GeoProgressions

Learning Progressions for Maps, Geospatial Technology, and Spatial Thinking:

A Research Handbook

Editors:
Michael Solem
Niem Tu Huynh
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National Center for Research in Geography Education

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Information about the GeoProgressions project is available at www.ncrge.org.

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PREFACE

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Michael Solem
Niem Tu Huynh
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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 stand-alone 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 Boehm, Texas State University

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Biographies

About the Editors

Michael Solem is Educational Affairs Director 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.

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 and is currently organizing an interdisciplinary workshop on learning progressions. 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
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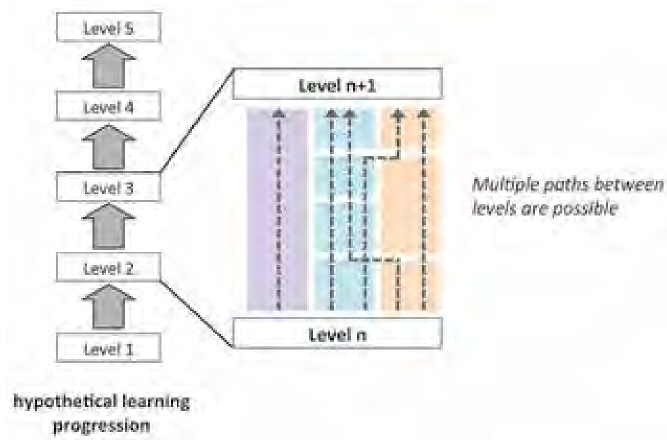
Since the mid-2000s, the mathematics and science education communities have accelerated efforts to explore learning progressions (LPs) and learning trajectories (LTs) as frameworks to help support student learning over time. LPs, in science, are defined as "descriptions of the successively more sophisticated 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 endpoint 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

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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

Lindsey Mohan, Audrey Mohan, David Uttal

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 in practice can be different from person to person and from culture to culture. Some individuals prefer to navigate using cardinal directions and grid systems (i.e., survey strategy), while others navigate using landmarks (i.e., route strategy).

Even young children, as early as age four, can successfully identify routes, such as roads and walkways, between two objects on spatial representations (Blades et al. 1998) or navigate mazes successfully (Blades and Spencer 1990). By age six, students can plan routes through complex environments (Sandberg and Huttenlocher 1997). Map alignment issues are a struggle at this age, however (Bluestein and Accredelo 1979). Much like mapmaking, there are few studies between early childhood and adulthood to guide us. However, we know that by adulthood, individuals have developed strategies and processes for navigation (e.g., Lobben 2007, 2004; Golledge 1999; Golledge, Doherty, and Bell 1995).

Geospatial Technologies. Finally, there is a developing, but still small, research base on geospatial technologies, particularly focused on the use of GIS in the K-12 setting or with teachers (e.g., Hong 2014; Demirci, Karaburun, and Ünlü 2013; Huynh 2009; Milton and Alibrandi 2007; Shin 2006; Kerski, 2003; Kim and Bednarz 2013; Wiegand 2003; Meyer, Butterick, Olkin, and Zack 1999). These studies focus largely on high school students and adults (teachers), but can certainly provide some valuable information for determining the upper anchor possibilities integrating geospatial technologies.

Geospatial technologies are particularly an important consideration as they extend the opportunities for students to further their spatial thinking beyond the traditional static representations in classrooms. Geospatial technologies allow students to examine dynamic data at multiple scales and in multiple layers using different formats (remotely-sensed images, aerial or satellite photography, or GIS). They can further their spatial thinking with deep spatial analysis of patterns between multiple layers of spatial data. Geospatial technologies expand the range of possibilities for upper anchors in a learning progression; however, they are a tool and a process and should not be considered in isolation of the spatial concepts and spatial reasoning that would also be part of the learning progression.

Acknowledging the Current Gaps in Spatial Thinking Research

We have alluded to the major gaps we have in the knowledge base on spatial thinking, but we feel it is warranted to discuss these gaps more explicitly.

Lack of K-12 Context. Perhaps most significantly, the majority of research on spatial thinking has primarily been conducted in absence of the K-12 setting, without regard to the context and curriculum that young children are situated within. It often focuses on easily accessible adult populations, often at colleges or universities, or young children (ages 2-4), leaving a large gap in our understanding of the developmental progression.

Small, Fragmented Studies. The research also tends to be studies with small sample sizes and often the methodology changes from one study to the next (e.g., the measurement tasks change; the spatial concepts being studied change). There is very little cross-sectional research that uses the same task across multiple age levels, so consequently we know very little about how individual thinking changes as children grow and learn. An exception to this would be the studies conducted by Golledge and colleagues from grade six through college (Golledge, Marsh, and Battersby 2008a, 2008b; Marsh, Golledge, and Battersby 2007; Battersby, Golledge, and Marsh 2006). The lack of cross-sectional studies across multiple grade levels or longitudinal studies reflects the challenges of conducting studies that follow individual children for months or years or gain access to a range of student populations (which means coordinating multiple school sites, teachers, and classrooms). But a lack of this research goes to the core of what learning progressions are and can be. Without information about how spatial concepts or processes progress over multiple years, and how learning progressions or trajectories vary, we cannot build an empirical basis for a hypothesized learning progression.

Measurements. This debate over early childhood spatial thinking (which has been discussed previously) raises an important methodological question of interest to learning progressions research: Is it tasks themselves that are causing such varied results, or are there more deeply rooted aspects that we just do not fully understand? Much of the ambiguity around measuring spatial thinking can often call the assessment tasks into question. The kinds of measures that we use have been limited. Measures have been limited to one or two spatial concepts or tasks. There are very few studies that have integrated multiple spatial concepts across multiple measures.

We are finding that the types of task chosen to measure spatial thinking might inadvertently favor particular populations over others. For example, Hegarty, Montello, Richardson, Ishikawa, and Lovelace (2006) found that different parts of the brain are engaged in solving spatial thinking tasks when they are at the table-top level versus tasks in the real-world. Newcombe (2007) also reports that men tend to perform better on paper-pencil spatial thinking tasks; since a large number of spatial thinking items are paper-pencil, has this led to the common belief that males are better at spatial thinking, or perhaps are the measurements giving us skewed results?

Another concern is the size or scale of the map and of the space that it represents. Most psychological studies have involved small-scale spaces, often the size of a standard living room or smaller. Some geographers, however, (e.g., Montello 1993) stress that there are fundamental differences in the comprehension, perception, and mental representation of spaces at different scales, and thus challenge the claim that information learned in very small spaces will transfer to real-world navigation or map-reading.

Currently choosing measures for spatial tasks is still often a matter of guesswork or anecdotal experience. We need integrated, coordinated measures of constructs that can reveal both group similarities and differences.

Learning Progressions Research to Better Understand Spatial Thinking

In closing, we see learning progressions research as an avenue to provide the much needed systematic and strategic research on spatial thinking that will span across multiple ages and across multiple related concepts and processes. Learning progressions research focuses on coherence and consistency not only in measurement tasks themselves, but also in the iterative process of defining and redefining the progression of development. Learning progressions provide an avenue for collaboration, debate, and consensus among researchers in defining the research domain more clearly and then establishing consistent measurement tasks that can be replicated across grade levels and settings to better understand the development of spatial thinking. Finally, and perhaps most practically, learning progressions on spatial thinking can provide much needed guidance for the development of standards, the design and implementation of instructional materials, and professional development for teachers.

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CHAPTER 3

Learning Progressions Research Planning and Design

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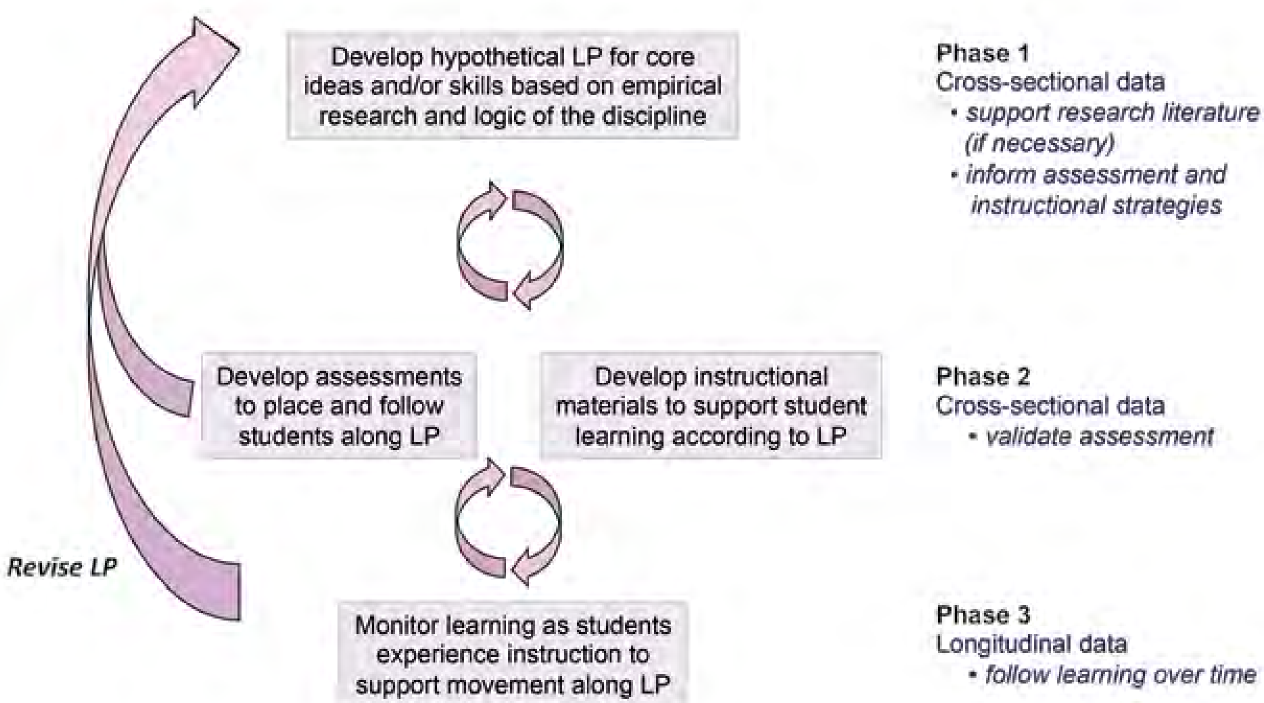
Introduction

Empirical research is critical in learning progression (LP) and learning trajectory (LT) development and research. LPs and LTs differ from a top-down decomposition of the discipline (that is characteristic of standards development) by incorporating research on *how* students learn material. Research into how students learn material involves better understanding of the nature of student thinking at different stages and how students build on their current knowledge to gain more sophisticated understandings and abilities in specific disciplines. In order to ensure that LPs and LTs accurately capture the pathways that students take as they learn, they must be developed based on current research and empirically tested. An empirically tested LP includes:

- A potential pathway that describes how ideas build upon one another to create more expert understanding
- Assessments to place and follow students along the LP
- Tested instructional strategies to help students move along the LP

Empirically designing and testing a LP is an iterative process. Figure 1 illustrates the process of development and empirical testing. Although it may appear somewhat linear in nature, each step can also provide feedback to any prior step. A LP focuses on the core ideas and/or skills of a discipline, which are linked to standards documents. The *Common Core State Standards for Mathematics* (National Governors Association Center for Best Practices and Council of Chief State School Officers [NGA and CCSSO] 2010) define the core ideas, skills for mathematics as well as mathematical practices. Similarly, *The New Framework for K–12 Science Education* (National Research Council [NRC] 2012) and the *Next Generation Science Standards* (NGSS Lead States 2013) define the core ideas, crosscutting concepts, and science practices for science literacy. In the case of Geography, the focus of a LP will relate to one or more of the 18 standards within the six essential elements of geography found in the *Geography for Life: National Geography Standards, 2nd Edition* (Heffron and Downs 2012).

Figure 1: Illustration of iterative process of developing and empirically testing a learning progression.

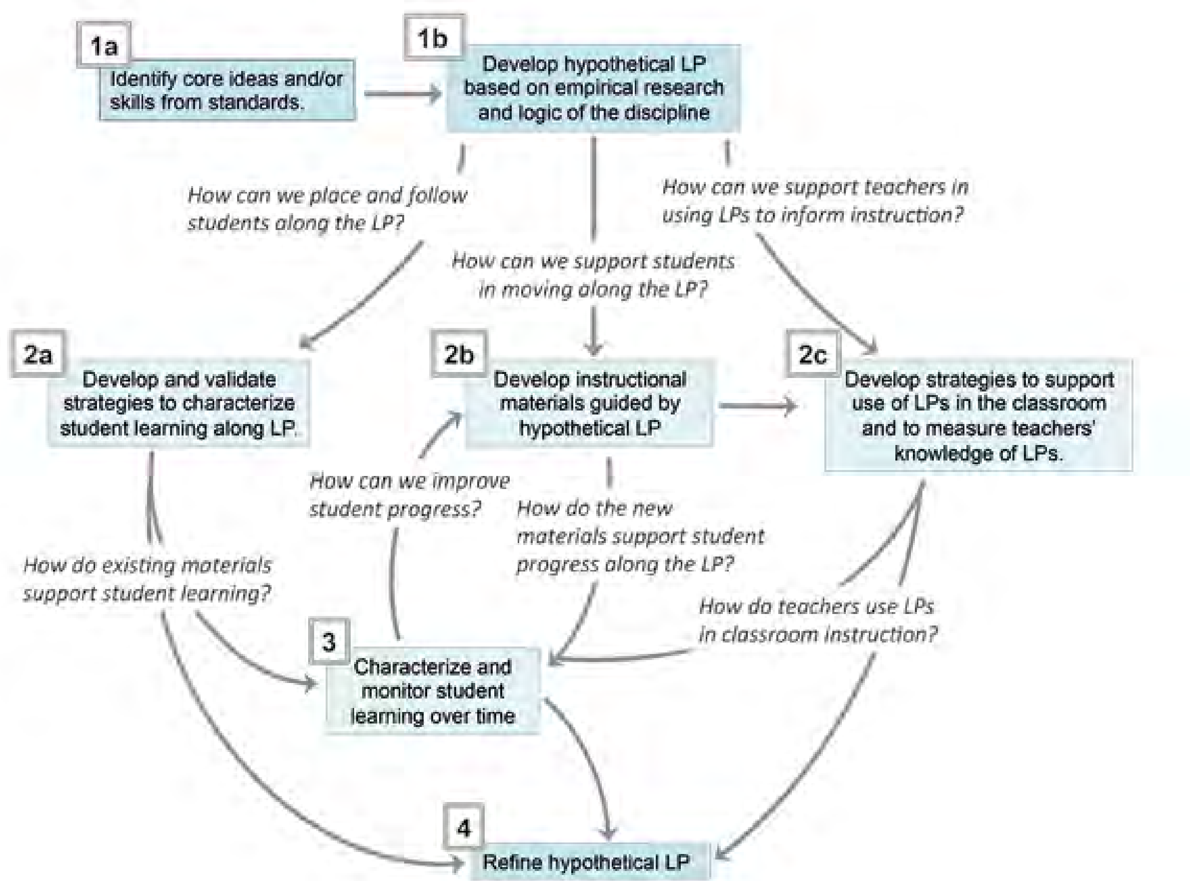


Once the focus for the LP is defined, a hypothetical LP is developed based on prior learning research and the organization of the discipline. If there are gaps in the research, some empirical studies may be used to supplement the literature. Instructional materials to help support students' movement along the LP must be identified or developed in order to test the hypothetical LP. In addition, assessment instruments that can locate students on the LP are also needed to characterize their progress. Following student learning longitudinally in the classroom will test the hypothetical path described by the LP.

Each of these phases requires a significant commitment of time and effort. Thus, a single research group usually is not responsible for carrying out the research and development associated with the entire process. Usually, a group chooses just a portion of the LP to test or focuses on one aspect (e.g., developing and testing instructional materials or assessment). In theory, multiple groups can be involved in different aspects of research for the same LP.

The process of developing and empirically testing a LP involves a wide range of research approaches and methodologies. Figure 2 provides a summary of major questions that can guide much of the LP research through the different phases of development and empirical testing. From the range of questions, it is clear that there is no single approach to LP research; the methodologies will differ depending on the question (s) being addressed. In this chapter, we will provide examples of goals and methodologies related to each of these questions from science and mathematics learning research. The examples, chosen from a several different research groups, have been chosen to illustrate the range in scale and scope that exists for LP research.

Figure 2: Illustration of research questions and approaches during the development and empirical phases.



Although LP research involves a wide range of methodologies, it is just one framework for research on student learning. Many of the same methodologies can be used within other theoretical frameworks to answer different types of research questions. In this chapter, we describe how these methodologies apply to LP research by providing case studies linked to research goals described in Figure 2. We do not mean to imply that this is the only way to apply these methodologies or that LPs are the only way to research student learning.

1. Develop a Hypothetical LP Based on Empirical Research and Logic of the Discipline

The first step in LP research is to identify key ideas and skills based on the knowledge needed for being "geographically literate" and productively engaging in society (in this case, Essential Element 1 of *Geography for Life* provides a starting point for defining and bounding the topic of study). In addition, it is important to consider whether the idea is generative (i.e., facilitates deeper understanding of ideas) and has broad explanatory power (i.e., helps to explain many geographical phenomena). At this point, LP researchers will often consult with standards and gather the opinions of experts (e.g., geographers, geography educators) as to what the goal or target learning should be for the LP. Some teams refer to the top level of a LP as the "upper anchor." The upper anchor will differ based on the scope of the LP. For example, some LPs span K-12 (e.g., Mohan, Chen, and Anderson 2009) and so the upper anchor is the knowledge and skills that we hope students graduating high school will have. However, other LPs may cover less time (e.g., Smith, Wiser, Anderson and Krajcik 2006) and so the end point of the LP will reflect what students at that given point know and can do with their understanding (in the case of a K-8 LP, the upper anchor reflects what students who are entering high school need to know and be able to do). When defining the upper anchor, it is important to ask several questions:

- What are the key components (e.g., big ideas, ways of reasoning) of this upper anchor?
- What should students know and be able to do when they have "achieved mastery" with this idea?
- Is this upper anchor achievable?

Learning progressions, however, are more than experts' logical decomposition of a given disciplinary domain. It is also important to gather evidence of what is already known about how students at certain ages understand the given concepts and what is known about how students learn the concepts. For this, researchers go to the literature and review research not only in their disciplinary field (e.g., geography education), but also in related disciplines that might provide insight into the given topic – for example, developmental psychology, cognitive science, cognitive linguistics, learning sciences, science and mathematics education. The types of literature available for any given topic may vary. Some studies may provide "laboratory" evidence of what students at a given age are able to do when interviewed or presented with a task. Findings from this type of research often help to identify what students know and can do without specific types of formal instruction. Alternatively, there may be intervention studies available that illustrate what types of experiences promote (or do not promote) learning in the given domain. These intervention studies may provide clues as to the types of experiences and instructional activities that move students along the LP.

Once the literature has been gathered, researchers analyze the main findings to elucidate the patterns within and between studies. Specifically, researchers examine the studies to see what types of ideas students have as they progress in their learning through the topic. Especially important are (1) the types of ideas that students may bring to instruction based on their out-of-school experiences and (2) the types of partial understandings/ conceptions;, incomplete strategies, and even misconceptions that students may develop (or tend to develop) that can be fruitful stepping-stones toward deeper and more sophisticated understandings. Research shows that students' intuitive ideas about the natural world can sometimes be barriers to more sophisticated understandings (often referred to as misconceptions or alternative conceptions). However, LPs represent how ideas build upon each other over time. Thus, it is valuable to identify some of the intermediate ideas that may be productive stepping-stones on the way to higher-level understanding. These intermediate stepping-stones may not resemble the correct idea in that they are either a gross simplification (e.g., in science, "genetic information specifies the structure of proteins") or even inaccurate (e.g., in science, "equating weight with mass"), but may be conceptually productive steps in the process of moving from naïve ideas to more sophisticated scientific reasoning (Duncan and Rivet 2013).

Researchers in different projects disagree as to whether actual incorrect ideas belong in a LP. Some argue that these incomplete understandings represent the actual learning that students move through in order to get to deeper understandings, and so including them in the LP can be helpful for designing assessments, instructional activities/curricula, and professional development. However, others argue that if LPs are to guide the development of standards or large-scale assessment, these incorrect ideas could be confusing unless there is empirical evidence that the "incorrect" ideas are a productive step toward more expert understanding.

There are some cases where the empirical research is so underdeveloped as not to be productive in hypothesizing the LP. In these cases, it may be useful to propose a hypothetical LP based on experts' "best guesses" about how ideas build upon one another within specific topics; however, even more than in cases where the research is rich, the empirical testing of the LP will be essential. The final hypothetical LP should include: (1) descriptions of progressing levels of understanding, (2) examples of assessment tasks that will allow the researcher to know students' understanding, and (3) hypotheses of instructional activities that may allow students to move toward deeper understanding of the content.

The process of empirically testing the LP can follow different paths. The following sections do not imply an order that must be respected. The process can begin using any of the research questions from Figure 2. Note that the following sections represent a variety of research projects carried on by one of the authors of this chapter, in conjunction with various colleagues. These sections are voiced in the first person plural, using the pronoun *we* to describe the participation of one of the authors in each project. The participating researchers for each project discussed will be found in the associated tables.

2a. Developing and Validating Strategies to Characterize Student Learning

The ability to accurately place and follow student progress along a LP requires a valid instrument to characterize students' knowledge and skills. The type of instrument that will provide adequate characterization of student understanding depends on the research goals and scope of the project. Clinical interviews with individual or small groups of students can generally provide a more in-depth picture of student understanding than a more traditional written assessment. However, interviews are a time-intensive means of collecting information. So, for a large population, a good and valid written assessment is useful. This section will illustrate how to develop and validate both types of instrument (2a from Figure 2) and describe how the instruments were used to characterize student understanding (3 from Figure 2).

Written assessment

This section is based on lessons learned from a project that devised and developed a multidimensional hypothetical LP to describe how students' models of the structure, properties and behavior of matter can develop over grades 6-12 (Stevens, Delgado, and Krajcik 2010 describes a portion of the LP). The focus of this LP relates to two core ideas for physical science (NRC 2012). As part of the empirical testing process, we developed and validated an assessment instrument to place and follow students' movement along the LP. We chose to focus on the assessment first because the project goals were to characterize how, or whether, existing instructional materials support students' movement along the hypothetical LP. Identifying instructional experiences that successfully, or not so successfully, support student progress can be used to inform future materials development.

The process of developing and validating the assessment instrument occurred in two phases, the first to validate the items in the item bank (**2a** from Figure 2) and the second to validate the instrument as a scale to locate students along the progression (**2a** and **3** from Figure 2). Table 1 summarizes the team that completed this aspect of the research project.

Table 1: Research Team Information for Developing and Validating Assessment

Expertise on Team	Learning science, science education, science (biophysical chemistry), psychometrics
Number of researchers (primary and secondary)	• Primary: 1 research scientist, 2 graduate students, post-docs and/or research associates • Secondary: 1 research scientist, 2 professors, 1-2 graduate students, post-docs and/or research associates
Number of Subjects	• ~1000 to validate the items • ~4000 followed to validate the instrument and the LP
Time this took	• 1.5–2 years (developing and validating the items) • 3+ years subsequently (validating the instrument and following student progress along the LP
Funding for Project	$2.3 M
References/Website associated with project	• Shin and Stevens 2012 • Shin, Stevens, and Krajcik 2010

Developing the items

There are various approaches to item development. Many LP research groups follow the Berkeley Evaluation and Assessment Research (BEAR) system of item development (Wilson 2005). We followed a modified version of evidence-centered design (Mislevy, Steinberg, and Almond 2003; Mislevy and Risconcente 2005), which we could use to guide the development of all of our research products including assessment, instructional materials, and the LP itself (Shin, Stevens and Krajcik 2010). Approaches to item development are iterative, involving multiple rounds of development, testing, and revision. In addition, explicitly defining the ideas to be measured is essential. For example, the development of a more scientifically accurate model of atomic structure is part of our LP. When developing an assessment task, it is not enough to indicate that it relates to atomic structure. For Level 2 of our LP, atoms are spheres with no internal structure that, when bound tightly together, can form molecules. The model of the atom at Level 3 includes a positively charged nucleus consisting of protons and neutrons surrounded by negatively charged electrons; ideas about energy levels and orbitals are not included. Clearly and thoroughly specifying the ideas helps to ensure the assessment task will measure the desired ideas.

Validating the items

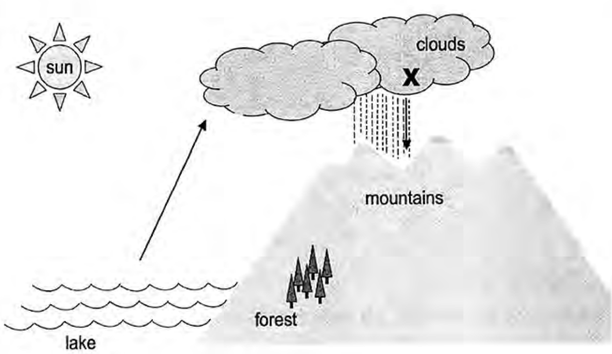
Validating the items consisted of two pilot studies. For each pilot, we assessed grade 6-12 and undergraduate students who experienced multiple curricula (pilot 1, N ~600; pilot 2, N ~800). For Pilot 1, the assessment instrument consisted of five items. Each item was accompanied by a survey that asked students to respond to statements and to answer questions, such as: Restate the question in your own words; Is the figure/diagram helpful in answering the question (See Figure 3). Surveys differed slightly depending on item. These surveys have been found to be adequate for validating most items (DeBoer, Lee, and Husic 2008). We conducted interviews with individual students to supplement the surveys for problematic items (N=3-5 per item). At least 50 students responded to each item. The quality of the items was evaluated using Item Response Theory (IRT; Wilson 2005) with the partial credit model for Rasch analysis (Masters 1982). Differential Item Functioning (DIF) analysis determined whether any factors other than students' ability levels and the item parameters (e.g., gender, test form) contributed to the likelihood of responding correctly. For basic Rasch analysis, ConstructMap software is sufficient (Wilson 2005); for large-scale samples and more complex analysis a more complete software package such as ConQuest (ACER) is required. Based on the results, items were modified or deleted from the item bank.

Pilot 2 also involved cross-sectional data collection. In this case, the instrument consisted of eight test forms, each containing 20 items (without surveys), that represented the full range of the LP. To improve the statistics, we ensured that at least 100 students responded to each item. If the IRT analysis identified an item as problematic, individual interviews were carried out to guide the revision.

Figure 3: Sample item and accompanying survey.

SoM-28.

What change of state is occurring at point **X** in the picture below?



A. Boiling
B. Condensation
C. Evaporation
D. Sublimation

Circle any words on the test question you don't understand or aren't familiar with.

1. Is there anything about this test question that was confusing? Explain.
NO

2. Is Answer A correct? Yes No Not Sure
Why: There is no boiling occuring in picture, only evaporation

3. Is Answer B correct? Yes No Not Sure
Why: the water is condensing in clouds

4. Is Answer C correct? Yes No Not Sure
Why: At the lake the water is evaporating

5. Is Answer D correct? Yes No Not Sure
Why: because no sublimation occues in this picture

6. Did you guess when you answered the test question? Yes No

7. Please suggest additional answer choices that could be used. precipitation

8. Was the picture or graph helpful? Yes No

9. Have you learned this topic in school? Yes No Not Sure

Validating the instrument

Collecting longitudinal data using the validated items links to two aspects of the empirical testing, as it both characterizes student learning over time (**3** from Figure 2) and is part of validating the instrument as a ruler to place and monitor student progress along the LP (**2a** from Figure 2). Because of the scale of our LP (grades 6-12), following students along the full time period was not possible. Instead, we focused on just a part of the LP, grades 6-8. We followed ~4000 students from nine schools in four states across three time points that occurred over about 20 months. IRT analysis that indicated students' ability levels changed as expected according to the instruction experienced. For instance, we could differentiate a curriculum that addressed LP content primarily in grades 6 and 7, but little in grade 8 from a curriculum that only significantly addressed content from the LP in 8th grade. The instructionally sensitive character of the instrument validated its use for characterizing student progress along the LP (Shin & Stevens, 2012).

IRT analysis can have significant limitations when modeling more complex questions about learning. Depending on the structure of the LP and research interests, other psychometric models may be more useful. Consulting a psychometrician early in the project can be valuable for planning the instrument development and data collection.

Clinical Interviews

In this section, we illustrate a method of developing a clinical interview to characterize student learning along a LP (**2a** from Figure 2). Many LPs have been developed based on cross-sectional assessment data, meaning that the data were collected with students from different grade levels and across a wide age range during a semester or several months of teaching experiments. This type of data sampling brings a significant challenge for assessment: How do we design clinical interviews that fit students from a wide range of age groups and scientific backgrounds? Within the scope of the Environmental Literacy Project (http://envlit.educ.msu.edu/), we have developed an approach to this problem. We designed a "branching structure" interview that can be used with students across school levels (Jin and Anderson 2012a; 2012b; Jin and Wei 2014). A branching structure interview starts with general questions that make sense to elementary students, who have very limited knowledge of science, and proceeds to increasingly more specific questions that call for application of scientific concepts and principles. The researcher may stop asking questions, when he/she feels that enough information has been obtained to interpret the student's ideas and decide the level of the student's understanding. Therefore, interviews with students who have limited scientific knowledge usually only contain general questions, while interviews with more advanced students often have many specific questions about scientific concepts and principles (cf., Ginsburg, 2009). In the paragraphs that follow, we discuss how to design a branching structure interview, using an example from the Environmental Literacy Project. Table 2 summarizes the team that completed this aspect of the research project.

Table 2: Research Team Information for developing clinical interviews (belonging to a larger Environmental Literacy Project)

Expertise on Team	Science education, science, psychometrics
Number of researchers (primary and secondary)	• Primary (science education focus): 1 Primary Investigator (science education), 2 post-docs, and 5 graduate students • Secondary (psychometrics focus): 1 Primary Investigator, 2 graduate students
Number of Subjects	• 12 focus teachers from 4th grade to 12th grade; other teachers participated the research during different times of the project • 48 clinical interviews • ~4,000 written tests
Time this took	5 years
Funding for Project	$3.5 Million (from National Science Foundation)
References/ Website associated with project	• http://envlit.educ.msu.edu/ • Jin and Anderson 2012a • Jin and Anderson 2012b • Jin and Wei 2013

We used a branching structure interview to assess student understanding of plant growth; plant growth is an important topic in the life science curriculum across school levels. To design the interview, we first investigated scientific ideas based on review of the science education standards and literature on disciplinary knowledge in biology and ecology. This work enabled us to identify two important components of scientific explanations about plant growth (for more detail, see NRC framework and NGSS Lead States, 2013; NRC 2012):

- *Tracing Matter:* Carbon dioxide reacts with water to produce organic substances (e.g., glucose, carbohydrates, cellulose, etc.) and oxygen.
- *Tracing Energy:* Light energy from the sun transforms into chemical energy of organic substances. In this process, heat is also released to the outside environment as a byproduct.

In order to design good interview questions, we also needed to have a preliminary understanding of students' intuitive ideas. Research in linguistics suggests that people use a force-dynamic reasoning to construct and use language (Pinker 2007). We therefore hypothesized that people, especially children who have not had extensive experience in school science learning, might use force-dynamic reasoning to explain plant growth. Force-dynamic reasoning explains events at the macroscopic scale; it focuses on "actors" (i.e., living things such as plants and animals) using "enablers" (the needs of the actors) to achieve their goals (e.g., to grow, to move). As one can see, force-dynamic reasoning is very different from the scientific reasoning that explains changes in terms of matter and energy at the atomic-molecular scale (as elaborated in the two bullets above).

Based on the understanding of scientific explanations and students' common intuitive ideas, we designed a hypothetical LP that describes a developmental trend from force-dynamic reasoning to scientific reasoning. To assess the level of individual students' understanding of plant growth, we designed a clinical interview. The clinical interview used a branching structure (Figure 4) to elicit students' ideas. It begins with general questions (i.e., questions in blue boxes) that fit younger students' force-dynamic reasoning. As the interview proceeds, the probing questions become more and more specific; they range from questions targeting general ideas about matter and energy (i.e., questions in the orange boxes) to questions specifically targeting atoms, molecules, and forms of energy (i.e., questions in the green boxes). It is important to note that the development of these interview questions was based on an in-depth understanding of students' common intuitive ideas. It took us three research cycles of designing/revising interview questions, collecting data, and analyzing data to become familiar with students' intuitive ideas and to develop a set of relatively effective interview questions.

Figure 4: Diagram of flow of branching structure interview.

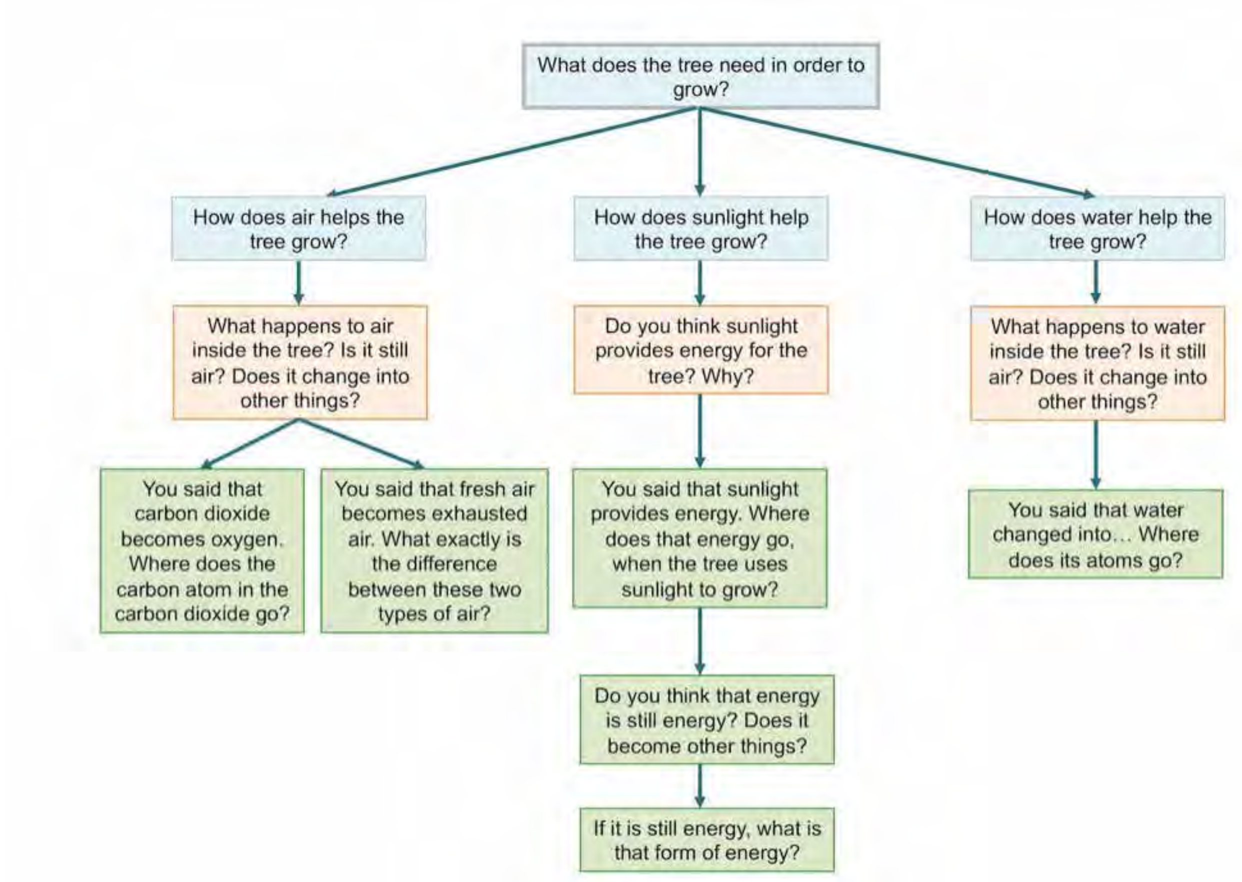


Table 3 provides excerpts from our interviews with an elementary school student, a middle school student, and a high school student. These excerpts present how interviewers elicit and exhaust students' ideas step-by-step, allowing the interviewer to gather enough information to place the students on the LP.

Student A is a 4th grader, who mostly relied on informal ideas to explain tree growth. After the student provided a list of "enablers for plants", the interviewer began to elicit his ideas about one enabler, air. The interviewer first asked: "How does the air help the tree grow?" The student responded that air helped the tree breathe. The student talked about an action (i.e., tree breathing) instead of matter, which is an indicator of force-dynamic reasoning. To examine whether the student held any ideas about matter, the interviewer pressed the student to explain changes in matter, using a follow-up question: "What happens to the air inside the tree?" The student responded that the air was still air, indicating that he was not reasoning about changes in matter; instead, he reasoned about macroscopic relations between the tree and its enabler – air (i.e., force-dynamic reasoning, level 1 of the LP).

Student B is an 8th grader, who began to reason about matter and energy, but mostly relying on alternative conceptions of matter/energy. After Student B provided a list of enablers, the interviewer began to probe his ideas about one enabler, carbon dioxide. Student B stated that the tree took in carbon dioxide and produced oxygen. It was not clear what exact process Student B was talking about. It could be a conversion process ($CO_2 \rightarrow O_2$; an alternative idea), a reaction process ($CO_2 + H_2O \rightarrow$ Organic molecules + O_2; the scientific idea), or any other processes that involve carbon dioxide and oxygen. Therefore, the interviewer asked a sequence of probing questions to elicit Student B's ideas. Student B's responses to these questions suggest that he was reasoning in terms of a matter-energy conversion process: The carbon atom in carbon dioxide was converted into energy. This is an alternative idea described in level 3 of the LP.

Student C provided a scientific explanation (the upper anchor or level 4 of the LP) after the interviewer asked how the tree used carbon dioxide to grow. Therefore, the interviewer did not ask follow-up questions about carbon dioxide.

Table 3: Examples of Using the Branching Structure Interview to Place Students on the LP

Types of Questions	**Student A: 4th grade; pre-interview**	**Student B: 8th grade; pre-interview**	**Student C: 9th grade; post-interview**
Questions about actors and enablers	Interviewer: *What does the tree need in order to grow?* Student A: Water, sun-light, air, habitat.	Interviewer: *What does the tree need in order to grow?* Student B: Nutrients, water, sunlight, carbon dioxide, things to make it do photosynthesis.	Interviewer: *What does the tree need in order to grow?* Student C: Well, it needs water and light for photosynthesis in order to make food for itself, glucose that is. It needs soil for nutrients, and it needs air, particularly carbon dioxide, which it uses for photosynthesis.
Questions about general ideas of matter	Interviewer: *How does air help the tree grow?* Student A: Well, with-out air, the tree couldn't breathe.	Interviewer: So you said that the tree needed carbon dioxide. *How does carbon dioxide help the tree grow?* Student B: The carbon dioxide, like makes it breathe, like how we breathe in, but they [plants] produce oxygen from the carbon dioxide.	Interviewer: You mentioned carbon dioxide. *How does it help the tree grow?* Student C: Well, carbon dioxide, that's again the photosynthesis process. Carbon dioxide and water are used to make glucose and oxygen. So carbon dioxide, its carbon is taken away, and then the oxygen molecules, the ox-ides, they're just released as oxygen, I think.
Questions specifically about atoms and mole-cules	Interviewer: *What hap-pens to the air inside the tree?* Student A: It just stays as air.	Interviewer: *How can carbon dioxide change into oxygen?* Student B: By the different, like it's, it goes through like the system of, like the tree, or through the system of like a body. Interviewer: *So, if you compare carbon dioxide and oxygen, carbon dioxide has a carbon atom in it, right? Oxygen does not have that.* Student B: Right. Interviewer: *So, where does the car-bon atom go?* Student B: Because like other things in carbon dioxide, it gets like, during the process, it gets used as energy or used as different things to make the tree grow and to make it produce oxygen. Interviewer: *You mean the carbon atom of the carbon dioxide becomes the energy? Is that what you mean?* Student B: Yes. And carbon gets used for other things like carbon can go back into a different cycle like air. And then back into another cycle.	

2b. How can we support students in moving along the LP?

The growth in knowledge and skills represented by a LP are generally not developmentally inevitable. Thus, specific instruction is necessary to support students in moving along a LP. Often, the upper anchors of LPs represent ideas that very few students are able to achieve with current instructional practices in schools. In fact, in most cases, students may not be able to achieve these upper anchors at all without supported exposure to specific phenomena and specific experiences. In these instances, examining cross-sectional data with students who have experienced "status-quo" instruction may not provide the type of evidence that is needed to ensure that LPs provide representations of how students actually learn and to promote the types of learning that will allow students to achieve desired upper anchor understandings. When current curricula in schools are not successfully helping students to reach upper anchors, then new instructional materials/curricula are needed. Thus, another approach to finding how students move along the LP is to conduct longitudinal teaching experiments that follow a hypothetical curricular sequence of instructional interventions, each targeted at a specific level of the LP.

In this section, we provide two examples that illustrate how researchers support students in moving along a LP. In the first example, researchers developed, tested, and re-designed a hypothetical LP and associated curriculum in parallel. In the second example, researchers developed a hypothetical LP and sequences of instructional tasks and then revised and validated them in a teaching experiment over time.

Curriculum Development

One method for supporting students' learning is to use a LP as a framework to develop instructional materials/curricula (e.g., see Songer, Kelcey, and Gotwals 2009). In this section, we briefly describe an example of LP work that had curriculum development as a central component. Our research project had developed a 6th grade curriculum, BioKIDS: Kids Inquiry of Diverse Species. This curriculum was designed to give students the opportunity to explore local biodiversity, collect local animal (invertebrate) species, and investigate individual animals and how they interact with one another. Students used CyberTracker, an animal-tracking program that runs on hand-held computers (PDAs), to log animal sightings in their schoolyard. Students then analyzed the data for class and team experiments to determine the microhabitats that were the most biodiverse (e.g., the sidewalk vs. the area with trees). The curricula provided students with multiple experiences to collect data in their schoolyard, find patterns in the data, and then develop explanations based on these data. The curriculum was successful in helping students learn (Songer, Kelcey and Gotwals 2009); however, we wanted to develop students' ability to engage with the practices of science within ecology even more. Thus, we decided to develop a 3-year LP that focused on disciplinary core ideas in ecology as well as multiple science practices, but we specifically focused on developing evidence-based explanations. Table 4 summarizes the team that completed this aspect of the research project.

Table 4: Research Team Information for BioKIDS: Kids Thinking about Diverse Species

Expertise on Team	Learning Sciences; Science Education; Scientists (Ecologists and Zoologists); Psychometrician; Web designers and technology experts; Classroom teachers
Number of researchers (primary and secondary)	• Primary: 2 Primary Investigators (science education) and 3 graduate students • Secondary: 1 Primary Investigator (zoology); 2-3 research assistants, post-docs, web designers
Number of Subjects	3 year-long cohorts: 200-300 students (10 teachers) per cohort
Time this took	5 years and counting
Funding for Project	$3 Million (from National Science Foundation)
References/ Website associate with project	• http://www.biokids.umich.edu/ • Gotwals and Songer 2013 • Songer and Gotwals 2012 • Gotwals and Songer 2010 • Songer, Kelcey, and Gotwals 2009

After conducting a literature review, consulting with scientists (e.g., ecologists, zoologists) and classroom teachers, and using our understanding of students' knowledge from our prior work, we developed a hypothetical, 3-year LP (4th through 6th grades) that had two main dimensions: disciplinary core ideas in ecology related to biodiversity and the science practice of developing evidence-based explanations (a more generalized description of the process of this development is described in **1b** of Figure 2). The development of this initial hypothetical LP took about 6 months (but the LP has been revamped multiple times based on empirical data). Our initial LP had a core ideas (content) dimension and a separate scientific explanations dimension (see Table 5 and Table 6 for modified descriptions of the LPs). However, we have since merged these two dimensions. We keep them separate here as an example of how to deal with content and skills that are embedded in the complex learning goals that we may have for students.

Table 5: Description of Initial Disciplinary Core Ideas LP (simplified) for BioKIDS

	Classification Strand	Ecology Strand	Biodiversity Strand
6th Grade		**Complex Ecological Idea:** A change in one species can affect different members of the food web… . . . **Middle Ecological Idea:** Plants and animals of a habitat can be connected in a food chain	**Complex Biodiversity Idea:** Humans and other factors affect biodiversity… . . . **Middle Biodiversity Idea**: Biodiversity differs in different areas…
5th Grade	**Complex Classification Idea:** Patterns of shared characteristics reveal the evolutionary history… . . . **Middle Classification Idea:** Organisms are grouped based on their structures…		**Middle Biodiversity Idea**: An area has a high biodiversity if it has both high richness and abundance . . . **Basic Biodiversity Idea:** A habitat is a place that provides food, water, shelter…
4th Grade	**Middle Classification Idea:** Organisms have different features that allow them to survive . . . **Basic Classification Idea:** There are observable features of living things	**Middle Ecological Idea:** Only a small fraction of energy at one level … moves to the next level . . . **Basic Ecological Idea:** Every organism needs energy to live…	

Table 6. Initial practice progression for evidence-based explanations (for full description, see Songer et al., 2009)

Level 4 Student constructs a complete evidence-based explanation (without scaffolding)
Level 4s Student constructs a complete evidence-based explanation (with scaffolding)
Level 3 Student makes a claim and backs it up with sufficient and appropriate evidence but does not use reasoning to tie the two together (without scaffolding)
Level 3s Student makes a claim and backs it up with sufficient and appropriate evidence but does not use reasoning to tie the two together (with scaffolding)
Level 2 Student makes a claim and backs it up with appropriate but insufficient (partial) evidence (without scaffolding)
Level 2s Student makes a claim and backs it up with appropriate but insufficient (partial) evidence (with scaffolding)
Level 1 Student makes a claim (without scaffolding)
Level 1s Student makes a claim (with scaffolding)

We then used the LP to develop three 8-week curricular units (one in 4th, 5th, and 6th grades). These units were directly mapped onto the main components of the LP. Specifically, we used the ideas in the LP to design written scaffolds to help students move from their everyday explanations of phenomena to explanations that used a claim, evidence, and scientific reasoning. In addition, we integrated specific experiences mapped to core ideas in order allow students to develop deeper understanding of ecological phenomena. The curricular design took about 6 months (but, again, the original curricula have been revamped multiple times since then). In parallel with the curriculum design process, we also developed multiple embedded assessment tasks to be used formatively as well as summative assessment tasks to evaluate student learning, both of which were mapped to the LP (see Figure 5 to illustrate how we used the LPs to create learning objectives and see Figure 6 to see an embedded assessment task mapped to the LP).

Figure 5: Sample of how to use the learning progressions to create learning objectives.

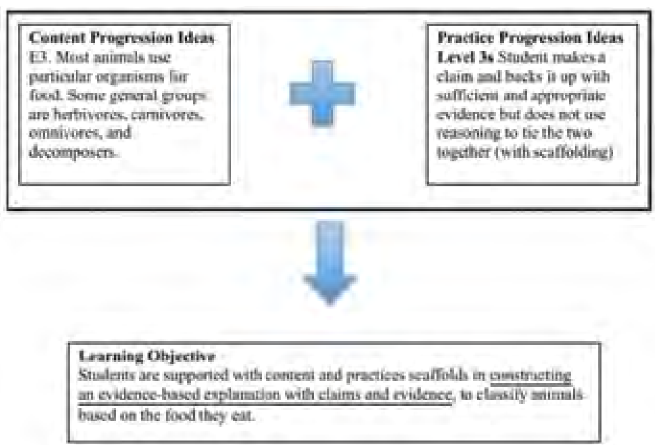
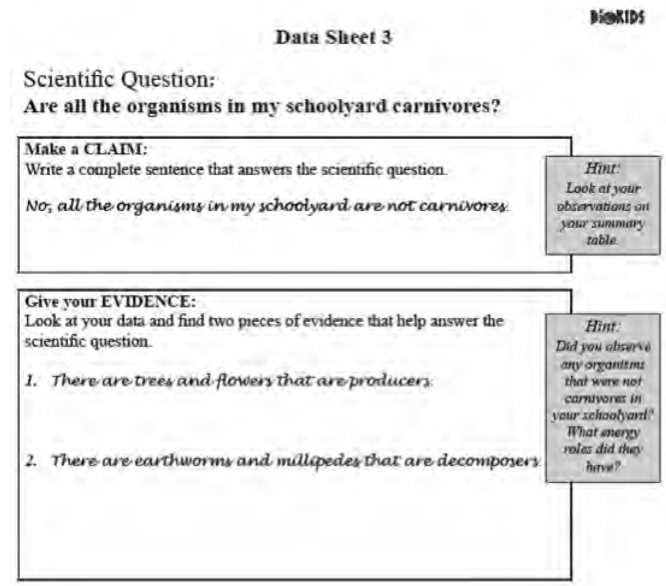


Figure 6: An embedded assessment task mapped to the learning progression (related to Figure 5).



After designing the curricula we engaged in iterative design-based research (e.g., Gravemeijer and Cobb 2006; Cobb et al., 2003), where we worked with teachers to implement these curricula in schools and made changes to the curriculum (and the LP) based on the empirical data we collected. We engaged in three rounds of implementation over three years with analysis and design changes happening between each round. We built from working with about 4 classes at each grade (4th, 5th, and 6th) for the first iteration to about 12 classes at each grade by the third iteration (in this iteration we worked with almost 1000 students). Specifically, for each iteration of curricular implementation, we observed (and sometimes videotaped) teachers implementing the curricular units and noted what worked and what needed to be revised using an observation protocol. We collected pre-/post-tests and embedded assessments to examine student learning. We conducted interviews with a subset of the students and teachers to gather more in-depth information about their interactions with the curricula and the learning.

The types of analyses that we did with these data included qualitative coding of interviews and observations; developing case studies of teachers and their classrooms; inferential statistical examination of students learning (t-tests, multiple-regression analysis, hierarchical linear modeling); and a Rasch Analysis of our assessment data to examine validity (see Masters 1982; Wilson 2005; also see description in the section of this chapter above).

This type of research has been very helpful in thinking about student learning because if the instructional materials are mapped onto the LP, then, when implemented, the results of student learning can provide feedback both about the validity of the LP and about the effectiveness of the instructional materials. However, there are a few challenges in conducting this type of LP-based curricular work. For example, if students do not learn as hypothesized, it is sometimes difficult to know if the instructional materials were ineffective; if the teacher did not implement the instructional materials with fidelity; if the assessment tasks used to determine students' placement on the LP were invalid; or even if the LP framework on which they were based was an inaccurate representation of how students learn (e.g., see Gotwals and Songer 2013). Despite these challenges, design experiments where hypotheses about how to best help students make progress up a LP are an important part of LP work.

Curriculum Development Through Teaching Experiments

Another way of supporting students to move along a LP (or a Learning Trajectory: LT) is to conduct a teaching experiment to investigate hypothetical sequences of instructional tasks that follow from a hypothetical LT (Simon 1995; Clements and Sarama 2004; Sarama & Clements, 2009). What follows is a description of the methodology of teaching experiments as we used it to develop and improve a LT for length measurement (cf., Hart, 1981) in an NSF-funded project spanning four years and two research teams (See Table 7). Here we describe the work of one team at a Midwestern research site. This approach is another form of design-based research that focuses more directly on a cohort of students over time (Cobb and Gravemeijer 2008; Cobb et al., 2003). First, we conducted a pretest, using a clinical interview based in prior assessment development cycles. Based on the results, we identified participants representing a range of levels of thinking about linear measurement within a set of second-grade students from two classrooms in a typical Midwestern suburban elementary school (n=46). We adapted the teaching experiment methodology as follows:

- We conducted *teaching episodes* (otherwise described by Ginsburg (2009) as formative assessment using clinical interviews) with eight individual students, and then we analyzed the videotaped records of students' actions and dialogue with the teacher/researchers during each teaching episode;
- Student responses during the teaching episodes were used to track his or her level of thinking along the learning trajectory, and to predict what level they might exhibit on similar tasks;
- We grouped students in the cohort based on their current level and prepared follow-up episodes for each group (3 groups were identified);
- We predicted the performance level for these groups of students for each new task, and we prepared tasks that we expected to be easy, on level, and above their level (to check our theoretical models of their level of thinking);

Table 7: Research Team Information to Describe Students' Understanding of Length Measurement

Expertise on Team	Mathematics education
Number of researchers (primary and secondary)	Conducting Teaching Experiment • Primary 2 graduate students, 1 researcher Learning Trajectory (LT) revision and elaboration • Primary: 2 graduate students, 1 professor • Secondary: 3 professors, 1 graduate student
Number of Subjects	• 8 subjects • ~6 sessions for each child participating in the study • (~50 video-taped sessions across the study)
Time this took	• ~1.5 years (designing and conducting the teaching experiment) • ~1 year (analysis and reporting)
Funding for Project	~$1.6 M over four years (this part was only a portion of the project)
References/ Website associated with project	• Barrett et al. 2012 • Sarama et al. 2011

- Subsequent TEs would be conducted, each checking the predictions from previous episodes.

Much less frequently (once per semester), we carried out supplemental clinical teaching episodes with other students (background cohort) from the same school to check the generality of our observations and findings with the focus cohort of students. This process allowed us to modify and improve our tasks based on reflection and discussion that emerged from the individual TEs and to develop tasks and lessons to try out in full classroom settings as well.

The research team addressed three emergent themes from our ongoing and post hoc review of the TE cycles: (1) the concept of unit based in comparisons of continuous linear space, (2) the integration of schemes for cardinal counting, ordinal counting, partitioning distances, subdividing lengths, and motion broken by hash marks and (3) the coherence and consistency of the LT for length measurement (Sarama et al. 2011; Barrett et al. 2012). Following work each year with these students, we proposed tentative improvements, or we made claims about the potential validity of our LP and the corresponding task sequences that constitute the LT (see an extended example in chapter 4 of this volume, showing sequences of instructional tasks).

2c. Develop strategies to support using LP for classroom teaching and to measure teacher knowledge of LP

Researchers are just beginning to study how teachers use LPs in classroom teaching. Here, we describe two examples of LP research on teaching and teacher learning. The first example is about using a LP to support classroom teaching, while the second case study relates to measuring teachers' knowledge of LPs.

Using LPs to support classroom teaching

In this section, we discuss an example about using a LP for classroom formative assessments. Furtak (2012) conducted a qualitative study to examine how a group of six high school teachers used a LP for natural selection to design and enact formative assessments. At the beginning of the project, she reviewed extensive literature about scientific and intuitive ideas of natural selection. Based on this work and suggestions from the participant teachers, she developed a LP for natural selection. Teachers used this LP to design and enact formative assessment tasks.

The study lasted for two years and the researcher met with the six teachers monthly. During the first year, the focus of the monthly meetings was designing formative assessment tasks. The teachers identified their students' ideas and mapped those ideas onto the LP. Based on this work, they explored strategies for eliciting students' ideas and developed a set of formative assessment activities. Then, each teacher enacted these formative assessment tasks in class. During the second year, the focus of the monthly meetings shifted to reflections of teaching practice. Teachers watched and discussed videos of each other enacting the formative assessment tasks. Based on this reflection, they revised the formative assessment tasks and enacted these revised tasks in class.

The researcher collected two datasets: (1) videos of teachers enacting the formative assessments in class, and (2) teacher interviews focusing on how teachers perceived the LP as a support for their instruction. Here, we elaborate how the researcher coded these two datasets.

- *Teaching videos.* Two coding processes were carried out to code the teaching videos. First, the researcher coded student responses according to which student ideas from the LP were presented in the responses. Second, the researcher coded each teacher response for one of four teaching moves classified as highlighting students' responses/ideas: (1) repeating or reconstructing student statements, (2) asking clarifying questions, (3) asking students to provide mechanisms, or (4) making inferences either by re-voicing or explicitly categorizing student ideas. This coding scheme was developed based on literature of formative assessment research.
- *Teacher interviews.* Teacher interview data were used for two purposes. The first purpose was to examine teachers' perceptions of how they used the LP. During the interviews, the researcher asked teachers to talk about the research project, formative assessments, and how LP influenced their thinking and teaching. The second purpose was to triangulate the claims about the teachers' inferences about student thinking in the videotaped classroom conversations. For each teacher, the researcher selected segments from the teacher's classroom teaching videos and asked the teacher to reflect on his/her teaching practice. The researcher asked the following interview questions: How did you interpret what the student was thinking here? Talk a little about the way that you responded/why you responded this way. The teacher's responses to these questions were used to help the researcher better interpret the classroom conversations.

Putting all coding results together, the researcher was able to identify several patterns about how the teachers used the LP to design/enact formative assessments. For example, one pattern is that "several of the teachers seemed to use the LPs simply as catalogs of misconceptions to be 'squashed' rather than drawing upon the developmental affordances offered by a LP" (Furtak, 2012, p. 1181). These patterns provide significant implication for research and professional development that help teachers use LPs to teach.

Develop LP-based measures for teacher knowledge

Teacher knowledge plays an important role in effective instruction. Here, we discuss how to assess teachers' knowledge of LPs. For assessing teachers' content knowledge, we can simply use the LP and associated assessments that have been designed and used with students. Therefore, we focus the discussion on a more challenging topic: assessing teachers' pedagogical content knowledge (PCK) as it relates to LPs. We use examples from the Environmental Literacy Project to discuss: (1) how to design LP-based PCK items, and (2) how to develop a PCK rubric that is linked to the LP.

Researchers in science education have identified a set of important PCK components, including orientation toward science teaching, knowledge of science curriculum, knowledge of instructional strategies, knowledge of student thinking, knowledge of assessment in science (Anderson and Smith 1987; Magnusson and Krajcik 1999). In our study, we specifically focused on two PCK components:

- Component 1. Knowledge of student thinking
- Component 2. Knowledge of instructional strategies

The assessment strategy we used was to design items that required teachers to analyze scenarios that could happen in real classrooms; these scenarios are linked to different levels of the LP. For each PCK component, we designed a set of written items. *Items on knowledge of student learning* required teachers to analyze students' typical responses and/or generate follow-up questions. For example, one item was developed based on our previous study with students. We had identified a set of typical responses from students to an item about tree growth. We used these typical responses to design a PCK item; the item asked teachers to sort six typical responses into three qualitatively different levels and explain their sorting. In another item, a classroom scenario was provided: *A teacher asks students where plants get their food. A student responds, "Along with soil, plants use carbon dioxide, sunlight, and water to help them make food."* Teachers were asked whether a follow-up question is needed to fully understand students' ideas and what is a good follow-up question. *Items on instructional strategies* asked teachers to make decisions on the next instructional move in different classroom scenarios. For example, one item asked what would be a good next instructional move when students debated whether or not water is food for plants.

It is also important to connect the PCK rubric with the LP. We made the connection by focusing on how teachers used their understanding of the LP to analyze students' responses, to generate follow-up assessment questions (measuring component 1: knowledge of student thinking) and to make decision on next instructional moves (measuring component 2: knowledge of teaching strategies). The specific levels of the PCK rubric and their connections to the LP are presented below:

- Level 1. When analyzing students' ideas, generating follow-up assessment questions, or using instructional approaches, the teacher focuses on content-general features rather than specific scientific concepts and principles. This level is not associated with any levels of the LP.
- Level 2. The teacher either does not identify the big idea or holds alternative ideas about the science topic. Therefore, this level is associated with levels 1 and 2 of the LP, suggesting that the teacher does not hold scientific understanding of the content. Lack of necessary content knowledge largely affects how the teacher generates follow-up questions and makes instructional moves.
- Level 3. The teacher understands the scientific ideas described at the upper anchor (level 4), but has very limited knowledge of students' intuitive ideas described at levels 1, 2, and 3 of the LP. In such situations, the teacher's analysis of student thinking and use of instructional strategies often focus on whether students correctly describe the science content. This level is associated with level 4 of the LP.
- Level 4. The teacher understands the scientific ideas described at the upper anchor (level 4) and students' ideas described at levels 1, 2, and 3 of the LP. That is, the teacher holds a complete understanding of all levels of the LP. Based on this understanding, the teacher targets the conflicts or gaps between students' intuitive ideas (levels, 1, 2, and 3 of the LP) and scientific ideas (the upper anchor of the LP) when analyzing students' responses, generating follow-up questions, and making next instructional moves.

3. Characterizing and Monitoring Student Learning Over Time

The development of curriculum for science and math instruction in K-12 schools has often been based on intuition, or the judgments and suggestions of experienced teachers or professional writers, rather than being based on rigorous research in keeping with standards of educational researchers in science or mathematics. More recently, there have been calls for a rigorous approach to the use of a Curriculum Research Framework (Clements 2007). This framework involves three components: (1) a serious consideration of *extant research*, (2) the development and use of a *learning model,* and (3) *substantive evaluation.* The concerns raised here represent the wider concerns of both science and mathematics educators. The following section outlines some current efforts to base such frameworks on the use of LPs or LTs. The model proposed by Clements insists upon the development and enactment of a learning model (see phases 4, 6 and 7 particularly, pp. 41-49) that is defined most clearly as a LT or LP with associated task sequences (cf. Barrett and Battista, 2014). Here we illustrate this connection between LT or LP levels and the associated claims about student's learning in keeping with corresponding instructional tasks.

Teaching Experiments and Clinical Interviews

Learning progressions (or learning trajectories: LTs) are often helpful for curriculum development, standard writing, assessment writing, or designing professional development lessons for teachers (Clements and Sarama 2007; Sztajn et al. 2012; Wickstrom 2014; Wilson, 2009). LPs or LTs provide insight into children's ways of learning and struggles along their learning paths. Thus, it is important to check the extent to which a hypothetical trajectory or progression provides a natural, sequential account of students' developing knowledge over time by conducting longitudinal research with a cohort of students. The external validity of the sequential nature of a learning progression can be determined most naturally by a longitudinal *teaching experiment* that tracks individual students over the full extent of the progression (Barrett, Sarama, and Clements, forthcoming; Steffe and Thompson 2000). Here we describe the use of teaching experiments in tandem with clinical interview data with a cross-sectional population of students. These data were analyzed through IRT analysis.

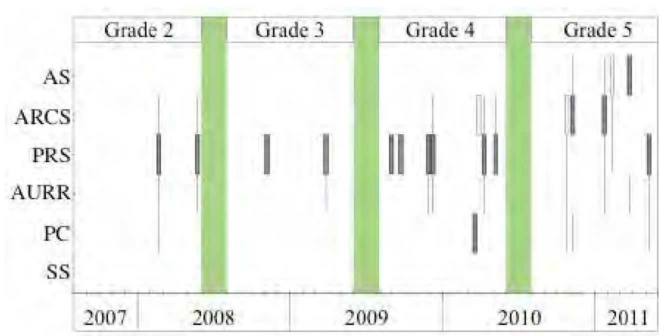
Learning progressions may extend for several years, and so the task of checking the natural sequence of the progression may not be plausible with a single longitudinal study. In our work, we split a LT that spanned from Pre Kindergarten through Grade 5 into two parts, with one grade level overlapped by the two studies. One part of the study followed students from PreK through Grade 2, and the other followed students beginning during their Grade 2 year, through Grade 5. Thus, we followed each child's growth over a span of four years. We complemented the teaching experiment data with two cycles of IRT analysis of assessment items derived from the same LP. This provided a validation of the direction and separation of the sequence of levels.

It can be challenging to follow individual students over more than one school year, but in cases where this is plausible, a teaching experiment can provide relevant evidence for the progression, or it can provide a strong rationale for changing the progression. A teaching experiment of this type is focused around a cyclical set of interactions with individual students that involves tutoring the children on the target domain of knowledge or through a given curriculum. This tutorial work is often carried on in a clinical setting although it can be adapted within a classroom situation. The experiment naturally integrates instructional tasks and assessment (this is formative assessment); such work often extends across at least six months, and sometimes as long as four years or more (cf., Steffe and Cobb 1988; and see Maher's work following students from Grades 6 through 12 in mathematical development in: Steencken and Maher, 2003), These are adequate spans of time to capture major shifts in sophistication level or extent that will be described by the progression (see the discussion by Ginsburg (2009) on clinical interviews and formative assessment).

Our research group (led by Clements, Sarama and Barrett) designed and conducted a teaching experiment to check the validity of a LP established in prior research on mathematics education related to measuring space and understanding geometry (Sarama & Clements, 2009; Clements et al., 2011). We worked to improve three progressions for children's reasoning and knowledge of length, area and volume measurement (including measuring practices). Part of our research team (at a Northeast site) worked for four years with the same cohort of children as they grew from Pre-K to Grade 2; between 2009 and 2011, they followed eight case study children, and also carried on classroom lessons approximately once each semester with their entire set of classmates. The other part of our team (at a Midwest site) worked for four years with another cohort between Grade 2 and Grade 5. Two graduate research assistants conducted the teaching experiments with support from one senior faculty member at each of the research sites, and all team members participated in the ongoing analysis of successive sessions (every 2 or 3 weeks another session was conducted with each pair of children).

The outcomes of these studies with both cohorts of students, covering PreK to Grade 5, describe the progress of each of eleven children who completed the longitudinal study. The reports track the children's progress through the LT levels for each of three domains: length, area and volume (Barrett, Sarama, and Clements, forthcoming). Further reports describe particular changes made in the LTs for each domain to improve the generality and breadth of the level descriptions, and to offer sample instructional tasks that were associated with the growth of the children and with the assessment tasks used to place the children at those levels (Barrett et al. 2011; Barrett et al. 2012; Sarama et al. 2011). For example, Figure 7 describes the progress of one child (Abby) as she developed increasingly sophisticated knowledge and strategies for measuring area. We placed her development along the LT for area measurement over a period of four years by reporting the outcomes of our teaching experiment:

Figure 7: Sample of a longitudinal growth chart of a student's growth over 4 years.



Characterizing how students build upon and connect ideas

This example focuses primarily on aspects 2 and 4 of Clements' model and links to step **3** followed by **2b** from Figure 2. We collected data to develop an empirical progression to combine with the relevant learning research to develop a multidimensional LP that involves multiple knowledge domains (Stevens, Delgado, and Krajcik 2010). Table 8 summarizes the project teams that completed these aspects of LP research.

Table 8: Research Team Information for Characterizing How Students Develop Understanding

Expertise on Team	science education, science (chemistry, biochemistry, physics)
Number of researchers (primary and secondary)	LP development • Primary: 1 post-doc • Secondary: 1 professor, 3 graduate students Instructional materials development • Primary 1 graduate student, 1 post-doc • Secondary: 1 professor, 1 graduate student, 1 post-doc
Number of Subjects	• ~100 individual interviews (LP development) • ~50 students for each pilot (instructional materials
Time this took	• ~2 years (LP development) • ~1.5 years (instructional materials development and pilot)
Funding for Project	~$2 M (this part was only a small portion of the project)
• References/ Website associated with project	• Stevens, Delgado, & Krajcik, 2010 (LP development) • Short, Lundsgaard, & Krajcik, 2008 (materials development)

The learning model we used to guide the LP development was for students to develop conceptual understanding, where they are able to apply ideas to solve problems, and to make connections between related ideas (Bransford, Brown and Cocking 1999). To do this, learners must take new ideas and connect them to related ones to create organized knowledge frameworks (Ausubel 1968; Linn, et al. 2004). One of the goals for science literacy is for students to be able to explain phenomena important to both science and their lives. Explaining phenomena related to any science discipline generally involves applying ideas from multiple knowledge domains. For example, ideas about the structure of matter, energy and conservation are important for phenomena as diverse as star formation, the rock cycle, chemical reactions and the water cycle. To be able to appropriately connect and relate ideas to various situations and phenomena requires students to build organized and integrated knowledge structures. Thus, we aimed to develop a learning progression that characterized the ways in which students not only could develop an understanding of important concepts within individual knowledge domains, but also could make connections between related concepts both within and across domains.

Our project team developed a multidimensional LP that describes how students' models of the structure, properties and interactions of matter can develop over grades 6-12. It is termed a multidimensional LP because it describes learning in terms of ideas and relationships between ideas both within and across multiple knowledge domains and has definable levels that are consistent across domains. Since most of the research literature focused on how students understand and learn about individual content domains, we created the multidimensional LP by piecing together progressions for individual knowledge domains. We collected empirical data to supplement the learning research literature to gain insight on how students relate ideas across domains as they progress through current science curricula.

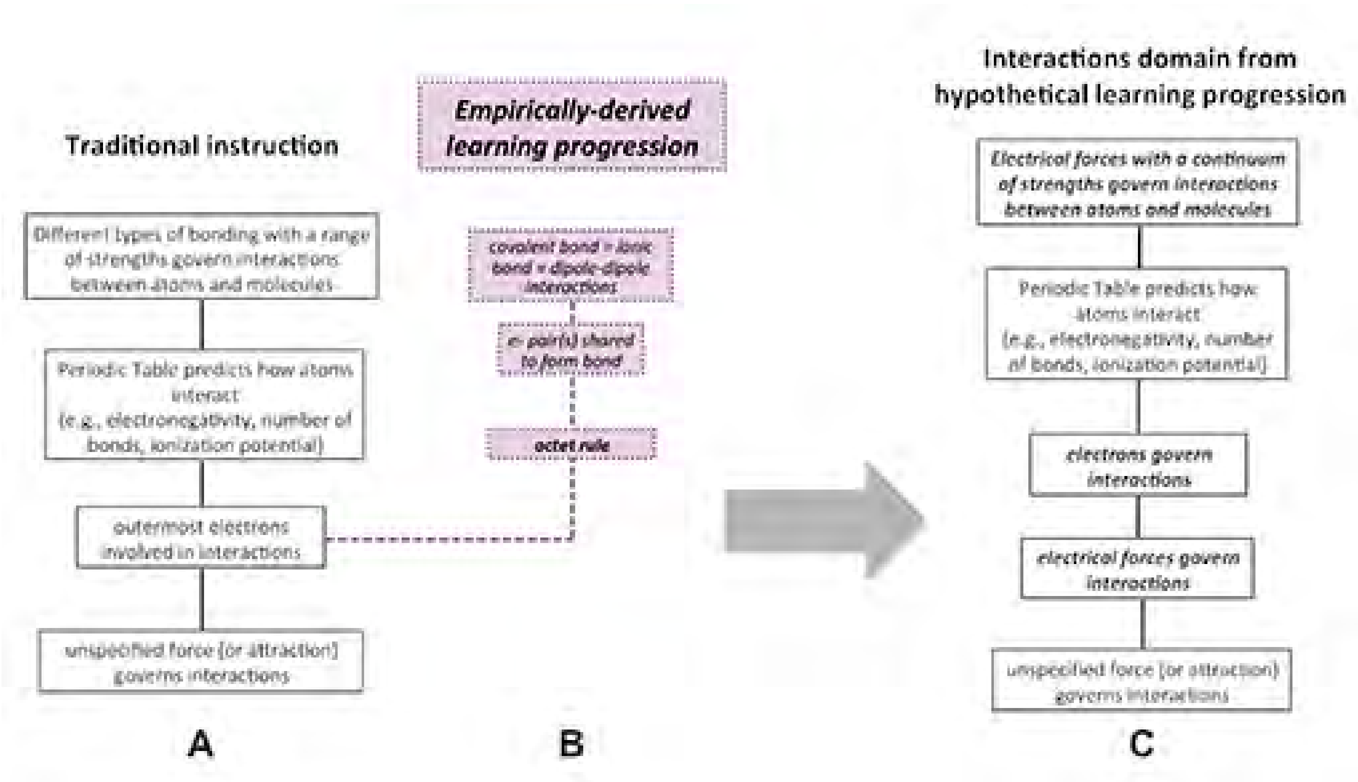
Developing an empirical progression

The data consisted of ~100 semi-structured interviews consisting of open-ended assessment tasks designed to measure students' understanding of the structure of matter including the atomic model, the properties of matter; and the interactions that occur between atoms and molecules. The tasks focused both on situations similar to those students might see in the classroom as well real world phenomena. The individual interviews were carried out with 7th grade and high school (pre-chemistry and post-chemistry) students. Collecting cross-sectional data provided insight as to how students collectively build understanding in three separate curricula.

The data were analyzed using a set of codes defined using a modification of Minstrell's (1992) facet approach where important concepts from each domain were broken up into independent ideas that are readily measurable and can characterize progress in student knowledge. Focusing on the individual ideas students used in their responses prevented favoring predefined models and ensured that we characterized all student models. For each domain, we sorted the ideas students used into a Guttman scale (Guttman 1944) to form individual progressions. The McNemar test (McNemar 1947) established the significance of each step of the progression. A significant difference indicated an ordered connection. We found the individual progressions could be connected by the ideas needed to explain various phenomena across domains.

When we compared the hypothetical LP to the empirical LP, we found that regardless of curricula, students tended to follow an unproductive path in one knowledge domain (See Figure 8). Students tended to apply a model (the Octet Rule) that predicts and explains *some* intramolecular interactions (chemical bonding) in an indiscriminant manner to explain all intra- and intermolecular interactions. We hypothesized that not having a conceptual understanding of the interactions was the cause for the misapplication of the model.

Figure 8: An example of the interaction between empirical and hypothetical learning progression.



Testing the hypothetical progression

The group developed and tested instructional materials designed to support students in developing understanding intermolecular interactions using the hypothetical LP as a guide (**2b** from Figure 2). Two iterations of development, testing and revision, were performed in 2-4 classrooms of a single urban high school (N= ~50). Data sources included student artifacts, classroom observations and interviews with teachers and individual students. Results indicated that the materials successfully helped students progress along the hypothetical LP (Short, Lundsgaard, and Krajcik 2008), suggesting that the ideas are not fundamentally too difficult for students, but that these instructional strategies can help students build ideas along a productive path that helps prepare them for future learning. This provided evidence that the hypothesis put forth by the LP is a productive path toward a more sophisticated model of matter, its behavior and its interactions.

Preparing to start a LP research program

We conclude with a few things to think about when starting a LP research program. While each research goal from Figure 2 is different, there are a few aspects that are common to all of them.

When preparing a grant proposal, funders generally want the participants (e.g., teachers, schools, school districts) specified through letters of support. This can often take a significant amount of time, so make sure you begin to build relationships well before the grant deadline. The National Geographic Society coordinates the Alliance Network for Geographic Education to help support geographic education reform. The alliances are state-based organizations designed to build connections between K–12 educators and university faculty or other education professionals. These alliances can be a good source of potential participants for educational research related to geography. [1]

All of the research goals in Figure 2 involve interacting with human participants. This type of research requires approval from your Institutional Review Board (IRB). Every institution's IRB has different requirements for dealing with data from human participants, For example, for certain types of electronic data, the IRB may require your research group to maintain a secure server to store confidential data. In other cases, your institution may provide a place to store your data that meets with IRB approval. What may be acceptable at one institution may not be at another. Therefore, it is critical to communicate directly with the IRB at your institution when beginning a research project or preparing a grant proposal.

Assembling a good research team is an important step. Even if the proposed research involves primarily one person, it is useful to have a good set of advisors with a variety of expertise. It is valuable to have members with both content expertise and learning research experience. To gain traction in the schools, it is helpful to have teachers involved in the research, not just implementing research products in the classroom. Additional expertise depends on your research goals. Building a team with the right combination of expertise is not enough; be sure they are all people who can communicate well with each other as working with interdisciplinary teams can be challenging.

The examples presented in this chapter were meant to illustrate the range of research goals and methodologies associated with LP research. Figure 2 shows that any combination of studying teacher or student learning, teacher professional development, developing instructional materials or assessment can be associated with LP research. While most of the examples were part of large $1–3M projects consisting of large interdisciplinary teams, aspects of these projects were completed primarily by one or two researchers. Certain research questions and goals such as developing and validating assessment with a large-scale (1000+) data collection require a fairly large, interdisciplinary team (e.g., content expertise, learning science, psychometrician). For other goals (e.g., case studies) one or two researchers can make a significant contribution. Aspects of LP research can occur at any scale. The important thing is to choose a research goal in which you are interested, as LP research on any scale is requires a significant commitment of time and resources.

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[1] For more information, visit http://education.nationalgeographic.com/education/programs/geography-alliances/?ar_a=1

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CHAPTER 4

Examples of Research Tools Developed in Mathematics Education and Science Education

Jeff Barrett and Hui Jin

This chapter provides two examples of developmental frameworks: one for science education (a learning progression, hereafter "LP") and one for mathematics education (a learning trajectory, hereafter "LT"). As was mentioned in prior chapters of this handbook, there are differences of grain size and purpose within the broader community of educational researchers, particularly between science and mathematics (Anderson and Battista 2014). Closer grain sizes of analysis provide insight about levels of thinking that may change from one day to the next, or from one week to the next, guiding teacher decision making through very detailed descriptions of thinking and actions from lesson to lesson. Broader grain sizes of analysis provide more discrete, salient levels of thinking and paint these across several years of curriculum, guiding district personnel in assessing progress through a developmental curriculum from elementary school through high school. These analyses provide broad comparisons of types of reasoning and strategies that address conceptual shifts accompanying human development from the early years into the adolescent years.

The mathematics and science education communities tend to use different frameworks to address different grain sizes. Mathematics education researchers often favor closer accounts of learning and development from day to day, week to week, or perhaps from month to month. They are often interested in a small grain size analysis that entails describing and predicting instructional outcomes related to particular interventions or curricular sequences. Their interest is in the design and production of specific, localized classroom lessons or units of instruction to support the immediate decision-making processes of teachers, or to support professional development designers and the production of a specific curriculum. They often build LTs that make distinctions among the reasoning processes of students from one unit of instruction to another, perhaps from week to week, or month to month. In brief, researchers in mathematics education use closer grain sizes of analysis to ensure the validity of learning trajectories and the effectiveness of curriculum and instruction.

Science education researchers, on the other hand, are more interested in using wider grain sizes of analysis to identify typical developmental trends, i.e., LPs. They use the LPs as guiding frameworks to coordinate multiple components of education research (i.e., curriculum, instruction, assessment and professional development) in an iterative process. Sometimes, researchers begin their research with pre-designed curriculum. They conduct teaching experiments, in which teachers implement the curriculum and students take assessments before and after the teaching intervention. Then, the assessment data are used to revise and refine all research components, including the LP, curriculum, assessment, etc. This cycle is then repeated several times to enhance validity and effectiveness.

Sometimes, researchers begin their research without a good curriculum in place. In such situations, they first collect assessment data and use the data to develop "status quo" LPs, which reflect students' typical development under traditional teaching. The status quo LPs enable researchers to identify students' learning difficulties, upon which more effective curriculum and instruction can be developed. It is important to note that researchers in science education use an iterative process to enhance the validity of LPs and the effectiveness of the curriculum, instruction and professional development.

A Learning Trajectory on Linear Measurement from Mathematics Education Research

The following example illustrates the design focus of LTs in mathematics education. A research team consisting of researchers from three different universities collaborated on a longitudinal study of children's thinking about spatial measurement from Pre-Kindergarten through Grade 5 (See Table 1). As part of that project, Barrett, Sarama, Clements, Cullen, McCool, Rumsey and Klanderman (2012) conducted a study to evaluate and improve a LT for Linear Measurement in Grades 2 and 3. The study was longitudinal, using a teaching experiment methodology with a cohort of 8 children. We focused on producing prototypical narratives of children's ways of gaining conceptual and strategic competence. To do so, we used instructional task sequences in keeping with a LT that had been developed from prior research (Sarama and Clements 2009, 273-292). We used the LT to predict children's performance levels, to design appropriate instructional tasks and to design assessment tasks to fit successive levels of reasoning and strategy. We also anticipated revising the LT to improve the specific accounts of children's mental actions on objects that constitute the core of the LT. These accounts are hypothetical cognitive sketches of the children's schemes and relevant concepts for length measurement.

Table 1: Research Team Information to Describe **Students' Understanding of Length Measurement**

Expertise on Team	Mathematics education
Number of researchers (primary and secondary)	Conducting Teaching Experiment • Primary 2 graduate students, 1 researcher Learning Trajectory (LT) revision and elaboration • Primary: 2 graduate students, 1 professor • Secondary: 3 professors, 1 graduate student
Number of Subjects	• 8 subjects • ~6 sessions for each child participating in the study • (~50 video-taped sessions across the study)
Time this took	• ~1.5 years (designing and conducting the teaching experiment) • ~1 year (analysis and reporting)
Funding for Project	~$1.6 M over four years (this part was only a portion of the project)
References/ Website associated with project	• Barrett, Sarama, Clements, Cullen, McCool, Rumsey & Klanderman (2012); • Sarama, Clements, Barrett, Van Dine, & McDonel, (2011).

We considered the following four questions as essential foci for the study: (1) Are the tasks that relate to each level of the LT consistent with each other? (2) Are successive levels incorporating prior levels completely? (3) Is the order of the levels invariant? And (4) Are the aspects of each level coherent? These questions are based on two separate reviews of the theory of children's development of mathematical reasoning (Hart 1981; Steffe and Cobb 1988). We address these questions in our analysis of the teaching episode data collected through the teaching experiment as it began during Grade 2 and progressed into Grade 3.

Table 2: Length Measurement Learning Trajectory, Adapted from Sarama & Clements (2009)

Developmental Progression (level name)	Mental Actions on Objects: (Conceptual Structures and Strategies)	Instructional Tasks
Age 5: **Indirect Length Comparer (ILC):** Compares the length of two objects by representing them with a third object. May assign a length by guessing or moving along a length while counting without equal length units. May use ruler, but often lacks understanding or skill.	A mental image of a particular length can be built, maintained, and (to a simple degree) manipulated. With the immediate perceptual support of some of the objects, such images can be compared. A counting scheme operates on an intuitive unit of space or of movement.	To shift toward End-to-End: children should talk about numbers for lengths that they can compare indirectly. Use physical or drawn units along objects to compare. Focus on long thin units and help them count to make comparisons. Accentuate the linear aspect of any object, and use thin, long objects as units that can be accumulated.
Age 6: **End-to-End Length Measurer (EE):** Lays units end-to-end. May not recognize the need for equal-length units. The ability to apply resulting measures to comparison situations develops later in this level. Needs a complete set of units to span a length.	An implicit concept that lengths can be composed as repetitions of shorter lengths underlies a scheme of laying lengths end to end. This initially only applied to small numbers of units. The scheme improves by attending more explicitly to covering distance or composing a length with parts.	Have the child create a ruler and mark it with ticks and numerals to match units (in or cm). Ask students to guess objects by telling them a length, with only one unit to model it. Use measuring software that snaps to whole number values of units to report length.
Age 7: **Length Unit Relater and Repeater (URR):** Measures by repeated use of a unit (initially may be imprecise). Relates size and number of units explicitly, but may use units of varying lengths. Can add lengths to obtain the length of a whole. Iterates a single unit to measure. Uses rulers with minimal guidance.	Action schemes include the ability to iterate a mental unit along a perceptually-available object. The image of each placement can be maintained while the physical unit is moved to the next iterative position. With the support of a perceptual context, scheme can predict that fewer larger units will be required to measure an object's length. These action schemes allow counting-all addition schemes to help measure.	Pretend to gap or overlap units as they are repeated to challenge consistent measures. Have students draw objects beginning from a zero point and discuss the end-to-end measures coordination with intervals and numbers along rulers. Measure in different-sized units for the same object and describe the inverse variation to the length of units. Ask students to guess objects by telling them a length, with only one unit to model it.
Age 8: **Consistent Length Measurer (CLM):** Considers the length of a bent path as the sum of its parts (not the distance between the endpoints). Measures, knowing need for identical units, relationship between different units, partitions of unit, zero point on rulers, and accumulation of distance. Begins to coordinate units and subunits.	The length scheme has additional hierarchical components, including the ability simultaneously to image and conceive of an object's length as a total extent and a composition of units. This scheme adds constraints for equal-length units and, with rulers, on use of a zero point. Units themselves can be partitioned to increase precision.	Use a physical unit and a ruler to measure line segments and objects that require both an iteration and subdivision of the unit. Build sub-units to fourths and eighths. Discuss how to deal with leftover space, to count it as a whole unit or as part of a unit.
Age 9: **Conceptual Ruler measurer (CR):** Possesses an "internal" measurement tool. Mentally moves along an object, segmenting it, and counting the segments. Operates arithmetically on measures ("connected lengths"). Estimates with accuracy.	Interiorization of the length scheme allows mental partitioning of a length into a given number of equal-length parts or the mental estimation of length by projecting an imaged until onto present or imagined objects.	In "Missing Measures," students have to figure out the measures of figures using measures for a subset of sides. Prompt students to make explicit strategies for estimating lengths, including developing benchmarks for units and composite units.

Table 2 displays the initial LT for Length Measurement that undergirded our investigation. This was developed by Sarama and Clements (2009) through a review of prior research and their own studies. Notice that each row of the table shows first a name for the level and a brief list of observable actions or behaviors at that level (first column), then a hypothesized account of mental actions on objects (second column), and finally, the instructional tasks thought to promote growth out of this level (third column).

We investigated the validity and the fit of the learning trajectory by conducting a teaching experiment to follow children and support their growth through the levels over several years. Next, we discuss the findings of our study from the first year and a half of that teaching experiment data. We adapted the teaching experiment methodology (Cobb and Gravemeijer 2008; Steffe and Thompson 2000) in the following ways:

- Teaching episodes in which two researchers posed questions and followed up each child's response to elaborate on her/his thinking (videotaped for further analysis);
- Each question/response pairing during a teaching episode was categorized by level;
- The case study children were grouped by level for each session;
- Subsequent episodes addressed each group or individual level, targeting student performance with tasks to match recent levels;
- Subsequent teaching episodes were carried out to check predictions.
- We summarized our findings, and modified our collection of tasks for presentation to a group of background students (Eight children other than the case study children).

Figure 1a: Tasks for Length Instruction Related to Learning Trajectory, Early Levels

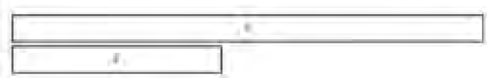
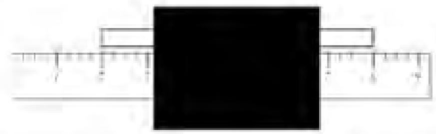
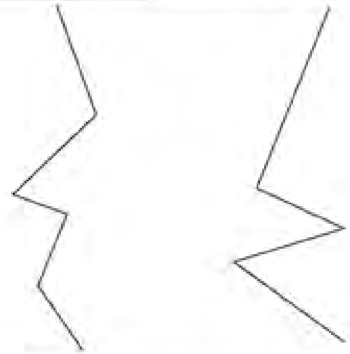
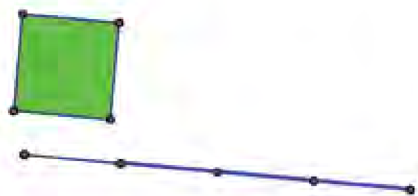
Task	Purpose	Description	Image
a. Yellow-Strip Tool	To determine if the student was capable of displaying EE level thinking and to help the student identify units of length.	The student was given one-inch yellow-strips and asked to measure longer strips that were cut to whole number lengths. Next, use a taped strip of one-inch strips to measure.	
b. Compare table and door width	To motivate URR strategies and precise measure by providing a real measurement task without a procedure. Judge whether the student was at least an EE measurer.	The interviewer measured in a way that was obviously wrong because of the gaps and overlaps to see how the student would react to the measuring. Then the student was given the chance to offer a technique for measuring more accurately.	
c. Broken Ruler	To determine if the student is beyond the EE level and can correctly identify the units of length from the tool or can re-zero the object.	The student is given a ruler with the ends broken off. In some instances the student was not allowed to slide the ruler along the object to re-align it.	
d. Wooden Rods	To determine if the student has the arithmetic ability to answer the broken ruler tasks.	Using twelve different unmarked and unlabeled wooden rods one rod was set below another and the student was asked which rod would be added to shorter rod to match the length of the longer rod.	

Figure 1b: Tasks for Length Instruction Related to Learning Trajectory Levels

e. Partially covered ruler	To determine if students can coordinate arithmetic and measurement when units are not visually available. This ability occurs after URR level.	A ribbon covered some of the standard ruler that was needed for the student to measure a strip that did not start at the zero point.	
f. Bent-Path Analysis	To determine if the student understood bent paths and if they differentiated between distance traveled and displacement. We were also interested in observing how the students dealt with accumulation of length around turns.	The student was shown two different paths and asked to predict which was longer. Then the student compared the paths using a standard ruler to see which was actually longer.	
g. Perimeter Wrap	To observe how the students dealt with the coordination of units and super units in a context that they have not experienced previously.	The student was shown that a four-inch pipe cleaner was the same length as the length around one square inch, then asked to compare the length of the pipe cleaner to the path around the set of tiles.	
h. Decreasing Lengths	To help a student who is counting tick marks when measuring that this technique will result in assigning a length of one inch to something that has essentially no length. This task relies on the importance of zero and one to force a student to develop a consistent understanding of measurement	The student is asked to draw or measure a set of objects with decreasing lengths starting with three inches down to one inch.	

This process allowed us to modify and improve our tasks based on reflection and discussion that emerged as our research team summarized observations across teaching episodes. Our analysis addressed three themes identified through our ongoing and post hoc review of the teaching experiment work: (1) the concept of unit based in comparisons of continuous linear space, (2) the integration of schemes for cardinal counting, ordinal counting, partitioning distances, subdividing lengths, and motion broken by hash marks, and (3) the coherence and consistency of the LT for length measurement.

Our findings can be summarized as follows. We developed eight tasks, lettered tasks a through h (see Figure 1a and Figure 1b). We used these tasks to prompt growth from the level named Indirect Length Comparer (ILC) to the level named Conceptual Ruler Measurer (CR). During the study, the children moved from level End-to-End Length Measurer (EE) up through Length Unit Relater and Repeater (LURR) and into level Consistent Length Measurer (CLM) (see Barrett, et al. 2012, 37 for details). The outcome of the sessions using these tasks provided data that was used to improve the hypotheses in column two and the instructional tasks in column 3 of the length LT (see Table 3).

Table 3: Length Measurement Learning Trajectory, Improved (Barrett, et al., 2012)

Developmental Progression	Conceptual Structures and Strategies	*Instructional Tasks*
Age 6: **End-to-End** Length Measurer (**EE):** Lays units end-to-end. May not recognize the need for equal-length units. The ability to apply resulting measures to comparison situations develops later in this level. Needs a complete set of units to span a length. *[This level is concurrent with Serial Orderer to 6+.]*	An implicit concept that lengths can be composed as repetitions of shorter lengths underlies a scheme of laying lengths end to end. This initially only applied to small numbers of units. The scheme *is enhanced by the growing conception of length measuring as sweeping through large units coordinated with composing a length with parts (unit sticks). The scheme may be curtailed as sets of objects are internally presented as images that are symbolized by re-tracing the set using only one unit, or by mere pointing and sweeping in a coordinated set of actions (leading toward URR at the next level).* *An Ordering Scheme is organized in a hierarchy (initially implicit) for an ordered series of objects, eventually supporting a graduating sequence scheme.*	1. Provide incomplete sets of linear objects to span the length of an object to measure. *2. Use relatively large objects as units (and build a ruler with pen length units).* *3. Compare two objects that must be compared indirectly using only shorter objects.* *4. Provide the student with a contiguous set of yellow strips taped in a row to find length for comparisons.* 5. Draw a ruler and mark it with ticks and numerals to match units (in or cm).
Age 7: **Length Unit Relater and Repeater (URR)**: Measures by repeated use of a unit (initially may not *establish a zero point for reference*). Relates size and number of units explicitly, but may use units of varying lengths. Can add lengths to obtain the length of a whole. Iterates a single unit to measure. Uses rulers with minimal guidance. *May attribute quantity for units without explicitly finding a linear dimension.*	Action schemes include the ability to iterate a mental unit along a perceptually-available object. The image of each placement can be maintained while the physical unit is moved to the next iterative position *and counted. A partitioning scheme provides linkages from partial collections of iterated unit images to the entire collection. If these action schemes integrate unit spaces, tick-marks along a tool and cardinal number labels at tick-marks, then the integrated scheme set engenders* counting-all addition schemes to help measure. Cardinal values are clearly connected to space units for small quantities: 0, 1, 2 or 3 units), but weaker beyond these. With the support of a perceptual context, scheme can predict that fewer larger units will be required to measure an object's length.	1. Given a drawing of a 5-unit segment, ask students to draw a 3-unit length line segment (Cannon, 1992), or a 7-unit segment. 2. Have students create units of units, such as a "footstrip" (Lubinski, 1996). 3. Repeat measures using several different-sized units and then relate the units. 4. Broken ruler task. 5. Ribbon covered ruler section. 6. Compare wire around tile perimeter with tile edge as units. 7. Ask students to draw and measure decreasing sequences of segments, using only one unit object or using a ruler.

In summary, we used the tasks shown in Figure 1a and 1b to engage the participants in our study in length measurement activities that spanned the five levels of the LT. Based on our findings, we revised portions of the LT as indicated with italics in Table 3. For a complete account of our work with these students and our specific findings regarding each level that we addressed in the LT, refer to the complete report (Barrett et al. 2012).

In contrast to the approach often taken in mathematics education, the science education community often focuses more broadly on building assessments that can be used to evaluate the progress and status of groups of students at a range of grade levels, providing guidance to curriculum developers or the writers of specific evaluation tools. Thus, they often build LPs that make distinctions among the achievements of students from one year to the next year of instruction. The following example illustrates this larger grain size and keeps a focus that is broadly relevant to many years of schooling, from grades 3 to 8.

Using a Status Quo LP to Develop Effective Curriculum

This section describes how science education researchers use a wider grain size and an iterative process to develop LPs. In particular, it focuses on situations where researchers begin the development of LP without a good curriculum in place. In such situations, researchers first collect assessment data in contexts where status quo teaching is delivered. Therefore, the LPs developed based on the assessment data reflect status quo learning; they do not describe productive development that we hope to have students experience. However, these kinds of LPs do have significant implications for curriculum development and teaching. In this section, we discuss this issue.

First, we discuss ideas from cognitive sciences, which provide a foundation for understanding the development and usefulness of the status quo LPs. Students enter schools with prior knowledge and informal ways of reasoning. What will happen when they learn science in school? Piaget differentiates two processes of learning: assimilation and accommodation (Piaget 1971; Posner, Strike, Hewson, and Gertzog 1982). We expect students to accommodate scientific ideas—to form a framework of scientific knowledge through restructuring their existing knowledge. However, what usually happens in class is that students assimilate the concepts and principles into their existing knowledge structure; in this learning process, the meanings of the scientific concepts and principles are modified to fit informal reasoning frameworks.

This is the reason why students generate a variety of alternative ideas in school science learning. A status quo LP provides important information about how students assimilate scientific concepts and principles, and therefore can be used for curriculum development. Here, we use an example in the Environmental Literacy Project to describe how to use a status quo LP to develop effective curriculum and instructional approaches (Jin, Zhan, and Anderson 2013; Jin and Wei 2014). The project information is provided in Table 4.

Table 4: Research Team Information for Using a Status Quo LP to Develop Effective Curriculum (belonging to a larger Environmental Literacy Project)

Expertise on Team	Science education, science, psychometrics
Number of researchers (primary and secondary)	• Primary (science education focus): 1 Primary Investigator (science education), 2 post-docs, and 5 graduate students • Secondary (psychometrics focus): 1 Primary Investigator, 2 graduate students.
Number of Subjects	• 12 focus teachers from 4th grade to 12th grade; other teachers participated the research during different times of the project. • 48 clinical interviews • ~4,000 written tests
Time this took	5 years
Funding for Project	$3.5 Million (from National Science Foundation)
References/ Website associated with project	• http://envlit.educ.msu.edu/ • Jin, H., & Anderson, C. W. (2012a) • Jin, H., Zhan, L., & Anderson, C. W. (2013)

In the project, we first implemented assessments with students; teaching intervention was NOT involved. We used the assessment data to develop a status quo LP that depicts a typical developmental trend in traditional science classrooms. This status quo LP enabled us to identify specific learning difficulties of students. We then developed curriculum and instructional approaches that target these LPs. This process is elaborated in the following paragraphs.

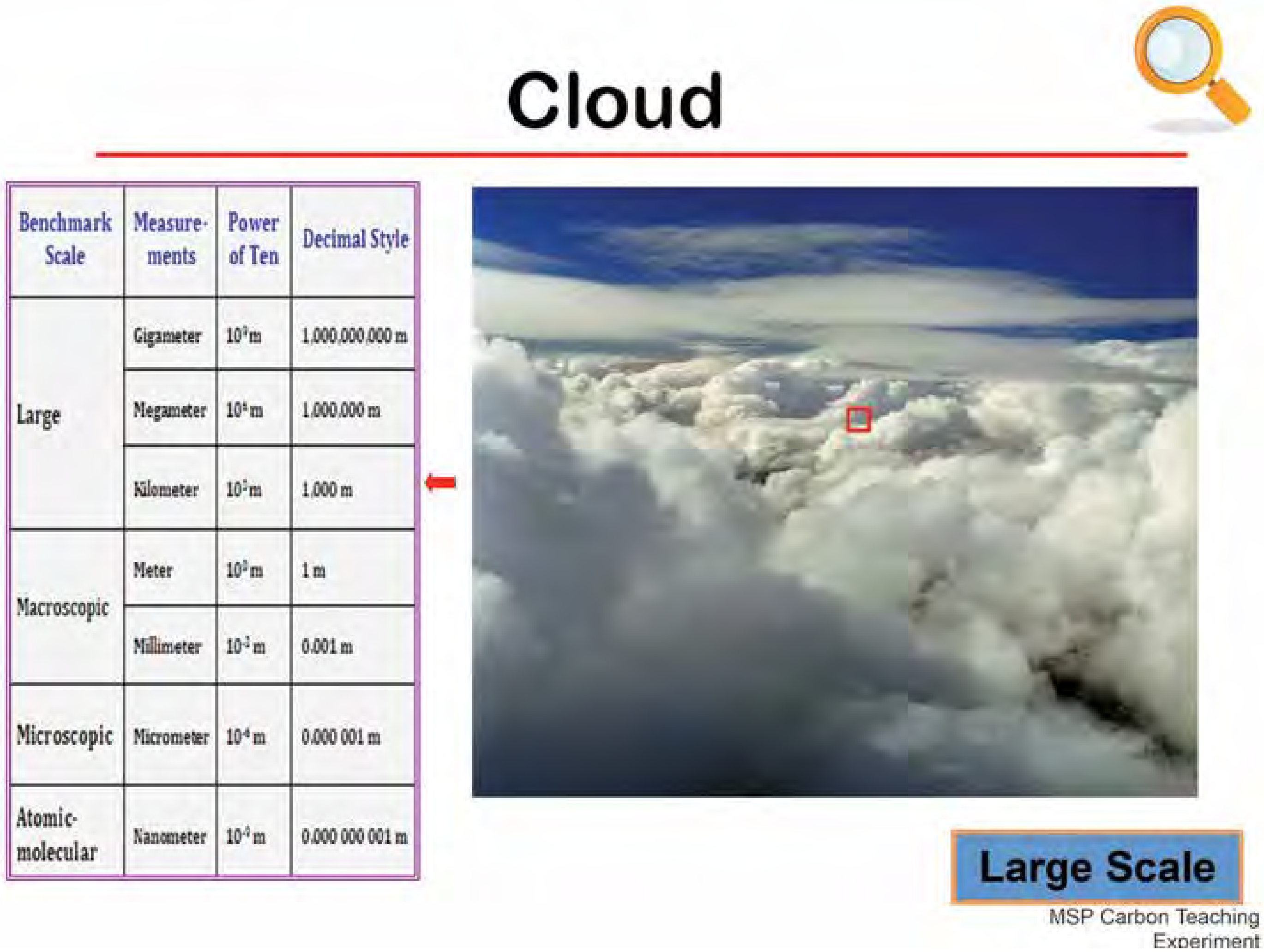
We collected clinical interview data and written assessment data from 12 science teachers' classrooms. Based on the data, we developed a LP that describes students' status quo development. In this LP, levels 1 and 2 are mostly about everyday intuitive ideas, and level 3 is the result of knowledge assimilation. To develop effective curriculum, we first compared the lower levels (levels 1, 2, and 3) with the upper anchor (level 4). The comparison is presented in Table 5. It helped us identify two specific learning difficulties that students encounter: 1) reasoning across scales—connecting macroscopic objects and materials with atoms and molecules; 2) tracing matter and tracing energy—matter transformation and energy transformation in chemical reactions. Our investigation into existing curriculum and teachers' classroom teaching also suggests that these learning difficulties were not addressed under traditional teaching.

Table 5: Comparing Lower Levels with the upper anchor of the LP

Levels of the LP	Scale	Matter, Energy
Level 4. Scientific matter and energy reasoning	Atomic-molecular scale	Tracing matter: atom rearrangement Tracing energy: energy transformation with heat dissipation
Level 3. Modified matter-energy reasoning	Atomic-molecular scale	Not consistently tracing matter or energy (e.g., matter-energy conversion; no heat dissipation.)
Level 2. Hidden mechanisms reasoning	Microscopic scale (i.e., invisible processes or mechanisms but are not about atoms or molecules)	Explaining macroscopic phenomena in terms of invisible hidden mechanisms or processes that do not involve matter or energy.
Level 1. Force-dynamic reasoning	Macroscopic scale	Providing force-dynamic accounts that describe how actors use enablers to grow or move.

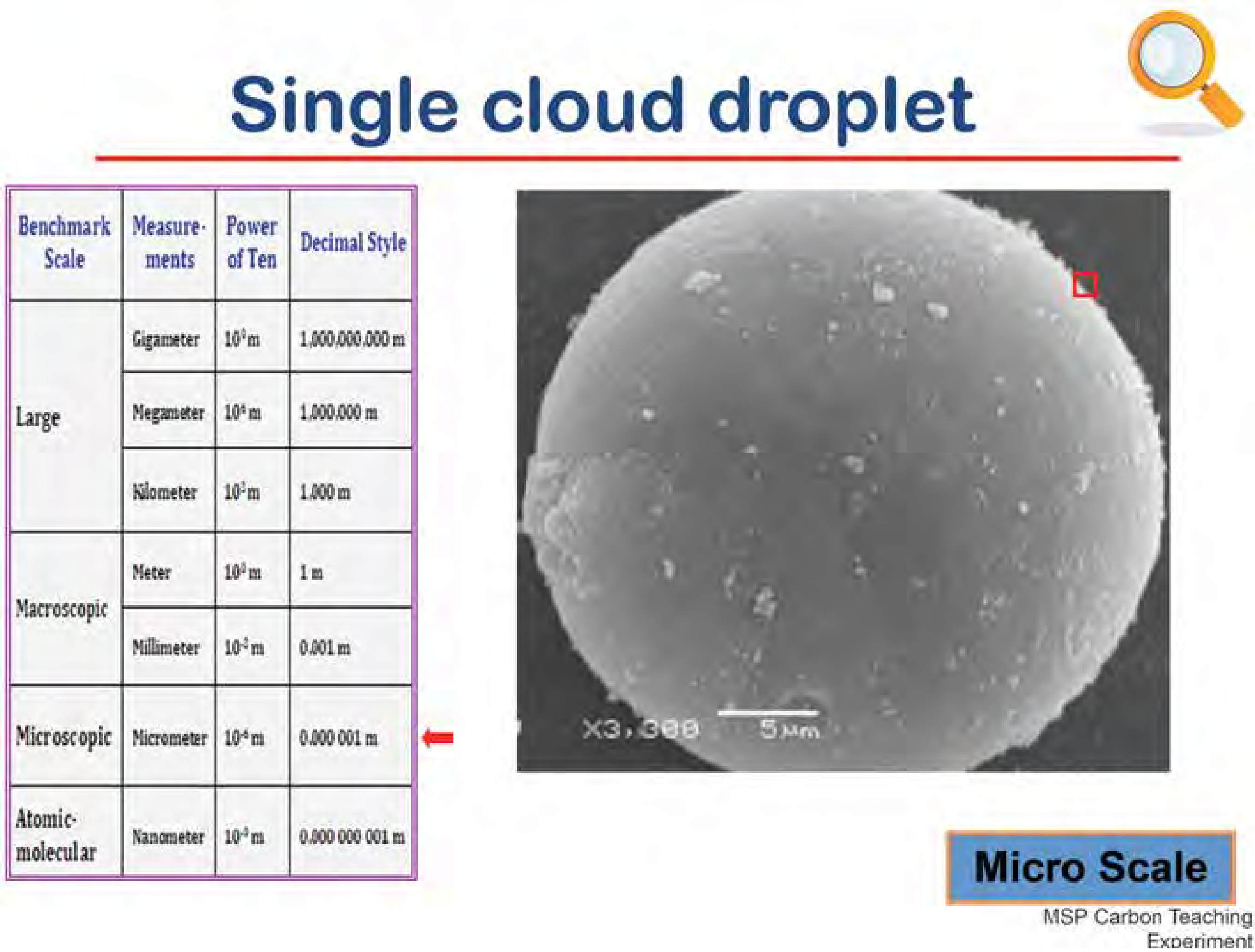
To help students overcome these difficulties, we developed two “tools of reasoning”. A Powers of Ten Tool was used to help students visualize the scientific way of connecting scales. It is a sequence of PowerPoint slides that guide students to zoom from macroscopic scale to atomic-molecular scale. When zooming in, students locate atoms of molecules in material objects (e.g., a tree, water, air, etc.). Here, we selected three slides from a PowerPoint that is used to guide students to explore the structure of water molecules through zooming into a cloud (Figures 2, 3 and 4). The red box on each slide shows the location for students to “zoom in”. The tables on the left show the scales of the observations.

Figure 2: The first slide of the Powers Of Ten Tool: Cloud



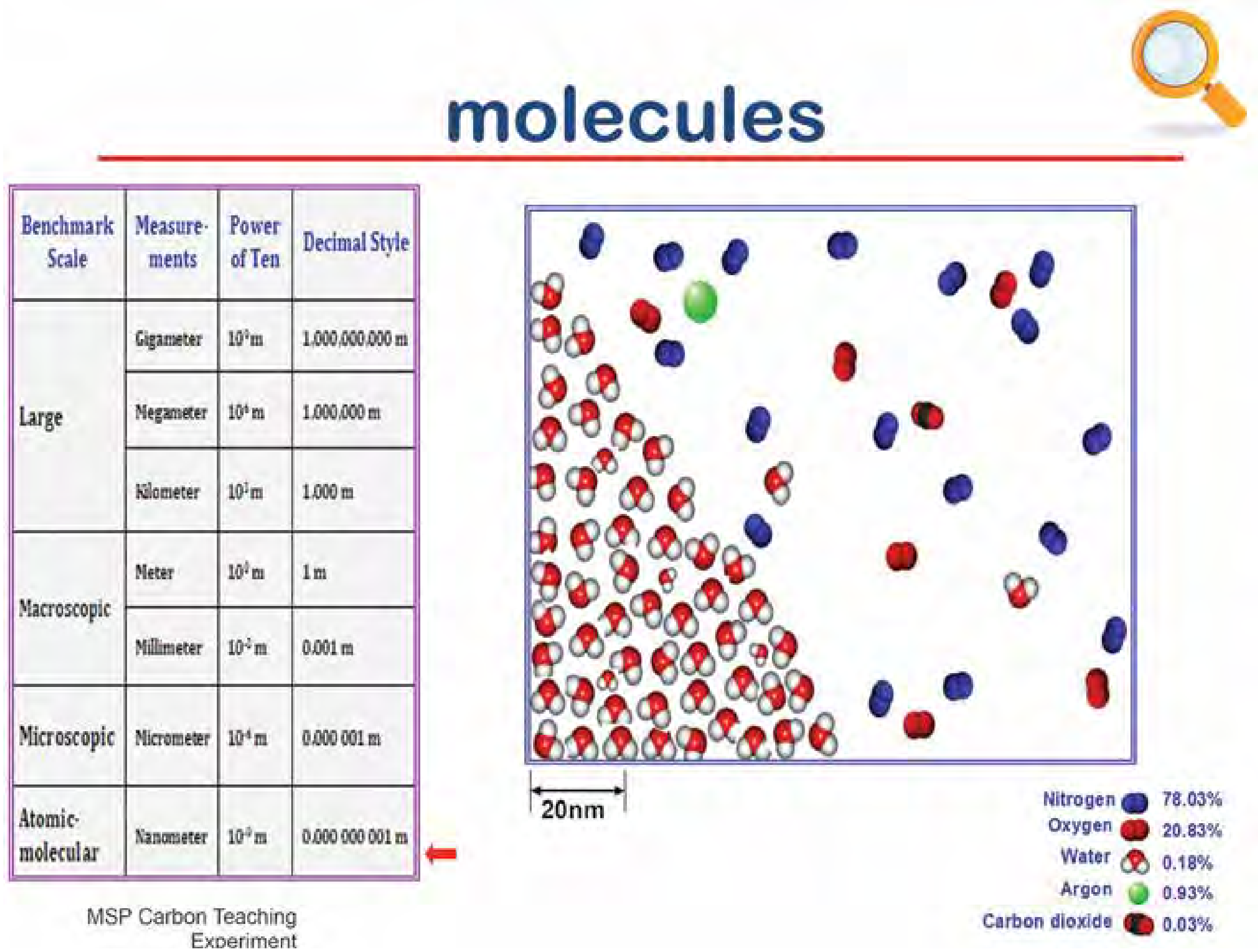
Benchmark Scale	Measure-ments	Power of Ten	Decimal Style
Large	Gigameter	10^9 m	1,000,000,000 m
	Megameter	10^6 m	1,000,000 m
	Kilometer	10^3 m	1,000 m
Macroscopic	Meter	10^0 m	1 m
	Millimeter	10^{-3} m	0.001 m
Microscopic	Micrometer	10^{-6} m	0.000 001 m
Atomic-molecular	Nanometer	10^{-9} m	0.000 000 001 m

Figure 3: The 7th slide of the Powers Of Ten Tool: A water droplet in the cloud



Benchmark Scale	Measurements	Power of Ten	Decimal Style
Large	Gigameter	10^9 m	1,000,000,000 m
	Megameter	10^6 m	1,000,000 m
	Kilometer	10^3 m	1,000 m
Macroscopic	Meter	10^0 m	1 m
	Millimeter	10^{-3} m	0.001 m
Microscopic	Micrometer	10^{-6} m	0.000 001 m
Atomic-molecular	Nanometer	10^{-9} m	0.000 000 001 m

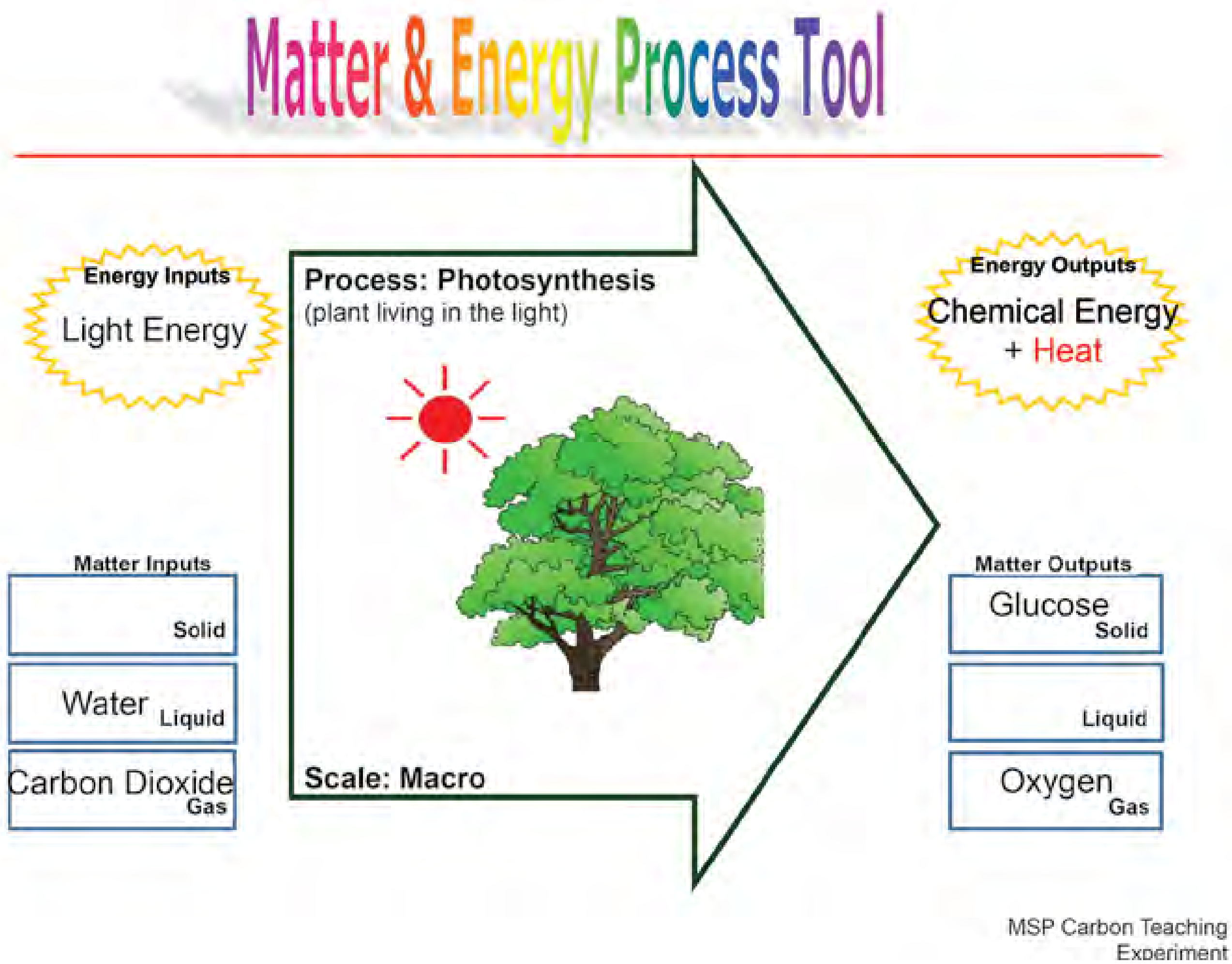
Figure 4: The fourth slide of the Powers Of Ten Tool: The edge of the water droplet



Benchmark Scale	Measure-ments	Power of Ten	Decimal Style
Large	Gigameter	10^{9} m	1,000,000,000 m
	Megameter	10^{6} m	1,000,000 m
	Kilometer	10^{3} m	1,000 m
Macroscopic	Meter	10^{0} m	1 m
	Millimeter	10^{-3} m	0.001 m
Microscopic	Micrometer	10^{-6} m	0.000 001 m
Atomic-molecular	Nanometer	10^{-9} m	0.000 000 001 m

We also designed a Matter and Energy Process Tool to help students learn the specialized ways of tracing matter and tracing energy. By using the tool, students will be able to visualize the scientific ways of tracing. For matter, atoms of reactant substances rearrange to form new products. For energy, input energy is transformed into output energy, and heat is released as a byproduct. An example of using the Matter and Energy Process Tool to understand photosynthesis is presented in Figure 5.

Figure 5: An example of using the Matter and Energy Process Tool



These levels of the learning progression have been useful in characterizing shifts in students' understanding and conceptual development from grade 4 to grade 12. This kind of learning progression serves the interests of curriculum designers and assessment writers.

Conclusion

This chapter has provided examples of a LP and LT, showing a range of grain sizes for the focus on learning and development of important concepts. In general, whether one uses a LP to characterize large-scale shifts in conceptual knowledge, or a LT to track and characterize smaller-scale changes in conceptual knowledge as one is engaged in particular instructional interventions, these research tools are intended to characterize the development of increasingly sophisticated knowledge and strategies in the disciplines of mathematics and science. They are also effective in enhancing the validity and/or effectiveness of the curriculum, instruction, assessment, and professional development. These characterizations of learning are benefitting our educational research communities by supporting the ongoing work of developing appropriate instruction, strong curricular resources, sensitive and reliable assessments for evaluation of student knowledge and learning strategies, and supports for teacher development efforts. Within the cycles of developing and implement instructional standards for each STEM discipline, one must support teachers, curriculum developers, teacher development leaders, and further research by establishing reliable, sensitive, yet conceptually-focused frameworks of children's growth in school. LPs and LTs provide a critical element in that research effort (cf., Smith, Wiser, Anderson, and Krajcik 2006).

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CHAPTER 5

Researching Progress and Sophistication in Geography Learning: Taking a Critical Stance

Michael Solem and David Lambert

The current movement to build capacity for researching learning progressions in geography is a response to the Road Map Geography Education Research Committee's (GERC) recommendation to emulate the methodologies of fields with more established research track records, namely math and science education (Bednarz, Heffron, andHuynh 2013). The committee's rationale was straightforward: the geography education community is presently small and largely unorganized, much of the literature consists of anecdotal and descriptive accounts of classroom practices, and there have been few attempts to replicate studies or pursue longitudinal research. As a consequence, research in geography education to date has played a minor role in shaping and improving practice in the nation's geography classrooms.

To improve upon this state of affairs, the Road Map GERC argued for a concerted agenda to implement systematic approaches to hypothesis testing, theory building, and the acquisition and use of evidence in decision making, drawing on the best practices and precedents for scientific educational research. Learning progressions and trajectories are examples of the sort of research-driven educational interventions that were embraced by the Road Map GERC (Huynh, Solem, and Bednarz, forthcoming). As the preceding chapters in this volume illustrate, learning progressions research carries intriguing potential for generating evidence that can help us interpret how students learn geography across and within grade bands, especially with regard to the disciplinary practices, core ideas, and cross-cutting concepts expressed in *Geography for Life: National Geography Standards* (Heffron and Downs 2012).

As the editors note in the preface, the three national geography standards in *Geography for Life* that relate to understanding "The World in Spatial Terms" (Essential Element 1) were chosen to initiate research activity on geography learning progressions. Given the shared presence of spatial concepts, patterns, processes and models across science, technology, engineering and mathematics (STEM) educational standards, such research might yield dividends for understanding learning in multiple disciplinary contexts. From a capacity building perspective, this appears to be a sound strategy. The GeoProgressions project that produced this research handbook attracted interest from a diverse group of math and science educational researchers (in addition to plenty of geographers). Over time, and assuming the research inspired by this project begins to validate learning progressions for maps, geospatial technology, and spatial thinking, the broader impacts of that research may well be appreciated and felt beyond the geography education community.

On the other hand, we acknowledge a note of caution about the significance of context, to which we will return later in this chapter. As Bennetts (2002, 2008) has pointed out, although there are good reasons why we may encourage all manner of cross-cutting skills in the school curriculum, a problem remains that "it opens the door to the belief that thinking abilities developed in the context of one field of study can be transferred easily to other fields" (Bennetts 2008, 115). His point is that there is rarely, if ever, a single principle for determining the sequence in which a specific knowledge or skill should be taught or acquired, as so much is dependent on context and use.

Thus, as in any research endeavor, pitfalls abound. Our objective in this concluding chapter does not concern threats to research quality that might arise from poor sampling techniques, or what constitutes authentic evidence of an intervention's educational effectiveness, or how researchers can better strategize to gain access to fourth graders for data collection, or any number of other issues of research planning and design. Instead, we wish to offer a critique of the purposes and assumptions inherent in doing learning progressions research in geography. We believe a critical stance is needed to avoid an undue restriction being placed, inadvertently or not, on how progress and sophistication in geography learning comes to be conceptualized and understood. We advocate for prudence and open dialogue aimed at critically assessing the broader impacts of learning progressions on the future geography curriculum, even though it will be many years before such learning progressions become available. Far from dissuading research on learning progressions, we hope to convince readers that adopting a critical perspective will only advance the quality and scope of the future work that is undertaken.

We begin our critique by reviewing some of the salient philosophical issues on learning that are raised by learning progressions. We next apply this critical perspective to how Essential Element 1 in *Geography for Life* defines goals for geography teaching and learning with maps, geospatial technology, and spatial thinking. Our critique considers debates about spatial intelligence that have arisen in the literature on spatial cognition, but we also draw upon other theoretical frameworks of geographic thought to encourage readers to reflect critically on the assumptions underpinning their future work, and how this form of research might implicate geography teaching and learning, as well as the very process of making the curriculum.

What constitutes "progress" and "sophistication" in learning?

With characteristic understatement, Trevor Bennetts, a former senior Her Majesty's Inspector (HMI) for geography in England, writes that, "The proposition that curricula should be designed to support progress in learning is one of the most widely accepted tenets of educational thinking. However, there is somewhat less agreement about what constitutes progression and how best to bring it about" (Bennetts 2008, 112). In his doctoral research on progression in geography, Bennetts (2005) focused mainly on the meaning of progression in *understanding*, and in particular geographical understanding, which of course brings us immediately to some challenging matters. Although we can readily agree that we want to promote in students a progressively more sophisticated geographical understanding, we first have to confront questions as to what this really means - and how we can tell when we have achieved it. Space does not allow a full discussion of his findings here, but it is pertinent to note three observations that emerged from Bennetts' work.

The first is that progress in geographical understanding (or any specialist or disciplinary mode of thought) is highly complex. As a result, and especially for research purposes, there may be a temptation to disaggregate it into components or elements of learning — as indeed we have done in this *Handbook* in concentrating primarily on The World in Spatial Terms: we need to be clear that this first Essential Element of *Geography for Life* is *not* synonymous with geography. Linked to this is another "reductive" tendency that often tempts the researcher, which is to provide "solutions" in the form of models or techniques: we should be wary of neat answers. Understanding according to Bennetts is influenced by *experiences*, the introduction and development of *ideas* and the application of *mental processes* that come together in myriad different ways, even within a single classroom. Thus, progress is unlikely to be linear, or to follow a predictable incline (or series of steps), and may even appear to regress from time to time.

This brings us to a second observation, which is that much research on progression understandably focuses on the *learner*. This is fine, but the application of any intelligence that arises from such research is of course in the hands of the *teacher*. Obvious though this may appear, what Bennetts is keen to point to is the important distinction between "sequence" and "progression". Progression has become a key idea in planning curricula, and it is often manifested in how curriculum content and activities are sequenced. However, in his words, "while a sequence of some sort is inevitable within any curriculum, progression in learning is not an inevitable outcome" (Bennetts 2008, 113). This is true, he implies, even when the sequence is the 'correct' one.

The third observation that we derive from this work has to do with timing. In the U.S., England, and elsewhere, teachers are currently under routine pressure to ensure that students show 'progress' in every lesson they are taught. This is taking the powerful idea of learning progressions to a potentially absurd place. Although progression can be applied to different timescales, Bennetts points out that the idea becomes especially pertinent when applied to longer periods during which time understanding can be consolidated, and a variety of evidence can be brought into play on which to judge progress. We should be wary of short-term tick-box approaches to monitoring progress against sharply defined objectives, not least because of the clear risk that geographical understanding becomes so diminished as an idea or goal that it actually inhibits or narrows progression - and depresses the expectations we may have of our students.

The issues we have raised in citing Bennetts' work have also been voiced by others in the context of science education. In a critical analysis of science learning progressions published in the mid-to-late 2000s, Tiffany-Rose Sikorski and David Hammer point out significant issues in how sophistication and progress have been conceptualized by researchers. With regard to assessing sophistication, Sikorski and Hammer (2010) note that learning progressions researchers tend to consider ideas to be more sophisticated when they align with "end-state canonical knowledge." In their view, it is a mistake to equate sophistication with correctness, for several reasons:

> Unlike basic ideas of arithmetic, which have been stable for millennia, basic ideas within science have gone through dramatic change. Concepts of life, matter, and energy that are foundational today were relatively recent constructions … Moreover, it has happened often in science that the formation of a wrong idea has been generative for later progress. (Sikorski and Hammer 2010, 280)

Instead of focusing primarily on students' attainment of "correct" answers with regard to scientific concepts, Sikorski and Hammer advocate for researchers to adopt a view of sophistication that places heavier emphasis on qualitative changes in students' capacity to *think scientifically*. This is because students, and even experts, can think in impressively complex ways, but may not arrive at accurate conclusions due to bad data or false assumptions. Yet over time, adhering to a systematic scientific method of thought with regard to evidence and reasoning should eventually generate explanations that are in line with contemporary canonical knowledge.

Sikorski and Hammer also question the conventional view of progression in learning as being developmental across a sequence of levels, from a lower anchor to an upper anchor. One aspect of their critique centers on the common assumption that levels represent "static" periods of knowledge:

> In this [conventional] view, a student who gives a Level 2 response on a Newton's third law question, for example, should give similar responses on all Newton's third law questions. Alonzo and Steedle (2009), however, found that students do not respond consistently across problem contexts. That is, students can appear to be on two different levels simultaneously. Alonzo and Steedle attribute some of the inconsistency to ambiguities in the language of assessment items. However, the authors also acknowledge that students' reasoning may be context sensitive, and so it may not be possible to "produce a single, reliable diagnosis of a student's level on a learning progression. (Sikorski and Hammer, 2010, 282)

Another noteworthy element of Sikorski and Hammer's critique concerns an emerging view of science learning as being "context-sensitive" and subject to influence by the physical and social environment. If this is so, it is difficult to envision a common set of levels of understanding that apply across diverse groups of learners:

> Evidence that student knowledge is generally not well characterized as level-like at any point in time, clearly, raises questions regarding learning progressions composed of a succession of qualitatively different levels of knowledge or understanding … That structural view is at odds with evidence of contextual sensitivity in student reasoning. (Sikorski and Hammer 2010, 282).

This critique from geography education in the UK and U.S. science education appears to offer serious pause for thought, lest we place too much faith in learning progressions (see also Empson, 2011). Important and productive though research in this field may be, we need to aware of its limits. In relation to the bold claims made by Sztajn et al (2012) for example, that "learning trajectory based instruction" may offer us a theory of teaching, we should be cautious. It is in this light that we next probe into the ways the U.S. national geography standards define progress and sophistication in terms of understanding the world in spatial terms.

Assessing sophistication and progression in geography learning

Geography for Life's Essential Element 1 begins with the standard, *How to use maps and other geographic representations, geospatial technologies, and spatial thinking to understand and communicate information.* The standard organizes knowledge and performance statements under three themes: Properties and Functions of Geographic Representations, Using Geospatial Data to Construct Geographic Representations, and Using Geographic Representations.

Progression in the theme of Properties and Functions of Geographic Representations begins with the goal of students being able by the 4th grade to distinguish among different types of geographic representations: maps, globes, graphs, remotely sensed images, and so forth (Heffron and Downs 2012, 21). The standard further sets the expectation that by the 8th grade students should be able to identify the most appropriate geographic representation to use for a specific purpose, based on an understanding of the geographic representation's properties. By the 12th grade, the standard expects that students should be able to explain the value of using multiple geographic representations for answering geographic questions.

The second theme of geography standard 1 outlines a developmental sequence of knowing and being able to use geospatial data to create maps and other forms of geographic representations. At the 4th grade benchmark, students should be able to explain the basic characteristics of spatial data in relation to actual locations on the Earth's surface. This ability anticipates students becoming capable of more advanced knowledge and performance tasks such as acquiring and organizing geospatial data from different sources and formats to create maps, visualizations, and other representations. And finally, by the 12th grade, students should have the know-how to evaluate the technical properties and quality issues of geospatial data, including being able to evaluate datasets from different sources and the use of metadata for organizing and maintaining datasets.

Students progress in their knowledge and performance of using geographic representations from the starting point of being able to interpret the information that is conveyed on a map (e.g., a legend, a data classification scheme, the meaning of cartographic symbols, etc.). From there, the standards expect 8th graders to know how to use geographic representations for conducting a geographic inquiry (asking and answering geographic questions). By the 12th grade, students should progress in their ability to communicate through spatial visualizations the outcomes of a geographic inquiry using maps, GIS, and other geographic representations.

Through a progressive set of knowledge and performance expectations for spatial thinking, geography standard 1 is designed to promote spatial intelligence and problem-solving abilities that are seen to offer value for lifelong learning (Heffron and Downs 2012, 21):

> Knowing how to identify, access, evaluate, and use appropriate geographic representations will ensure college and career readiness for students. Students will have an array of powerful problem-solving and decision-making skills for use in both their educational pursuits and their adult years.

The second geography standard composing Essential Element 1 reads, *How to use mental maps to organize information about people, places, and environments in a spatial context.* Standard two uses three themes to organize knowledge and performance statements about internal cognitive representations of geographic space: Developing Mental Maps, Using Mental Maps, and Individual Perceptions Shape Mental Maps.

The standard portrays a developmental progression in the sophistication of children's and adolescents' mental maps, how they can be applied for problem-solving, and their capacity to interpret the subjective meanings in the mental maps created by others. By the 4th grade, students are expected to know that mental maps develop in relation to physical and human features in the landscape. This awareness grows to include maps drawn from memory that depict spatial patterns by the 8th grade, and on toward mental maps of spatial relationships by the 12th grade.

Applications of mental maps follow a similar trajectory. Students at the 4th grade should be able to use mental maps to answer geographic questions about locations and characteristics of places and regions. Eighth graders are expected to use mental maps to answer questions about spatial patterns, and then reach the ability to address questions about spatial relationships by constructing maps from memory. The standard then concludes with indicators of what students should know and be able to do with regard to how individual perceptions and experiences shape the qualities of mental maps, and how changing perceptions can alter one's mental maps of people, places, regions, and environments.

The third geography standard of Essential Element 1 is, *How to analyze the spatial organization of people, places, and environments on Earth's surface*. This standard focuses on three themes at the heart of spatial analysis: Spatial Concepts, Spatial Patterns and Processes and Spatial Models. Each of these themes is portrayed as a developmental building block to higher-order spatial thinking ability.

First, spatial concepts provide students with the necessary vernacular for describing and analyzing spatial organization (Heffron and Downs 2012, 31):

> Spatial concepts provide a language for describing the arrangement of people, places, and environments … in terms of proximity, distance, scale, clustering, distribution, etc.

Geography standard 3 outlines a progression from the ability of students to describe and explain geographical space using fundamental concepts by the 4th grade (i.e., using terms of location, distance, direction, scale, movement, region, volume) and in increasingly complex and abstract terms by the 8th grade (i.e., using the concepts of accessibility, dispersion, density, interdependence). By the 12th grade, the standard considers students should be able to use advanced spatial concepts (e.g., connectivity, networks, hierarchies) for the spatial analysis of human and physical phenomena.

Once a student can speak the spatial language for describing arrangements, it follows developmentally that (Heffron and Downs 2012, 31):

> … they can begin to explore why the patterns and relationships among phenomena exist as they do, that is, what processes produce the patterns.

Using the knowledge gained from their spatial interpretations, students should be able to construct spatial models of the physical and human processes that are responsible for producing observable patterns. The complexity of the spatial models a student is capable of creating is also seen as following a developmental sequence, from working with models having highly tangible physical properties to those built solely with mental constructs (Heffron and Downs 2012, 31):

> Models can be organized along a continuum from concrete reality (a globe or diorama) to higher degrees of abstraction and generalization (models of urban structures, spatial interactions, and physical processes).

The progression in spatial thinking outlined in the preceding paragraphs is strongly connected to a body of research that principally draws on Piaget's theories of cognitive development. In a review of this literature, Mohan and Mohan (2013, 8) note that "Piaget proposed a progression of spatial concepts, beginning with topological concepts between the ages of two to seven, followed by the emergence of projective and Euclidian concepts after the age of seven." Researchers who have applied Piagetian frameworks argue that children's mapping abilities require instructional support for them to progress in their abilities to think and reason with spatial concepts and use geographic representations.

The Piagetian view of how spatial thinking abilities develop is not universally shared. Mohan and Mohan's review points to a competing literature that suggests pre-schoolers are capable of understanding very basic projective and Euclidean principles and concepts.

There is clearly an opportunity here for learning progressions research to interrogate and build upon this prior knowledge. As Mohan and Mohan (2013, 13) note, the existing literature is too limited to offer conclusions about the nature of spatial thinking and learning with maps:

> The most notable limitation we found in reviewing the research is the lack of systematic, long-term research across many grades looking at specific spatial thinking concepts or skills (such as the work done on learning progressions). Most studies have focused exclusively on very young children (e.g., only infants, toddlers, or early childhood children) or on one grade level (e.g., 3rd graders), which limits what we can say about the longitudinal development of spatial thinking from pre-K through Grade 12.

We would advocate for learning progressions researchers to delve directly into the debates and not assume that the grade benchmarks for Essential Element 1 are definitive. This will require being open to exploring a variety of possibilities of what students are capable of knowing and doing conceptually, a point of crucial importance to teachers devising formative assessment processes (see sidebar below).

Formative Assessment

Reduced to its essence, formative assessment is an integral aspect of effective teaching: it is the (usually) dialogic process through which the teacher *gets to know* the students - their experiences and capacities, what they find difficult, enjoyable, motivating, supportive. In turn, the students get to know what the teacher is driving at: the expectations for learning; what it means to learn (and make progress in) geography; what they are being asked to do and why.

Put this way it is perhaps perfectly clear that in formative assessment we simply do not need "levels" of attainment that purport to *measure* progress. Research is overwhelmingly supportive of this (Black and Wiliam, 1998). As soon as grades, percentages, and especially *levels* are introduced to assessment, these are all the students see - at the expense of any oral or written feedback. This is partly the result of the very natural desire to know how one is doing in relation to others (where are you are on the pecking order), whereas what we really want is for the students to focus on how well they have grasped the material being taught and to understand that in relation to themselves and their previous work (the latter is what we call "ipsative" assessment).

Formative assessment therefore is based on rich and varied classroom interactions — and lots of student "productions" — oral presentations and varied forms of writing and drawing resulting from decision making exercises, investigations and so on. The professional judgment of the teacher is guided by *criteria* that relate directly to the material being taught — and dialogic assessment processes aim to make sure the students grasp this, using techniques such as peer assessment of work, or the provision of precise subject focused feedback.

However, it is almost inevitable that when assessing students' work teachers will use a system that includes grades. So be it, but it is best to keep these simple and focused on the content — rather than the level the student has reached on some notion of a ladder of progress. The question requiring the teacher's professional judgment is:

Has this student grasped what I was intending to teach?

Perhaps the most straightforward marking system therefore is a three-grade system: where B= yes; A= very well; and C = not yet. Even if teachers use a traditional "marks out of 10" format they will almost certainly be using the same system: where, for example, 6-7 = yes; 8-9 = very well; and 4-5 = not yet. Using such a system is criteria related (the teacher needs to identify the criteria in relation to the *particular content* being taught). This is easy to understand by students, parents and other teachers and, crucially, does not involve shoe-horning children into levels which are essentially generic (they do not relate to the particular content).

We need to think carefully, therefore, about how the challenging idea of progression relates to a meaningful formative assessment framework as outlined above.

Progression is a very important idea because it expresses a fundamental belief that underpins teachers' work: we want students to benefit from our work with them — we want them to make progress. However, it is hazardous to believe that we can or even should be over concerned with "measuring" this — at least, it is if we try to do this at too frequent intervals or against a national standard.

Learning progressions and curriculum making in geography

Research into learning progressions in geography is rightly a priority. One of the themes that emerged in our reflections on existing and possible future research, whether on specific aspects of geography or on a more holistic notion of geographical understanding (or thinking geographically), is that of curriculum applications. Creating a progression "map" or template for geography, even if this were possible, would achieve little in itself. That is to say, the outcome of this research is not in itself a solution to the "problem" of how to improve geography education. The purpose of undertaking research in learning progressions is not so much to "fix" the teaching; it is more to inform the curriculum development processes on at least two distinct levels.

First, there is the level of "curriculum design," which could include textbook authors who need to offer a coherent sequence and progressive sense to the materials they devise (see Clements 2007). And secondly, there is the classroom level of "curriculum making" (see Lambert and Biddulph 2014) at which published materials are used with particular groups of learners, in specific contexts and settings.

As we have seen in the discussion already, several questions arise:

- How do we ensure that effective sequencing results in progression in learning?
- How do we maintain a healthy open-endedness to teaching and learning geography, one that allows for individual differences and avoids becoming too "programmed"?
- What is the role of formative assessment in ensuring progression, and what forms of assessment should be employed in order to minimize the "tyranny of the metric": the trap into which we can fall if progress is judged only by those skills and competencies that can be readily measured.
- How is the integrity of geography preserved if the tyranny of the metric cannot be resisted entirely?

One risk in focusing on the three national standards that make up *Geography for Life's* Essential Element 1 is that this is the aspect of geography that becomes prioritized and privileged. There is heavy emphasis being placed on geospatial technologies in education systems all over the world, particularly those in which geography has been perceived to be under threat. Articles such as Roger Downs' recent (2014) discussion of "generation M" fuel this sense that school geography's future is bound up with grasping the "geospatial revolution." While we do not doubt the significance of digital technologies on our everyday lives, and those born as digital natives in particular, from the point of view of the geography curriculum what is striking in Downs' article is the narrowness of his exposition of geographic knowledge, which according to him:

> … comes in three forms: declarative (factual knowledge such as what is where); procedural (knowing how to do something such as using GPS to reach a destination); and metacognitive (self-reflective knowledge of one's capacities such as understanding how to solve different types of route problems successfully). (Downs 2014, 48)

It is salutary to juxtapose what we might imagine a learning progression framework would look like in relation to this taxonomy, compared with some more closely aligned to a vision of geography's broader disciplinary purposes. For example, we could return again to Trevor Bennetts' attempt to understand progression in geographical understanding. From his research he concluded that the most significant dimensions of progression in geographical understanding are:

- Distance from experience, in the sense of the gap between what is required to be understood and what students have experienced or have knowledge of;
- Complexity — whether of experience, information, ideas or cognitive tasks;
- Abstraction — particularly of ideas about processes, relationships and values, but also forms of presentation;
- Precision, in the sense of being more exact, and knowing when that is appropriate and useful;
- Making connections and developing structures - ranging from applying simple ideas to experience and making simple links between ideas, to the use of sophisticated conceptual models and theories;
- The breadth of context in which explanations are placed, especially spatial contexts, but also temporal and other contexts;
- The association of understanding with cognitive abilities and skills; and
- The association of understanding with affective elements, such as attitudes and values, and the value-laden nature of particular ideas.

In his paper Bennetts (2008) illustrates these "dimensions" through a worked example of "weather and climate." But even so, we can see this list of principles is far from being a learning progression map or template. In some ways this is, of course, a weakness: but it is also a strength. It is a strength if we think that the enactment of learning progressions happens not through the implementation of a form of technical "fix" but through the professional process of curriculum making. The implications for sustained professional development are perhaps clear.

Arguably, the area for sustained effort in professional development, particularly if a more holistic approach to learning progressions is adopted, is the local interpretation of standards. This may take the form of teachers sharing, comparing and debating students' work — and agreeing (or even agreeing to disagree) on different stages of a progression sequence. The aim would not be to produce a definitive list or progression map, but to practice and clarify the application of a range of criteria in different contexts and settings. The overall question will always be: how do children (bearing in mind the diversity that is present in any cohort) show their progress in geographical understanding?

The knotty problem, without doubt, is the initial identification of such criteria: that is, the creation of an initial framework to get things going (see Daugherty 1996). In England, where geography is a strong school subject (and on the national curriculum) from the age of 5 through to 14 years old, the system has struggled with this for 25 years, ever since a national curriculum was established. Detailed "statements of attainment" have been tried; looser "level descriptions" have been tried, despite eloquent objections even at the time (see Davis 1995). All have floundered — in effect, failing to withstand the pressure to produce the definitive progression map alongside measureable, top-down and universally agreed criteria. Such a detailed progression map for geography is an illusive professional mirage if, as is the case in England, the assumed purpose is to underpin valid and reliable assessment at a national level. This does not reduce for one second the importance of the concept of progression and the potential benefit of describing learning progressions in geography; it crucially asks us to be clear about who should use this information and for what purpose.

This takes us back to the significance of curriculum making. Locally, teachers should be able to show how they are translating a curriculum sequence into students achieving a progressive geographical understanding. They will need frameworks of support to do this — such as for example "benchmark statements," being trialed by the Geographical Association (GA) in England currently[1]. It is envisaged that locally, schools will express progression criteria of their own, relevant to their particular curriculum content choices, contexts and settings, but within the national "benchmarks." [2] (See Appendix C).

Concluding remarks

Learning progressions have attracted considerable and broad interest in the educational research community, and for good reason. The approach is intellectually compelling, it challenges us to consider complex relationships between teaching and learning at the dynamic interface of disciplinary change, and if done "right" it may lead to significant advancements in educational practice and policy. Given the seemingly insurmountable structural challenges facing geography in U.S. education, we should embrace learning progressions as one of many possible routes toward broad-scale improvements in the field.

Yet we cannot let our enthusiasm, curiosity, and thirst for progress make us vulnerable to boosterism with regard to learning progressions, or for that matter *any* approach to researching any aspect of education. Taking a critical stance is a professional responsibility and the healthy skepticism it provides will compel us to ask questions about theoretical assumptions, research evidence, and practical goals that must be asked on a continuing basis. The existing critiques of learning progressions are most welcome and have helped to advance

1 An Appendix (B) has been provided in the form of a vignette to illustrate the thinking behind the GA's "benchmarks," which at the time of writing are still under review. This is in effect a case study of a national system attempting to establish standards and the means to measure progressive levels of attainment. It has been a struggle and the story is presented as a "cautionary tale." Its inclusion is not to suggest we should be against attempts to describe learning progressions in geography. The cautionary note is entirely to do with how such intelligence is used, and for what purposes and by whom.

2 Thanks to Jeff Barrett who has pointed out that what we say here about geography in England is similar to his understanding of mathematics in Japan: "The mathematics is stated in a terse yet specific national curriculum (K-12), and then elaborated with professional expertise at local levels by teachers who engage constantly in "lesson study." Lesson study means that teachers are consistently invited to relate their theoretical accounts of how to guide children and teach them, with empirical observations of children responding and learning in real classrooms where the ideal lessons are trialed. This allows for constant evaluation and also for constant innovation. The mixture is important."

this still nascent field of research. They warrant continual reflection and refinement moving forward.

In all likelihood, we will never through our research on learning progressions reach "certainty" as to how students acquire spatial and geographic understanding and comprehension. More realistically, the work we undertake will produce various kinds of evidence and analyses that then can be shared, interrogated, and critiqued. Through that process, we just may be able to offer recommendations for improving teaching practices in schools that go well beyond mere assertions, yet which must never be considered as being settled.

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APPENDIX A

Essential Element 1: The World in Spatial Terms from *National Geography Standards, Second Edition*

Essential Element: 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

Image credit: NOAA/Will von Dauster

Data visualization using Science On a Sphere® at the NOAA Earth System Research Lab, Boulder, CO.

Image credit: Joseph J. Kerski

Using a Global Positioning System (GPS) device, students can identify specific locations (georeference) where data are collected using latitude and longitude coordinates.

The geographically informed person must use maps and other geographic representations, geospatial technologies, and spatial thinking to acquire, understand, and communicate information. Knowing how to identify, access, evaluate, and use appropriate geographic representations will ensure college and career readiness for students. Students will have an array of powerful problem-solving and decision-making skills for use in both their educational pursuits and their adult years.

Therefore, Standard 1 contains these themes: Properties and Functions of Geographic Representations, Using Geospatial Data to Construct Geographic Representations, and Using Geographic Representations.

Thinking about the world in spatial terms (spatial thinking) allows students to describe and analyze the spatial patterns and organization of people, places, and environments on Earth. Spatial thinking skills are essential in processing geospatial data. Geospatial data link physical and human attributes of points or places on Earth's surface (such as roads, other built features, and rivers) and can be compiled, organized, stored, manipulated, and represented in many ways. Maps are graphic representations of selected aspects of Earth's surface and are still a key geographic mode of representation. Globes, graphs, diagrams, and aerial and satellite images (remote sensing) also allow us to visualize spatial patterns on Earth. No single representation, however, can show everything, and the features depicted on each representation are selected to fit a particular purpose.

Geospatial technologies such as geographic information systems (GIS), remote sensing (RS), and global positioning systems (GPS), as well as Internet-based mapping sites such as digital globes and geospatial visualizations, allow us to analyze and represent geospatial data in powerful ways.

At all grade levels, students need practice and experiences in how to collect and display information (data) on maps, graphs, and diagrams. They must understand what a map is and what it can—and cannot—do. They need to be able to read and interpret maps and other geographic representations. And finally, students must know how to make maps, from hand-drawn sketch maps to more complex representations using a range of appropriate technologies.

By learning to think spatially, students can understand such basic concepts as scale, alternative map projections that show Earth from different perspectives, and the relationships between spatial processes and spatial patterns. By understanding these themes, students will be equipped with tools that provide important problem-solving and decision-making skills in geography and across the entire K–12 curriculum.

Essential Element: 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

4th GRADE

the student knows and understands:

Properties and Functions of Geographic Representations

1. Properties and functions of geographic representations—such as maps, globes, graphs, diagrams, aerial and other photographs, remotely sensed images, and geographic visualizations

Therefore, the student is able to:

A. Identify and describe the properties (position and orientation, symbols, scale, perspective, coordinate systems) and functions of geographic representations, as exemplified by being able to

- Identify and describe the properties of a variety of maps and globes (e.g., title, legend, cardinal and intermediate directions, scale, symbols, grid, principal parallels, meridians) and purposes (wayfinding, reference, thematic).
- Identify and describe the functions of a variety of geographic representations.
- Identify and describe the properties and functions of maps students collect from magazines, news articles, and tourist brochures.

B. Describe how properties of geographic representations determine the purposes they can be used for, as exemplified by being able to

- Identify the maps or types of maps most appropriate for specific purposes, (e.g., to locate physical and/or human features, to determine the shortest route from one town to another town, to compare the number of people living at two or more locations).
- Describe how a variety of geographic representations (maps, globes, graphs, diagrams, aerial and other photographs, GPS) are used to communicate different types of information.
- Describe how maps are created for a specific purpose (e.g., school fire-drill map, the route from home to school, classroom map of learning center materials).

8th GRADE

the student knows and understands:

Properties and Functions of Geographic Representations

1. The advantages and disadvantages of using different geographic representations—such as maps, globes, graphs, diagrams, aerial and other photographs, remotely sensed images, and geographic visualizations for analyzing spatial distributions and patterns

Therefore, the student is able to:

A. Analyze and explain the properties (position and orientation, projections, symbols, scale, perspective, coordinate systems) and functions of geographic representations, as exemplified by being able to

- Analyze geographic representations based on their properties (e.g., orientation, grid system, scale, resolution, and content) and purposes (e.g., using GIS and digital globes to explore geographic information and relationships at a range of scales).
- Analyze the properties of three geographic representations of the same place (such as a street map, a topographic map, and a satellite image) and explain how each might be suitable for a different purpose.
- Explain how different geographic representations are used in a variety of settings (e.g., a GIS in a computer lab, topographic map for backcountry hiking, GPS navigation for car travel).

B. Evaluate the appropriate use of geospatial representations for specific geographic tasks, such as analyzing spatial distributions and patterns, as exemplified by being able to

- Explain why particular maps are appropriate for a specific purpose (e.g., a cartogram to illustrate total population, a remotely sensed image to observe land-use change, topographic maps to consider the best location for a wind farm, a highway map to consider best routes for new transportation corridors).
- Identify and evaluate specific maps and/or geospatial technologies for use in different occupations (e.g., ambulance driver, airline pilot, ship's captain, cross-country truck driver, business analyst).
- Compare the patterns shown by geographic representations at different scales (e.g., neighborhood, city, state, country).

12th GRADE

the student knows and understands:

Properties and Functions of Geographic Representations

1. The advantages of coordinating multiple geographic representations—such as maps, globes, graphs, diagrams, aerial and other photographs, remotely sensed images, and geographic visualizations to answer geographic questions

Therefore, the student is able to:

A. Explain the advantages of using multiple geographic representations to answer geographic questions, as exemplified by being able to

- Explain how multiple geographic representations and geospatial technologies (e.g., GIS, GPS, RS, and geographic visualization) could be used to solve geographic problems (e.g., help determine where to locate a new playground, or identify dangerous street intersections within a community).
- Describe how an analysis of urbanization can be done using different geospatial technologies (e.g., RS for land use, GIS data layers to predict areas of high/low growth, GPS and GIS for identifying transportation issues regarding growth).
- Explain how multiple geospatial technologies can be used to solve land-use problems (e.g., effects of new farming technologies on the sustainable production of food, preservation of wetlands in bird migration flyways).

Essential Element: 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

4th GRADE

the student knows and understands:

Using Geospatial Data to Construct Geographic Representations

2. Geospatial data are connected to locations on Earth's surface

Therefore, the student is able to:

A. Identify examples of geospatial data, as exemplified by being able to

- Identify landmarks on the school grounds and describe their size, shape, and location.
- Identify the spatial location of each student's assigned seat in the classroom.
- Identify the locations and types of trees in the neighborhood of the school.

B. Construct maps and graphs to display geospatial data, as exemplified by being able to

- Construct a map that displays geospatial data using symbols explained in a key (e.g., a sketch map to illustrate a narrative story, a map of cars in the school parking lot showing type and color, a classroom map showing different types of tables, desks, and chairs).
- Describe the results of a survey of classmates about a geographic question concerning their school (e.g., where to add another swing set, where to add a cover over existing playground equipment, where to place more drinking fountains) using graphs and maps.
- Construct a map of the United States using symbols to show quantities by state (e.g., population, professional sports teams, mountain peaks over a certain elevation).

8th GRADE

the student knows and understands:

Using Geospatial Data to Construct Geographic Representations

2. The acquisition and organization of geospatial data to construct geographic representations

Therefore, the student is able to:

A. Identify the variety of geospatial data sources (e.g., student-generated data such as surveys, observations, and fieldwork or data sources such as US Census data, US Geological Survey (USGS), and the United Nations) and formats (e.g., digital databases, text, tables, images), as exemplified by being able to

- Identify examples of different sources of geospatial data related to population, land forms, road networks, weather, etc. (e.g., Census Bureau, [USGS], Environmental Protection Agency).
- Identify the different data formats that can be used to organize data sets for population, land forms, road networks, weather, etc. (e.g., tables, graphs, maps, remotely sensed images).
- Identify the data to include in student-generated geospatial data sets to capture human or physical characteristics of the school neighborhood (e.g., count and map the location, amount, and directions of pedestrian traffic on streets near the school).

B. Construct maps using data acquired from a variety of sources and in various formats (e.g., digital databases, text, tables, images), as exemplified by being able to

- Construct paper maps to illustrate the links between geographic patterns (e.g., examine associations among geographic phenomena such as water resources and population distribution or topography and Civil War troop movements).
- Construct different types of maps to illustrate the distribution of population (e.g., cartograms, choropleth maps, isopleth maps, graduated circles maps).
- Construct flow maps to explain the amount, source, and direction of movement (e.g., international petroleum trade, migration of refugees, flyways of bird migration, immigration to North America during the 1800s).

12th GRADE

the student knows and understands:

Using Geospatial Data to Construct Geographic Representations

2. The technical properties and quality of geospatial data

Therefore, the student is able to:

A. Identify and explain the metadata properties (e.g., resolution, date of creation, and method of collection) of geospatial data, as exemplified by being able to

- Explain how the metadata information is used to understand differences in the creation and design of datasets (e.g., land use/land cover, street/storefront property uses, terrain features, scale) and to determine the usefulness of the data for mapping.
- Analyze the relationship between the quality of data and the source of the data (e.g., differences in reported population data by countries, boundaries as reported by different adjacent countries).
- Describe how metadata assist in determining appropriateness of the data set in relation to use or layering with other data sets.

B. Evaluate the quality and quantity of geospatial data appropriate for a given purpose, as exemplified by being able to

- Describe the many purposes for which a data set would be appropriate (e.g., 1:1,000,000 scale maps, 30-meter pixel satellite images, tables of state health data).
- Explain how data that are appropriate for a task at one scale may be inappropriate for a similar task at a different scale (e.g., census blocks and tracks for local data, county/parish for state or national data).
- Analyze a variety of data sets that present variations in space and time (e.g., Arctic ice in January and July, population counts for metro areas at different time periods, location and number of influenza infections by month).

Essential Element: 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

4th GRADE

the student knows and understands:

Using Geospatial Data to Construct Geographic Representations

3. Geospatial technologies—Internet-based mapping applications, GIS, GPS, geovisualization, and remote sensing—display geospatial data

Therefore, the student is able to:

A. Compare how different geospatial technologies are used to display geospatial data, as exemplified by being able to

- Identify and describe the types of information communicated by different Internet-based mapping technologies.
- Describe and analyze the similarities and differences among the results from different online navigation systems.
- Compare the similarities and differences of information presented in online road maps, satellite images, or street-view data.

8th GRADE

the student knows and understands:

Using Geospatial Data to Construct Geographic Representations

3. Geospatial technologies—Internet-based mapping applications, GIS, GPS, geovisualization, and remote sensing—can be used to construct geographic representations using geospatial data

Therefore, the student is able to:

A. Construct and analyze geographic representations using data acquired from a variety of sources (e.g., student-generated data such as surveys, observations, fieldwork, etc., or existing data files) and formats (e.g., digital databases, text, tables, images), as exemplified by being able to

- Analyze environmental change by annotating a series of remotely sensed images of the same location taken at different dates.
- Construct map overlays of GPS-based geospatial data using GIS (e.g., types of housing, local historical structures, neighborhood bus stops).
- Construct a map displaying the results of a community survey on a local issue (e.g., locating a new park or school, stream flooding, zoning decisions).

12th GRADE

the student knows and understands:

Using Geospatial Data to Construct Geographic Representations

3. The appropriate and ethical uses of geospatial data and geospatial technologies in constructing geographic representations

Therefore, the student is able to:

A. Evaluate the appropriate and ethical uses of different geospatial technologies and methods for acquiring, producing, and displaying geospatial data, as exemplified by being able to

- Evaluate the appropriateness of using geospatial data that may identify particular individuals (e.g., use of cellular phone geolocation data, license plates and faces in street-view data).
- Describe and evaluate the conditions under which geospatial data should be restricted (e.g., availability of infrastructure data on web-sites, sensitive areas not displayed on satellite imagery, confidentiality of individuals when displaying health data).
- Describe and explain the appropriate documentation needed to assess the credibility of a GIS-based project (e.g., quality of data files used, processes used, steps to duplicate the project).

Essential Element: 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

4th GRADE
the student knows and understands:

Using Geographic Representations

4. The interpretation of geographic representations

Therefore, the student is able to:

A. Describe and analyze the ways in which geographic representations communicate geospatial information, as exemplified by being able to

- Describe the purpose and components of a typical map key or legend.
- Describe and analyze the similarities and differences in information displayed at different scales.
- Analyze the different ways of symbolizing geospatial data (e.g., graduated circles, cartograms, choropleth versus isopleth maps).

8th GRADE
the student knows and understands:

Using Geographic Representations

4. The use of geographic representations to ask and answer geographic questions

Therefore, the student is able to:

A. Analyze geographic representations to ask and answer questions about spatial distributions and patterns, as exemplified by being able to

- Analyze printed and digital maps to observe spatial distributions and patterns to generate and answer geographic questions (e.g., use digital census data to determine demographic patterns in a state, or analyze census data and transportation routes to identify and locate services, such as a day-care center or stores needed in a region).
- Analyze choropleth maps to examine spatial relationships (e.g., between the number of doctors and mortality rates, between corn production and hog production, between global energy production and consumption).
- Analyze the overlap among multiple geospatial data layers to identify potential locations of interest (e.g., site for a new park, route for a new road, location of high incidences of crimes).

12th GRADE
the student knows and understands:

Using Geographic Representations

4. The uses of geographic representations and geospatial technologies to investigate and analyze geographic questions and to communicate geographic answers

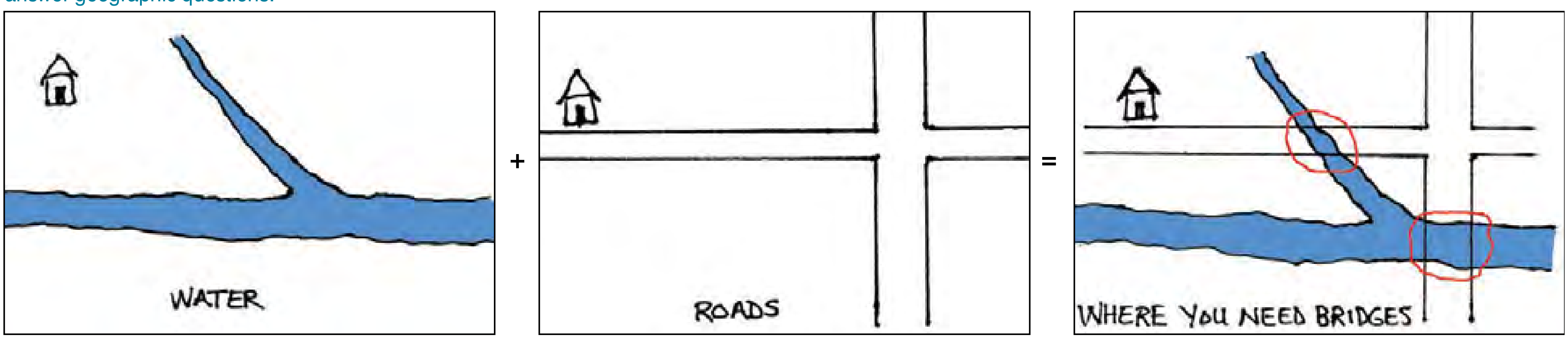
Therefore, the student is able to:

A. Analyze geographic representations and suggest solutions to geographic questions at local to global scales using geographic representations and geospatial technologies, as exemplified by being able to

- Construct a presentation using multiple geographic representations and geospatial tools that illustrates alternative views of a current or potential local issue.
- Construct maps using Web-based mapping of national forest areas showing terrain, vegetation, roads, hiking trails, campsites, and picnic sites to identify possible new areas of public use, trails and roads, and areas to close for habitat recovery.
- Analyze the possible relationships between global human and physical changes using GIS (e.g., the relationship between global climate change, sea level rise, and population distribution).

Where are bridges needed?

Students can use the basic GIS concept of overlay to answer geographic questions.



Basic GIS Step 1: Sketch the first data layer, in this case water, and the location of a house that will serve as a reference point for all data layers.

Basic GIS Step 2: Sketch the second data layer, in this case roads, and include the location of the house as the reference point.

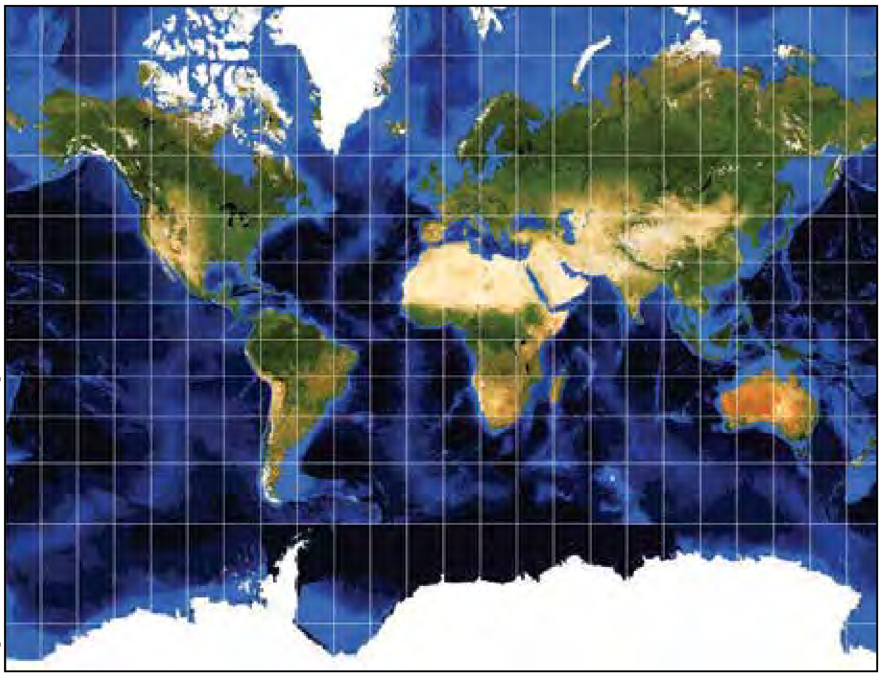
Basic GIS Step 3: Ask students to overlay the second data layer over the first using the house as the reference point and identify relationships between the two data layers, in this case where you need bridges for roads to cross the water.

Essential Element: 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

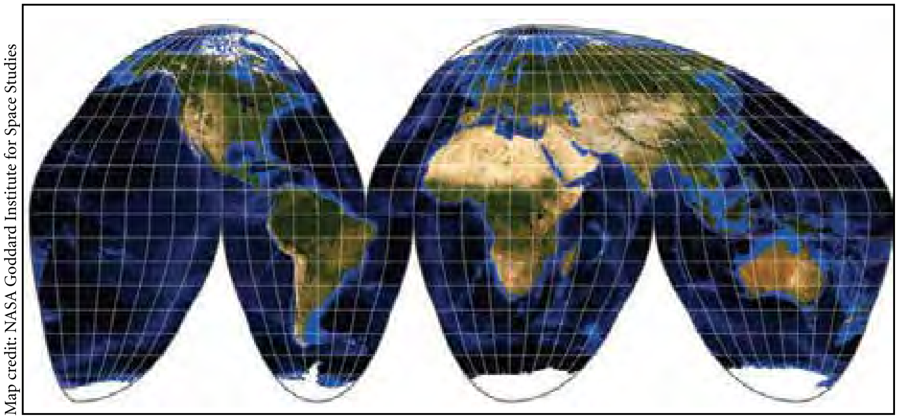
Projecting the round Earth onto flat paper presents problems for geographers because it always introduces some degree of distortion in at least one of the following four spatial properties: shape, area, distance, and direction. The Mercator Projection presents true shape (except at the poles) and true direction, but wildly distorts relative areas of land masses. Compare the shape of Greenland and South America, for instance, on the Mercator Projection and a globe. The Goode Homolosine Projection was developed as an antidote for the widespread use of the Mercator Projection in the early twentieth century. It maintains true relative areas and tries to minimize distortion in the other three spatial properties by using "interruptions," or cuts, through the oceans. It is called an equal-area projection. The Winkel Tripel Projection is a compromise because it tries to mediate between maintaining true shape and equal-area relationships, both of which still have some slight distortion.

Map credit: NASA Goddard Institute for Space Studies



Mercator Projection.

Map credit: NASA Goddard Institute for Space Studies



Goode Homolosine Projection.

Map credit: NASA Goddard Institute for Space Studies

Winkel Tripel Projection.

Essential Element: The World in Spatial Terms

GEOGRAPHY STANDARD 2: How to use mental maps to organize information about people, places, and environments in a spatial context

Image credit: iStockphoto.com

A spatial understanding of the environments people live in assists with making sense of the world.

Image credit: iStockphoto.com

Aboriginal Dreaming stories are sometimes told with sand drawings that contain symbols reflecting the locations of campsites and scarce water sources used by generations of people in desert regions of Australia.

The geographically informed person must mentally organize spatial information about people, places, and environments and must be able to call upon and use this information in appropriate contexts. Knowing the locations and characteristics of people, places, and environments is a necessary precursor to—and outcome of—geographic learning and thinking. An effective way of doing this is to develop and use what is called a mental map: an individual's internalized representation of aspects of Earth's surface. These maps in the mind are what a person knows about the locations and characteristics of places at a variety of scales, from the local (the layout of a person's bedroom) to the global (the distribution of oceans and continents across Earth). Mental maps are a mix of objective knowledge and subjective perceptions: precise knowledge about the location of geographic features as well as impressions of places, rough estimates of size and location, and a general sense of the connections between places.

Therefore, Standard 2 contains these themes: Developing Mental Maps, Using Mental Maps, and Individual Perceptions Shape Mental Maps.

Mental maps provide people with essential means of making sense of the world and of storing and recalling information about the patterns of Earth's physical and human features. These maps represent ever-changing summaries of spatial knowledge and are indicators of how well people know the spatial characteristics of places. We develop and refine our mental maps through learning from teachers and the media and through personal experience, moving from simple to more complex levels of completeness and accuracy, continuing to add layers of information so that our mental maps reflect a growing understanding of a changing world. As people read, hear, observe, and think more about the world around them, they add more detail and structure to their mental maps and accumulate layers of information that can be used in problem solving and decision making. Students must understand the role that perception plays in the creation and development of their understandings of the world.

Students must build their mental maps to develop detailed understandings of peoples, places, and environments. By understanding these themes, students can build and apply the mental maps that are the foundations for learning geography and other subjects.

Essential Element: The World in Spatial Terms

GEOGRAPHY STANDARD 2: How to use mental maps to organize information about people, places, and environments in a spatial context

4th GRADE
the student knows and understands:

Developing Mental Maps

1. The locations and characteristics of physical and human features are the basis for mental maps at local to global scales

Therefore, the student is able to:

A. Identify from memory the position and arrangement of physical and human features, as exemplified by being able to

- Identify from memory the locations of physical and human features (landmarks) in the classroom or school setting.
- Identify from memory the locations of physical or human features of interest to the student on their routes between home and school.
- Identify from memory on a sketch map the locations of the setting from a favorite book or movie.

2. Mental maps can change with direct experience (such as travel) and indirect experience (such as media exposure and looking at other maps)

Therefore, the student is able to:

A. Identify from memory with increasing detail maps of a place or region, as exemplified by being able to

- Identify details in a student's mental map of a route used frequently (e.g., to and from the grocery store, to and from a park, to and from a relative's home) over a period of time with an emphasis of adding details to the map.
- Identify from memory on a sketch map the locations of major community landmarks or boundaries.
- Identify from memory on a sketch map the locations of state physical features and the political boundaries of the student's home state before and after studying a state map.

8th GRADE
the student knows and understands:

Developing Mental Maps

1. The locations, characteristics, and patterns of physical and human features are the basis for mental maps at local to global scales

Therefore, the student is able to:

A. Identify from memory and describe locations, patterns, and characteristics of physical and human features, as exemplified by being able to

- Identify from memory and describe the locations of state political boundaries and major physical features.
- Identify from memory the locations of major land acquisitions to the United States following the settlement of the original 13 colonies, which resulted in the current political boundaries.
- Identify from memory and describe the major climate and vegetation regions of the United States.

2. Mental maps can change and become more accurate with direct experience (such as travel) and indirect experience (such as media exposure and looking at other maps)

Therefore, the student is able to:

A. Identify from memory with increasing detail and accuracy mental maps of a place or region, as exemplified by being able to

- Identify from memory the locations of major cities in the student's state with accuracy in both the scale and locations.
- Identify from memory the locations and boundaries of all adjacent states and major cities in those states.
- Identify from memory the locations of major transportation routes in the state.

12th GRADE
the student knows and understands:

Developing Mental Maps

1. The locations, characteristics, patterns, and relationships of physical and human systems are the basis for mental maps at local to global scales

Therefore, the student is able to:

A. Identify from memory and explain the locations, characteristics, patterns, and relationships among human and physical systems, as exemplified by being able to

- Identify the pattern of human settlement in the world from memory and explain the common physical characteristics where the majority of settlements occur.
- Identify the locations from memory and explain the connections between major transportation networks and population centers.
- Identify the locations from memory of historical world civilizations and explain how cultural markers or examples still remain from the past (e.g., Roman place names in Europe, structures or architectural styles, spread of English language through the British empire).

2. Mental maps can change through experience and iterative self-reflection

Therefore, the student is able to:

A. Explain the development of completeness and accuracy in the student's mental map of places and regions, as exemplified by being able to

- Explain how a new experience or encounter in an unfamiliar location resulted in added details or accuracy of the student's mental map of that place.
- Explain how the study of maps for game playing added details and accuracy to the student's mental map of a place or region.
- Explain how using a GPS or Web-based mapping application can aid in the development of a more complete and accurate mental map of places and regions.

Essential Element: The World in Spatial Terms

GEOGRAPHY STANDARD 2: How to use mental maps to organize information about people, places, and environments in a spatial context

4th GRADE

the student knows and understands:

Using Mental Maps

3. Mental maps are used to answer geographic questions about locations and characteristics of places and regions

Therefore, the student is able to:

A. Identify from memory locations and geographic characteristics to answer geographic questions, as exemplified by being able to

- Identify from memory the location and geographic characteristics of the most significant intersection near the student's home or school to answer geographic questions (e.g., What types of buildings are located at an important intersection near your home or school? What are the major landmarks used to help someone locate your home or school?).
- Identify from memory the locations of landmarks in the school building and on the school grounds to answer geographic questions (e.g., Where is the closest fire exit to the classroom? What is the shortest route to the nurse's office? Where is the most popular playground equipment located?).
- Identify from memory the map of North America to answer geographic questions (e.g., What are the countries to the north and south of the United States? Which state is located at the easternmost point of the United States? Which state is at the geographic center of the continental United States?).

Individual Perceptions Shape Mental Maps

4. Individuals may have different mental maps of places and regions

Therefore, the student is able to:

A. Describe how an individual's views and understandings of places and regions differ, as expressed by his or her mental map, as exemplified by being able to

- Identify and describe differences in students' sketch maps of their community, including differences in details on their maps, scale, labels, location of features, etc.
- Describe differences in students' understandings of a story or setting of a book based on the details in their mental maps.
- Describe the differences in students' views of a popular community attraction based on the details in their mental maps.

8th GRADE

the student knows and understands:

Using Mental Maps

3. Mental maps are used to answer geographic questions about locations, characteristics, and patterns of places and regions

Therefore, the student is able to:

A. Identify from memory and describe the locations, characteristics, and patterns of places and regions to answer geographic questions, as exemplified by being able to

- Identify from memory and describe the patterns of coastal population density and place characteristics to explain why people may choose to live where they do in the world.
- Identify from memory and describe the features that may have resulted in a change of route or engineering innovations in building the first US transcontinental railroad.
- Identify from memory the distribution, pattern, and characteristics of major world deserts and mountain ranges that can be barriers to travel or settlement.

Individual Perceptions Shape Mental Maps

4. Mental maps are shaped by individual perceptions of people, places, regions, and environments

Therefore, the student is able to:

A. Compare the mental maps of individuals to identify common factors that influence spatial understanding, perceptions, and preferences, as exemplified by being able to

- Compare mental maps of the state sketched by students to identify examples of spatial understanding such as scale on the maps.
- Compare mental maps sketched by students of the location or region of a historical event to identify the different perceptions students may have from the same information presented in the classroom.
- Compare the details in mental maps sketched by students of their most preferred and least preferred state in which to live.

12th GRADE

the student knows and understands:

Using Mental Maps

3. Mental maps are used to answer geographic questions about locations, characteristics, patterns, and relationships of places and regions

Therefore, the student is able to:

A. Identify from memory and explain the locations, characteristics, patterns, and relationships of places and regions to answer geographic questions, as exemplified by being able to

- Identify from memory the locations and significant details that would inform a possible solution to a community-based environmental issue including an explanation of relationships or patterns in the details.
- Identify from memory the pattern of world population and explain the relationship of population settlement to land features and available renewable resources.
- Identify from memory the location of strategic choke points in shipping routes that are most likely to influence the route of trade goods in the future and explain the relationships between the United States and other countries controlling these strategic locations.

Individual Perceptions Shape Mental Maps

4. Changing perceptions reshape mental maps of people, places, regions, and environments

Therefore, the student is able to:

A. Compare an individual's mental map before and after a geographic event or experience, as exemplified by being able to

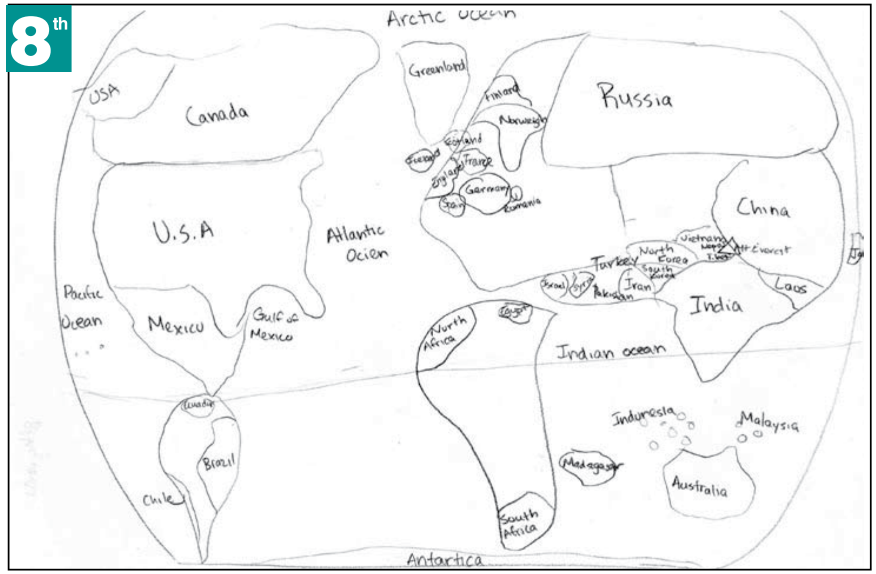
- Compare students' mental maps created before and after a school or family trip to identify changes in the details and accuracy of the maps.
- Compare students' mental maps created before and after the study of world regions that are most likely to experience political change or restructuring.
- Compare students' mental maps before and after studying a current news event to identify how additional information translates into changes in understanding of the location.

Essential Element: The World in Spatial Terms

GEOGRAPHY STANDARD 2: How to use mental maps to organize information about people, places, and environments in a spatial context

4th

8th



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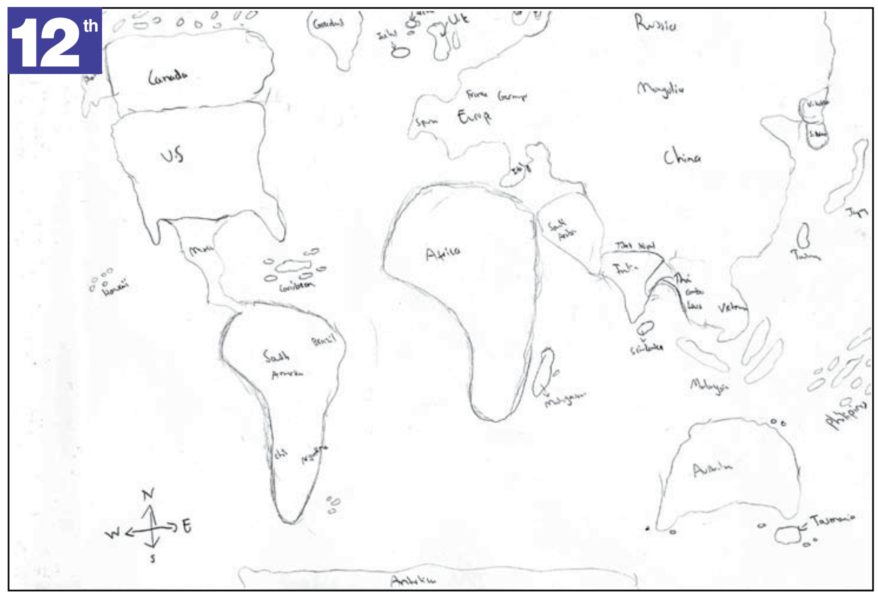

Asking students to sketch mental maps of the world can illustrate the level of detail and accuracy in their spatial perceptions of the world. These mental map examples were drawn by 4th grade (above), 8th grade (top right), and 12th grade (lower right) students.

Essential Element: The World in Spatial Terms

GEOGRAPHY STANDARD 3: How to analyze the spatial organization of people, places, and environments on Earth's surface

A satellite image of lower Manhattan captures the human and physical processes that give character to this place. Streets, highways, bridges, tunnels, ferries, and rivers are all part of the spatial pattern of transportation in New York City. Data source: ©Google Earth, ©DigitalGlobe.

Images credit: University of North Alabama/Lisa Keys-Mathews

This street map is a simplified model of the actual human and physical landscape from the above satellite image that helps visualize transportation patterns in and out of lower Manhattan. Note that a map can show some features, like tunnel routes into the city, that a satellite image cannot. Data source: 2005 TeleAtlas and Esri Streets.

The geographically informed person must understand that physical and human phenomena are distributed across Earth's surface and see meaning in their arrangements across space. Geography usually starts with questions such as, "Where?" "What is it like here?" and "Why is this located there and not here?" When considering "where" questions, geographers seek regularities—that is, patterns as well as relationships among phenomena (the features of Earth and activities that take place on Earth). They describe and explain patterns in terms of distance, direction, density, and distribution. They use spatial concepts, processes, and models as powerful tools for explaining the world at all scales, local to global.

Therefore, Standard 3 contains these themes: Spatial Concepts, Spatial Patterns and Processes, and Spatial Models.

Spatial concepts provide a language for describing the arrangement of people, places, and environments. Arrangements can be characterized in terms of proximity, distance, scale, clustering, distribution, etc.

Once students start to identify spatial patterns and use maps and remotely sensed images to discover patterns, then they can begin to explore why the patterns and relationships among phenomena exist as they do, that is, what processes produce the patterns. Processes are the driving forces and underlying causes of observable patterns.

Students must understand the mechanisms underlying processes, from the physical activities that shape the environment to the human processes of economic development, urbanization, migration, and cultural change. Models are idealized and simplified representations based on assumptions about reality, and they can help students analyze spatial organization by demonstrating properties of physical and human features, by simplifying the complexity of reality, and by serving as a source of working hypotheses in research. Models can be organized along a continuum from concrete reality (a globe or a diorama) to higher degrees of abstraction and generalization (models of urban structures, spatial interactions, and physical processes).

Understanding these themes and related concepts enables students to explore the patterns of human and physical phenomena and the processes that influence these patterns. Students use models to convey knowledge and generalizations related to Earth's spatial organization. The use of spatial thinking brings a deeper understanding and appreciation of the complexity and interconnectedness of the physical and human world.

Essential Element: The World in Spatial Terms

GEOGRAPHY STANDARD 3: How to analyze the spatial organization of people, places, and environments on Earth's surface

4th GRADE

the student knows and understands:

Spatial Concepts

1. The meaning and use of fundamental spatial concepts such as location, distance, direction, scale, movement, region, and volume

Therefore, the student is able to:

A. Describe and explain the spatial organization of people, places, and environments (where things are in relation to other things) using spatial concepts, as exemplified by being able to

- Explain the meaning of the spatial concepts of next to, behind, in front of, left, right, inside, outside, and between (e.g., moving people or desks to new locations, labeling spots in the room).
- Describe the meaning of the spatial concepts of distance, direction, and location used in selected literature (e.g., read an account of Paul Revere's ride and describe it in terms of locations [start to end], movement, region of action, distance, direction).
- Construct a story built on spatial concepts using directions, locations, distances, and movements in the plot (e.g., cardinal directions, relative and exact locations, real or imaginary locations, statements of distances).

8th GRADE

the student knows and understands:

Spatial Concepts

1. The meaning and use of spatial concepts, such as accessibility, dispersion, density, and interdependence

Therefore, the student is able to:

A. Describe the spatial organization of people, places, and environments (where things are in relation to other things) using spatial concepts, as exemplified by being able to

- Describe spatial concepts, such as population density, transportation networks or linkages, and urban or city growth patterns using paper or digital maps.
- Identify and describe related businesses and services needed in the vicinity of a popular vacation destination (e.g., hotels, restaurants, airport, ATM/banking for a theme park, hotels and camping equipment stores near national parks, tourist information centers in large cities, public transit options for stadiums and event centers).
- Identify and describe service functions along US interstate highways using a digital globe or street-view maps (e.g., shopping malls, service stations, restaurants, hotels).

12th GRADE

the student knows and understands:

Spatial Concepts

1. The meaning and use of complex spatial concepts, such as connectivity, networks, hierarchies, to analyze and explain the spatial organization of human and physical phenomena

Therefore, the student is able to:

A. Analyze and explain the spatial organization of people, places, and environments (where things are in relation to other things) using spatial concepts, as exemplified by being able to

- Construct various forms of geographic representations (hardcopy or digital maps, graphs, tables, or charts) to explain the spatial patterns of physical and human phenomena (e.g., maps that define a major watershed, composed of smaller watersheds and the hierarchies of streams and rivers within; maps that show the transportation networks within and between population centers of varying sizes to show hierarchies of cities, towns, and villages within a region).
- Construct data tables and digital maps using US Census data to analyze and explain the variability of population density in relation to the location of transportation nodes and networks.
- Construct and use various forms of geographic representations to explain that certain coastal urban centers gained locational, connectivity, and economic prominence (e.g., New Orleans, Calcutta, Rotterdam, Singapore).

Image credit: Carol and Phil Gersmehl

A model of a classroom can be used to teach spatial concepts such as next to, behind, in front of, left, right, inside, outside, and between.

Essential Element: The World in Spatial Terms

GEOGRAPHY STANDARD 3: How to analyze the spatial organization of people, places, and environments on Earth's surface

4th GRADE

the student knows and understands:

Spatial Patterns and Processes

2. The distribution of people, places, and environments form spatial patterns across Earth's surface

Therefore, the student is able to:

A. Describe and compare distributions of people, places, and environments to examine spatial patterns, sequences, regularities, and irregularities, as exemplified by being able to

- Identify features and patterns on geographic representations or remotely sensed images and describe the differences in the features and patterns (e.g., straight lines of roads forming a grid, curving roads in mountain areas, farmland and pastures versus the patterns of cities and suburbs).
- Compare distances and populations of towns and cities along a highway that runs through a state and look for patterns or trends (e.g., regularity of distances between towns of a certain size, the variability in distance from interstate highways between larger cities and smaller cities, sizes of towns closer or farther away from larger cities).
- Describe and compare the natural features and human factors using geographic representations that may influence where people live (e.g., access to water, climatic conditions, rivers, and bridges).

8th GRADE

the student knows and understands:

Spatial Patterns and Processes

2. Processes shape the spatial patterns of people, places, and environments over time

Therefore, the student is able to:

A. Describe and compare the processes that influence the distribution of human and physical phenomena, as exemplified by being able to

- Describe how changing transportation and communication technologies influence human distribution and settlement patterns using time lines, maps, and graphs (e.g., compare historic routes West, such as the Santa Fe Trail and Route 66 with current modes and routes of travel and discuss how these have influenced settlement, map the flow of emigrants to the United States by ethnic group, date, factors causing emigration, ports of entry, and settlement patterns, comparing early immigration to current immigration).
- Describe and compare the changes in environmental systems that cause changes in cultural, political, or economic conditions (e.g., a species becoming endangered leads to protected locations and conservation management, climate change influences emissions control legislation, depletion of a natural resource results in higher costs and effects new technologies).
- Describe and compare changes in natural vegetation zones and land uses on the slopes of a mountain (e.g., vertical zonation, tree lines in middle latitudes).

12th GRADE

the student knows and understands:

Spatial Patterns and Processes

2. Complex processes change over time and shape patterns in the distribution of human and physical phenomena

Therefore, the student is able to:

A. Analyze and explain changes in spatial patterns as a result of the interactions among human and physical processes through time, as exemplified by being able to

- Analyze and explain the human and physical characteristics of regions that have changed over time because of the interaction among processes (e.g., local economic patterns shift as international trade relationships evolve because of global social events, local populations of particular species rise or fall because changes in climate affect the viability of a region for other species).
- Analyze vegetation maps for an area over different time periods and explain how changing patterns reflect changes in physical processes and human activities (e.g., desertification, deforestation, natural land cover, agricultural land use).
- Explain how changes in the physical environment, political environment, and conflict influence changes in economic activity within a region. (e.g., interruption of economic activities and trade patterns in Africa, migration of people to economic trade zones in China).

In Morocco's High Atlas Mountains, land use zones are neatly patterned according to distance from the stream. Throughout the dry world, land near sources of fresh water is reserved for agriculture, while the villages where farmers live move out of the way and, in this case, upslope.

Image credit: D.J. Zeigler

Essential Element: The World in Spatial Terms

GEOGRAPHY STANDARD 3: How to analyze the spatial organization of people, places, and environments on Earth's surface

4th GRADE
the student knows and understands:

Spatial Models

3. Models are used to represent features of human and/or physical systems

Therefore, the student is able to:

A. Describe and construct models illustrating the properties of human and/or physical systems, as exemplified by being able to

- Construct a model of Earth and describe its shape, size, and key features (e.g., equator, poles, prime meridian, oceans, continents).
- Construct a model of the community and identify the different land uses (e.g., residential, industrial, retail).
- Construct a model of a watershed linked to a model of the hydrologic cycle and describe its key features and the interconnections to the local water supply (e.g., identify mountains, river systems, lakes, oceans, and groundwater that are a part of the system that supplies water to the local community).

8th GRADE
the student knows and understands:

Spatial Models

3. Models are used to represent spatial processes that shape human and physical systems

Therefore, the student is able to:

A. Describe the processes that shape human and physical systems (e.g., diffusion, migration, and plate tectonics) using models, as exemplified by being able to

- Describe a model that illustrates the diffusion of cultural characteristics (e.g., music styles, clothing styles, fast-food preferences).
- Describe how the demographic transition model explains historic changes in population and migration patterns (e.g., industrial revolution in Europe, declining birthrates in South Korea).
- Describe urban models, such as sector or ring models, using a digital globe or map (e.g., Paris as an example of a sector model, Moscow as an example of a ring model).

12th GRADE
the student knows and understands:

Spatial Models

3. Models are used to represent the structure and dynamics of spatial processes that shape human and physical systems

Therefore, the student is able to:

A. Analyze and explain the spatial features, processes, and organization of people, places, and environments using models of human and/or physical systems (e.g., urban structure, sediment transport, and spatial interaction), as exemplified by being able to

- Construct a model and explain the influence that spatial processes have on human and physical systems (e.g., urbanization and transportation; housing prices and environmental amenities such as water bodies, parks, or vistas; gardening associated with the growing season).
- Construct physical or digital models of a river valley and evaluate locations that may be suitable for different purposes (e.g., recreational sites, residential housing, resort hotels, industrial sites).
- Construct a model that shows how election strategists might determine which areas in the state should receive special attention and additional resources in advance of an election (e.g., political party membership, economic traits, past voter turnout).

Image credit: D.J. Zeigler

In the 1970s, a new highway through the Brenner Pass reduced the time required to travel across the Alps from Austria to Italy. Greater accessibility along the route led to changes in the spatial organization of the region.

APPENDIX B

A Cautionary Tale

A Cautionary Tale: the coming — and the going — of statutory progress 'levels' in the context of the national curriculum for geography in England.

In England, geography has been a part of the curriculum of primary and secondary schools for over a century (Walford, 2001). As in the USA (for example through the High School Geography Project) school geography was subject to progressive curriculum development initiatives in the second half of the twentieth century (Rawling 2001). One outcome of this was considerable professional interest in progression (see Bailey 1980; Bennetts, 1981; HMI, 1986). By the time a national curriculum was introduced for geography in 1991, it was no more than to be expected that it would be expressed in terms that showed progression.

As the following vignette tries to show, while progression remains a powerful educational idea, various attempts to describe it, especially for the purposes of *measuring* pupils' progress against national standards, have proved to be deeply problematic.

This raises the question of whether progression is a concept that informs curriculum thinking in the context of aims or aspiration, or assessment and attainment. This may, of course, be a false dichotomy - we need to attend to both. However, it does at least force the issue of whose responsibility it is - whether it is a system responsibility (falling to policy makers and or national bodies/agencies) or a classroom responsibility (thus falling to teachers, locally).

1. The origin of 'levels'

The idea of assessing students into criterion referenced 'levels' came into being as part of the national curriculum (NC) which was introduced to England (and Wales) following the Education Reform Act of 1988. During the initial NC deliberations, the proposal was to define levels of attainment in geography according to five distinct 'attainment targets'. This was logical, recognizing different aspects of geographical knowledge and skill. But in asking teachers to assess every student against five attainment targets was quite complicated!

By the time the curriculum became law in 1991, geography as a whole had become a single attainment target. However, attainment was defined by no fewer than 184 'statements of attainment'. These were distributed across 10 'levels' of attainment. These levels were intended to describe 'progress' in geography from age 5 through to 16 years of age.

Precise statements of attainment, which in effect attempted to define the national, statutory standards of geography, were difficult to write. Teachers expecting these statements to be usable as assessment criteria were quickly disappointed. On the one hand, they were too general, too rough-hewn and distant from what was actually being taught. On the other hand they proliferated. To many teachers they resembled simply a list of what had to be covered.

Statements of attainment didn't last long. By 1995 the curriculum had been reviewed and statements of attainment abolished in favour of 'Level Descriptions'. The ten-level (5-16 years) model remained[1], but this time described not by atomistic statements but by holistic paragraphs that tried to grasp, in the round, what distinguished the levels of attainment. Teachers were meant to use a 'best fit' methodology to assign periodic level judgments to their students' attainment in geography.

2. Were level descriptions a good thing?

In practical terms, ten 'level descriptions' seemed to offer more promise than nearly 200 'statements of attainment'. They were written more 'generically', which reduced the need for a 'mad dash' to get through the content, which statements of attainment seemed to encourage. They also seemed to avoid the 'Holy Grail' like search for precise, objective and easily agreed assessment criteria and instead restored broad teacher judgment of student achievement.

However, under pressure from school leaders and managers, who were themselves under intense pressure from Ofsted and the government to produce quantitative measures of school performance, teachers were encouraged, and sometimes instructed to misuse the levels. Read for example the following extract from an open letter to the new Secretary of State for Education in 2014:

> "Two years ago I worked in a school that had experienced an unprecedented level of staff turnover. "You should probably know that we're all leaving", one teacher told me, kindly, in the staff room. This was during a phase in which Ofsted had told the school - and many others – that pupils must be constantly evaluated using something called National Curriculum levels – numerical ratings that measure how advanced pupils' skills are in particular areas of the curriculum. This should happen throughout the school day, the inspectors said, every twenty minutes."

Source: https://www.opendemocracy.net/ourkingdom/teacher/open-letter-to-nicky-morgan

[1] Geography (and history) was taken out of the list of statutory subject in 'key stage 4' (14-16 years) — to ease a serious curriculum overload problem. As a result, eight levels, rather than 10, was deemed sufficient for geography.

We can find no evidence that Ofsted really did demand this. But the writer of this blog was not alone in *believing* that this is what was being demanded by 'the system'.

Remember, the main intention was to use level descriptions periodically as a basis for summative teacher assessments. They were broad brush. Think about it: ten levels across eleven years of school. It would not be surprising if individual children failed to progress a single level in a whole year! This simply would not supply adequate performance data. Thus, levels were sub-divided, often into three 'sub-levels'. But think about that! Can we really imagine describing progress in geography across what became 24 'levels' (three times eight)? This takes us back to the Holy Grail. It is an impossible ask, accomplished only by falsification: we allocate students to levels and we fit the evidence to suit our needs - to show progress.

The machine needs data on 'progress'? We can supply data. It is though, on the whole pretty meaningless data. As we have seen, in its most absurd manifestation teachers were led to believe that students should be *expected* to show 'progress' in a single lesson.

So unsatisfactory was this situation that Tim Oates, one of the 2010-5 government's main advisers on the curriculum, strongly recommended that the levels be abolished. This has been done. Attention was turned to 'assessment without levels' - together with a mild panic as to whether this was even possible such was the attachment of the machine to data that showed 'progress'.

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APPENDIX C

National Curriculum in England Geography

https://www.gov.uk/government/publications/national-curriculum-in-england-geography-programmes-of-study

Purpose of study

(How do we justify school geography?)

A high-quality geography education should

- Inspire in pupils a curiosity and fascination about the world and its people that will remain with them for the rest of their lives.
- Teaching should equip pupils with knowledge about diverse places, people, resources and natural and human environments, together with a deep understanding of the Earth's key physical and human processes.
- As pupils progress, their growing knowledge about the world should help them to deepen their understanding of the interaction between physical and human processes, and of the formation and use of landscapes and environments.
- Geographical knowledge, understanding and skills provide the framework and approaches that explain how the Earth's features at different scales are shaped, interconnected and change over time.

Aims of geography

(What is geography's contribution to the school curriculum?)

- develop contextual knowledge of the location of globally significant places – both terrestrial and marine – including their defining physical and human characteristics and how these provide a geographical context for understanding the actions of processes
- understand the processes that give rise to key physical and human geographical features of the world, how these are interdependent and how they bring about spatial variation and change over time
- are competent in the geographical skills needed to:
    - collect, analyse and communicate with a range of data gathered through experiences of fieldwork that deepen their understanding of geographical processes
    - interpret a range of sources of geographical information, including maps, diagrams, globes, aerial photographs and Geographical Information Systems (GIS)
    - communicate geographical information in a variety of ways, including through maps, numerical and quantitative skills and writing at length

Attainment target

(What does attainment in geography consist of?)

"By the end of each key stage, pupils are expected to know, apply and understand the matters, skills and processes specified in the relevant programme of study"

Assessment

(How do we judge attainment?)

The National Curriculum thus calls for summative assessment at or near the end of each key stage.

Teachers will therefore need to make summative judgements. To guide this process, which should be supported by 'standards portfolios,' a series of Benchmark statements will be helpful.

If such Benchmarks can be agreed they can also be linked to more detailed exemplification to help inform formative assessment processes using such techniques as peer assessment and the use of subject focussed feedback.

Bench Mark Standards for Geography

Key Stage 1

Orientation: *Between 5 and 7 years, pupils should develop knowledge about the world, the United Kingdom and their locality. They should understand basic subject-specific vocabulary relating to human and physical geography and begin to use geographical skills, including first-hand observation, to enhance their locational awareness.*

By the age of 7 pupils should be developing curiosity about the natural and human environments through direct observations of their surroundings and using other sources such as photographs and video. They should be able to use basic geographical vocabulary and spatial terms of reference. Pupils should be able to demonstrate basic locational knowledge of the UK and wider world using maps and globes. They can describe geographical characteristics of the places they explore and how to compare places in the UK and the wider world.

Key Stage 2

Orientation: *Between 7 and 11 years old, pupils should extend their knowledge and understanding beyond the local area to include the United Kingdom and Europe, North and South America. This will include the location and characteristics of a range of the world's most significant human and physical features. They should develop their use of geographical knowledge, understanding and skills to enhance their locational and place knowledge.*

(a) By the age of 9, pupils should demonstrate a broadening framework of world locational knowledge. Within this context they should also be able demonstrate an understanding of different environments in contexts beyond their own immediate surroundings, in particular in Europe and/or the Americas. In their investigations of different places, they should show an understanding of their similarities and differences *and* of the links between them and with their local area in the UK. Through their study of human and physical geography they are able to show an appreciation of some key geographical ideas such as environment, distance and movement. They are able to find, select and use geographical information from a range of sources including topographical maps, atlases, globes, climate graphs, photographs and film.

(b) By the age of 11, pupils can demonstrate an understanding of the globe as a whole, including knowledge about broad climate patterns and the distribution of human necessities such as energy, food and water. Pupils add further to their locational knowledge framework, for example by demonstrating knowledge of places they hear about in the news. They can also demonstrate an understanding of global connections between places through specific instances such as trade patterns using examples especially from Europe, North and South America. In their study of physical processes students can describe how physical mechanisms, for example in the work of rivers, help to shape landscapes. They can also explain the idea of cycles (eg hydrological) in both the human and physical worlds. They demonstrate the effective use of skills in analysing and interpreting a wide range of data including that which they gather themselves first hand and that taken from maps, photographs, graphs, tables and text.

Key Stage 3

Orientation: *Pupils should consolidate and extend their knowledge of the world's major countries and their physical and human features. They should understand how geographical processes interact to create distinctive human and physical landscapes that change over time. In doing so, they should become aware of increasingly complex geographical systems in the world around them. They should develop greater competence in using geographical knowledge, approaches and concepts [such as models and theories] and geographical skills in analysing and interpreting different data sources. In this way pupils will continue to enrich their locational knowledge and spatial and environmental understanding.*

By the age of 14, pupils are able to draw on extensive world knowledge of places and significant geographical features. In this locational framework, and in the particular context of Asia, Africa and the Middle East, they can demonstrate they understand the distribution of a range of human and physical geographical phenomena the significance of inter-relationships between physical and human systems. Pupils are able to explain change in physical environments, including the role of ice in shaping landscapes, within an accurate conceptualisation of geological time. They can also account for change in human environments and in particular the results of urbanisation. On a range of scales including the global pupils are able to describe the nature of unequal economic development and some of its consequences. They demonstrate a grasp of how different perceptions and competing interests between groups and nations can result in conflicts, for example concerning boundaries and resources. Pupils can demonstrate the ability to analyse and interpret a wide range of geographical evidence, including primary data from fieldwork. In evaluating evidence they show sensitivity to different viewpoints and are able to make careful judgments and draw effective conclusions about environmental questions, issues and problems.

Appendix C offers an *interpretation* the statutory wording of the National Curriculum for Geography, to help teachers work with what is a sparse and minimalist document focussing mainly on the 'essential contents' of the subject. The use of 'benchmark statements' was originated by the Geographical Association (GA) in 2011-12 in order to provide a broad framework of progression. This work continues, and the GA's official 2014 position can be found at http://www.geography.org.uk/news/2014nationalcurriculum/assessment/benchmarkexpectations/

Glossary

Learning progressions: 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) (NRC 2007, 219)

Learning trajectories: 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. (Daro, Mosher, and Corcoran 2011, 12).

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.

Developmental Progressions (sometimes called Progress Variables): Hypothesized pathways that students take en route to the upper anchor.

Assessments: Tasks that allow students to reveal their reasoning about the levels in the LP.

Instructional Sequences: Ordered instructions to help students move through LPs; and in the absence of instruction, they may be unlikely to progress much beyond their naïve conceptions in the domain.