementary. This might be a reasonable starting point for the lower anchor. Now we have determined that our initial round of development of assessments and instructional resources should examine students as young as grade 4. From existing literature we can expect that students have more advanced understanding of location, but may continue to struggle with map scales and cardinal directions, especially in unfamiliar regions around the world. They will likely be a very novice learner when it comes to concepts of hierarchy and networks.

The case described above is not intended to oversimplify the messy reality of defining the upper and lower anchor points and progress variables. This process involves significant back-and-forth negotiation among members of a research team, and lots of documents ending up in the recycling bin before even an initial learning progression is proposed and agreed upon. The case study does, however, show how existing resources on spatial thinking can be utilized to make the best guess possible at the outset of learning progressions work. Our review of the literature on spatial thinking has shown that great strides have already been made in this field that provide a solid foundation for learning progressions work to begin. Somewhat like someone finishing the border on your jigsaw puzzle for you, but leaving the middle parts for you sort out!

Process-Oriented Progress Variables

So far this chapter has focused for the most part on frameworks that have been developed to capture spatial thinking and research related to specific spatial constructs. One of the issues that has plagued learning progressions work in science education is the overemphasis on understanding the development of scientific ideas, with less research on the development of scientific practices. It is arguably easier to develop a learning progression on science concepts (e.g., matter, atomic theory, carbon cycle, water cycle, genetics, etc.) as opposed to one that focuses on the development of a practice, which may be one reason for the inequity in the learning progressions work so far. Even so, several science educators have given a great deal of thought to what it might look like to describe the development of a science practice. Schwarz, Reiser, Davis, et al., (2009) are working on a scientific modeling learning progression, while Nancy Songer, Amelia Gotwals and colleagues (2013, 2012, 2009) are developing a progression on evidence-based explanations. Given the nature of spatial thinking and the process-oriented aspects of it, learning progressions in spatial thinking will need to take on the challenge of describing how processes (e.g., map reading, mapmaking, navigation, spatial models, and spatial transformations and analyses) develop over time. As with science education a learning progression describing the development of a process or practice in spatial thinking will always be in the context of some spatial construct.

There are three processes or practices in spatial thinking that we would like to note as particularly important considerations for future learning progressions research, and of particular interest to geography educators. Those are: mapmaking, map reading and navigation, and using geospatial technologies. There is certainly overlap among the three, depending on how each is being used (e.g., GIS can be used for mapmaking or navigation, etc.). However, the spatial reasoning processes involved in traditional mapmaking, such as children's free-hand maps of a particular place, and the reasoning processes involved in creating a map using GIS, are very different, and thus would result in different types of assessment tasks and likely very different learning progressions. We call these out separately because we see them as a culmination of the spatial concepts, tools of representation, and process of spatial reasoning (NRC 2006) and thus they present in many ways the enduring practices of the discipline of spatial thinking in the geography education community. Like spatial concept development, there is existing research to build from in each of these areas. There are more studies that focus on either younger children (with mapmaking and navigation) and with secondary or adult populations (with navigation and geospatial technologies), but piecing together the messy middle is where we lack current research.

Mapmaking. A significant volume of publications have been produced over the last forty years in regards to the development of "mapmaking" in children (e.g., Lowes 2008; Weigand 2006; Newcombe and Huttenlocher 2000; Wiegand 1999a; also see Wiegand 1999b for a bibliography that represents a significant body of work on children's understanding of maps), but few studies contribute to our understanding of the mid- and upper-levels of development (e.g., Anderson and Leinhardt 2002; Bausmith and Leinhardt 1998).

Map Reading and Navigation. Map reading and navigation represent practices that bring together not only spatial concepts and tools of representation, but also often includes mental mapping, perspective-taking, and sophisticated processes of reasoning. Additionally it is generally situated in a real-world context (e.g., a natural or built environment) which introduces an entirely new set of variables to consider.

Everyone navigates through the world, with greater or lesser degrees of success. While not culturally universal in its manifestation, navigation is part of every person and every society. We navigate our personal spaces (e.g., offices, homes, bedrooms), our community spaces (e.g. neighborhoods, towns, parks and trails, urban spaces), and foreign spaces (e.g., travel to other places unknown to us). How navigation manifests itself