Journal of Geography

Routledge
Taylor & Francis Group

ISSN: 0022-1341 (Print) 1752-6868 (Online) Journal homepage: www.tandfonline.com/journals/rjog20

A Road Map for Learning Progressions Research in Geography

Niem Tu Huynh, Michael Solem & Sarah Witham Bednarz

To cite this article: Niem Tu Huynh, Michael Solem & Sarah Witham Bednarz (2015) A Road Map for Learning Progressions Research in Geography, Journal of Geography, 114:2, 69-79, DOI: 10.1080/00221341.2014.935799

To link to this article: https://doi.org/10.1080/00221341.2014.935799

A Road Map for Learning Progressions Research in Geography

Niem Tu Huynh, Michael Solem, and Sarah Witham Bednarz

Abstract

This article provides an overview of learning progressions (LP) and assesses the potential of this line of research to improve geography education. It presents the merits and limitations of three of the most common approaches used to conduct LP research and draws on one approach to propose a first draft of a LP on map reading and interpretation. It also highlights findings from LP research that may be especially significant for future work in geography education. The article concludes with a description of a new research project, GeoProgressions, to build capacity for LP research in geography.

Key Words: *geography education, learning progressions, National Geography Standards*

Niem Tu Huynh is a research fellow at the Association of American Geographers, Washington, D.C., USA. She actively engages in grant writing, academic publications, and conducts education project evaluations.

Michael Solem is director of educational research and programs at the Association of American Geographers, Washington, D.C., USA. He serves as the director of the GeoProgressions project and codirector of the National Center for Research in Geography Education.

Sarah Witham Bednarz is a professor of geography at Texas A&M University, College Station, Texas, USA, with research interests in geography education and spatial thinking.

Introduction

As part of *A Road Map for 21st Century Geography Education: Geography Education Research* (a report from the Geography Education Research Committee of the Road Map for 21st Century Geography Education Project; Bednarz, Heffron, and Huynh 2013), the committee conducted a review of geography education research published in the last decade. The findings reveal a field that is disconnected from educational research in other disciplines, including social studies. Moreover, the review found that much of the existing body of geography education research is limited to designs involving low numbers of study participants, disaggregated topics on student learning, and with few examples of longitudinal studies.

The Geography Education Research Committee report recommended parallels, closer alignments, and linkages with the systematic research approaches taken in mathematics and science education, with emphasis on the potential value of learning progressions (LP), as a strategy to improve the quality and quantity of research in geography education. Of the 400+ articles reviewed for the *Road Map* report from three prominent geography education journals (national and international), we found no LP research in the literature. The *Road Map* report presents LP as an area that can potentially contribute to a deeper understanding of the teaching and learning process in geography. At the same time, LP research may foster productive research collaborations between geography, mathematics, and science education researchers.

This article summarizes LP research and how this information is being used to build the capacity of geographers to conduct systematic and coordinated research on ways students learn geography. We begin by explaining LP as it has been defined and developed in mathematics and science education. Next, we consider the merits and limitations of three of the most common approaches utilized to conduct research in LP, drawing on one approach to propose a first draft of a map reading and interpretation LP. We also highlight findings from LP research that may be especially significant for future work in geography education. We conclude with a description of a new program, GeoProgressions,[1] designed to lay the groundwork for strategic, coordinated research on LP in geography.

Defining Hypothesized Learning Progressions/Trajectories

A hypothesized learning progression (LP), also known as a hypothesized learning trajectory (LT), is a "description of the successively more sophisticated ways of thinking about a topic that can follow one another as children learn" (National Research Council 2007, 219). In essence, the researcher seeks to acquire quantitative and qualitative evidence of students' thinking and how it develops over time in relation to a topic, concept, or practice. Generally, the terms *hypothesized learning progressions* and *hypothesized learning trajectory* are used to represent similar ideas in science education and mathematics education, respectively. However, sometimes when the latter term is used in science education, it also refers to smaller sequences of LP that have a more narrow time span and grain size (Duschl, Maeng, and Sezen 2011). In this article, we will consider the term *LP* to be synonymous with learning trajectories.

The idea of research on progressions of learning is not new; it is similar to other models of developmental and progressive learning such as the spiral curriculum (Bruner 1960) and learning hierarchies (Gagné and Briggs 1974). The premise of a LP is that empirical data can provide testable hypotheses about how students' knowledge and skills develop and are organized as they learn (Duncan and

Journal of Geography 114: 69–79

Hmelo-Silver 2009; Mosher 2011). LP research in math and science has been conducted using a number of methodologies but with a general agreement on measuring differences in learning along a continuum, following a hypothesized progression, from a lower to an upper anchor. *Anchors* are expectations of what students ought to know about a target topic at a specific grade or age. The lower anchor refers to the knowledge and practices learners possess when they enter the progression, whereas the upper anchor describes what students are expected to know and be able to do by the end of the LP (Duncan and Hmelo-Silver 2009; Duschl, Maeng, and Sezen 2011).

The idea that the hypothesized LP is a bridge between resources of large-scale time frames (e.g., standards, curricula, and assessments) and research focused on short time periods has been proposed by several researchers (e.g., Baroody *et al.* 2004; Anderson 2008). The resulting predictions about the learning process can inform the design of content standards for different academic subjects and serve to support instructional methods (Adadan, Trundle, and Irving 2010; Furtak *et al.* 2010; Sztajn *et al.* 2012; Mojica and Confrey 2009) and assessment practices (Alonzo 2011; Alonzo and Gearhart 2006). Standards are based primarily on the logic of the discipline as organized by adult stakeholders' (e.g., academics and teachers) experience regarding what, when, and how concepts are *taught* (Corcoran, Mosher, and Rogat 2009; Mosher 2011). A LP, on the other hand, emphasizes how students *learn* within the scope and sequence of formal education as expressed in standards and curricula. For an in-depth review of foundational ideas that shape our thinking about LP, see Duschl, Maeng, and Sezen (2011).

It is important to note that there may be multiple pathways to learning, and thus a validated progression of thinking does not necessarily make it the best or only path for effective learning and teaching (Baroody *et al.* 2004; Clements and Sarama 2004; Corcoran, Mosher, and Rogat 2009). Nonetheless, understanding student thinking has tremendous practical value for designing appropriate learning opportunities, instructional materials, and assessments. We discuss these merits and limitations as well as three methodologies of LP in the following section. For a detailed comparison of LP and LT, see Ellis, Weber, and Lockwood (2014).

Methodologies for Learning Progressions Research

Hypothesized LP typically include four to six levels of sequential learning and encompass the following general parts (*cf.* Clements and Sarama 2004; Simon and Tzur 2004; Corcoran, Mosher, and Rogat 2009; Songer and Gotwals 2012):

1. An educational goal based on students' current knowledge;
2. Hypothesized developmental pathways about students' thinking progress;
3. Activities that can be the basis of intended learning;
4. Assessments to measure student understanding and development over time.

The process to develop a LP varies across research projects. For this reason, differences exist in the time span and grain size of the topic, target audience, and data types collected for analysis (Battista 2011). To summarize the range of research methodologies employed, we present three approaches identified from the literature as example building blocks (Duncan and Hmelo-Silver 2009). These approaches fit into one of two refinement pathways defined as Validation LP and Evolutionary LP. The former process aims to validate the initial LP sequences while the latter seeks to revise the intermediate learning steps for use in meaningful instructional intervention (Duschl, Maeng, and Sezen 2011). Table 1 highlights the main features and differences between the three approaches.

The three approaches differ in various ways, including the LP development process and the types of measurements used to collect data to verify the LP. Approach 1 provides a LP grounded in the literature of student learning on the target topic. Approach 2 extends beyond this by employing different instruments to test student performance against the hypothesized LP. The testing phase may take multiple iterations of data collection either from different sample groups at one time or following the same group over time. The data is used to modify the LP. Approach 3, also building on approach 1, diverges from approach 2 in that an instructional intervention is used to measure student learning with curriculum. In this case, the test instruments, curriculum, and LP are all core to the research.

Approach 1—Data-Grounded Development

The development of LP is based on a body of literature on student learning (e.g., Catley, Lehrer, and Reiser 2005; Smith *et al.* 2006; Duncan, Rogat, and Yarden 2009; Lee and Liu 2010). These LP require further validation studies with students, in order to test the reliability of students' thinking against the progressions developed. Figure 1 illustrates the general steps taken to develop a LP that is based on findings about student learning in the literature.

Approach 2—In Situ Student Understanding

Approach 2 starts with a LP that is created using approach 1, but extends the research to include the validation of LP, generally from cross-sectional studies that document students' knowledge on a topic, across multiple grades. The data are collected with assessment tools, clinical interviews, and teaching episodes to determine students' current progressions of learning in situ. Researchers use the data to revise the hypothesized LP (e.g., Clements, Wilson, and Sarama 2004; Alonzo and Steedle 2009; Mohan, Chen, and Anderson 2009; Gunckel *et al.* 2012; Jin and Anderson 2012; Fig. 2).

Approach 3—Instructional Intervention

This approach differs from the two above due to the inclusion of a teaching intervention. LP may also come from data collected from carefully sequenced teaching

Table 1. Comparison of the main features across three methodological approaches.

	Approach 1: Data-grounded development	Approach 2: In situ student understanding	Approach 3: Instructional intervention
Main feature	Solely grounded on students' learning from literature.	Data collection from students across grade levels and/or over time.	Inclusion of a meaningful instructional intervention.
Development of hypothesized learning progressions/ trajectories	Based on published findings, disciplinary and/or societal goals, and researcher insights on student learning.	The hypothesized learning progressions/trajectories are tested against student performance and revised based on data collected.	The hypothesized learning progressions or trajectories are tested against student performance, with instructional intervention, and revised based on data collected.
Method of assessment	None	Quantitative (ordered-multiple choice, open-ended questions) and Qualitative (clinical interviews, observations).	Quantitative and/or qualitative assessment(s) prior to and after instruction intervention on target topic.
Research pathway(s)	None	Iterative refinement of assessment(s) and learning progressions/trajectories from the data collected.	Similar to Approach 2. Teachers may also be part of the research process as the instructor delivering the intervention.

experiments or episodes that span grade levels (e.g., Schwarz *et al.* 2009; Songer, Kelcey, and Gotwals 2009; Plummer and Krajcik 2010). These interventions provide evidence of what students understand and are able to do as a result of meaningful instruction. The context, including the curriculum taught and the professional development for the teachers delivering the curriculum, form part of the LP research (Fig. 3).

Researchers have taken a number of approaches to developing and testing LP. In math education, researchers typically collect data through what is known as *teaching episodes*, which may be a singular or a set of tasks directly

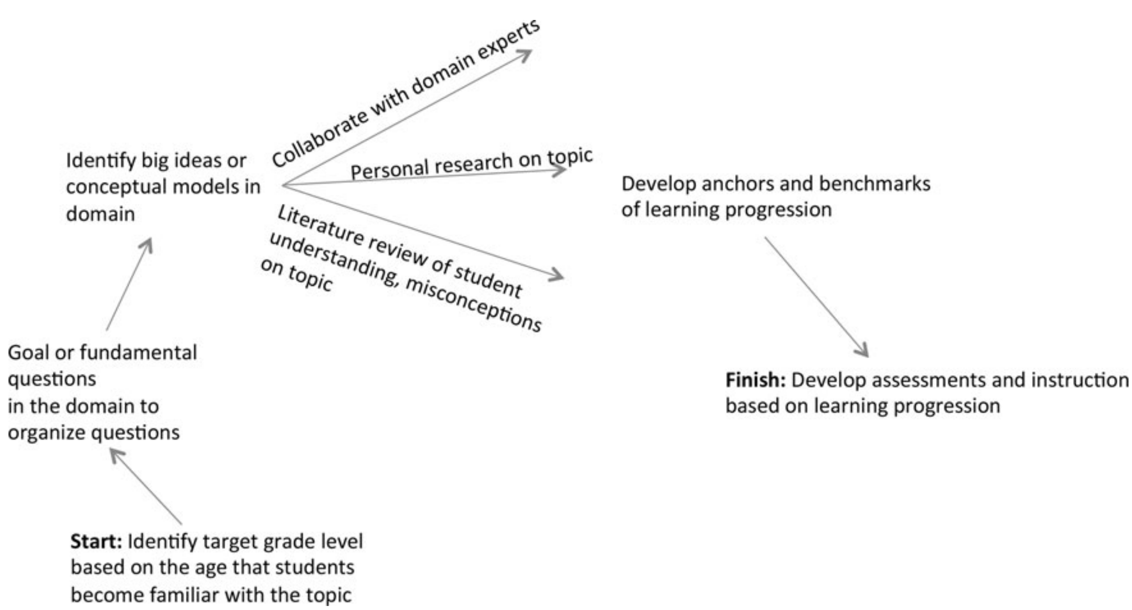

Figure 1. Learning progression/trajectory developed from body of literature on student learning.

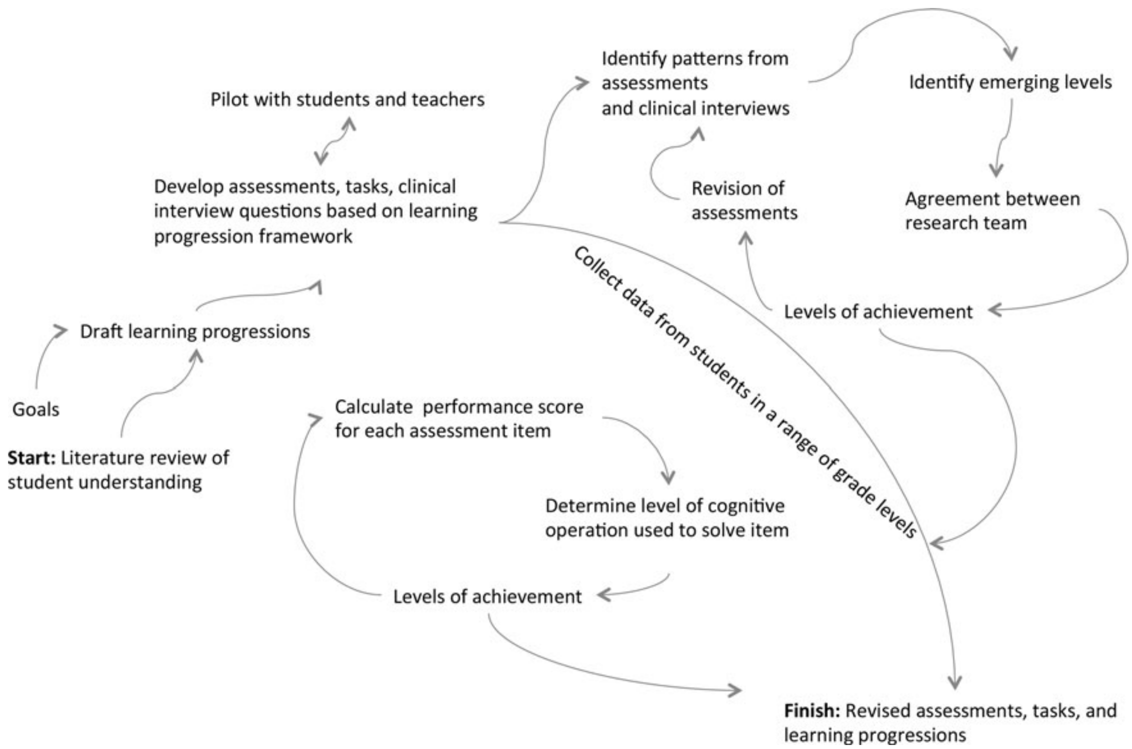

Figure 2. Learning progression/trajectory developed and revised with student assessments.

related to the target topic. The tasks include objects and actions that reflect the LP sequence (Clements and Sarama 2004). Another data collection opportunity is through a clinical interview that is commonly one-on-one, with each student asked to talk aloud or draw out a solution to each task. During this process the interviewer may ask for clarifications and pose a series of probing questions to explore students' thinking. The process is either videotaped or voice-recorded to understand student thinking. Some researchers also administer a standardized math test or a

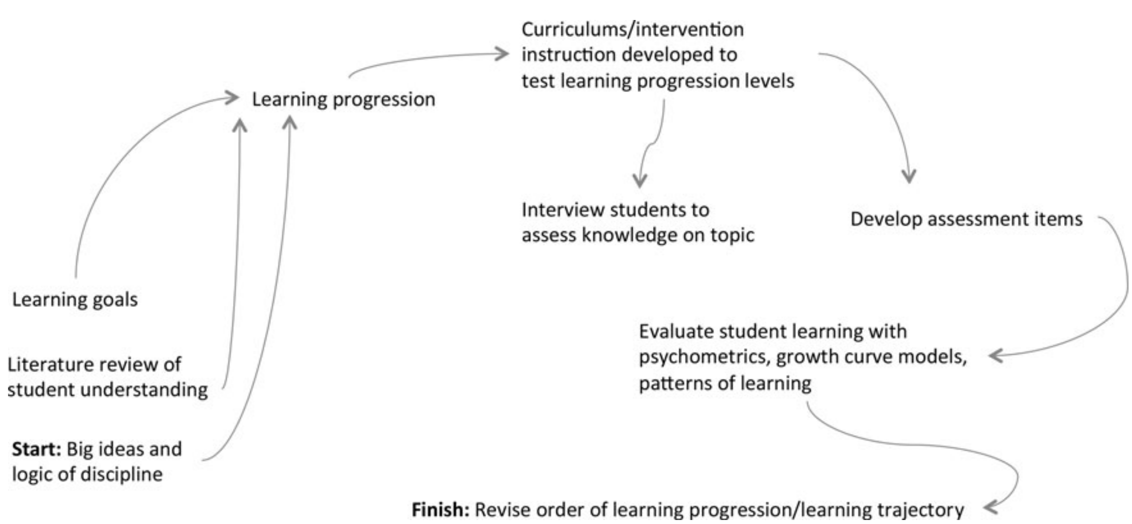

Figure 3. Learning progression/trajectory developed and revised based on instructional intervention and data collected from student assessments.

set of open-ended questions. Sample sizes in the studies published to date range from two (use of multiple tasks and an open-ended interview) (e.g., Steffe 2004) to over 2,000 students (large-scale with open-ended questions) (e.g., Lee and Liu 2010; Jin and Anderson 2012).

Some math researchers have called for the involvement of teachers in the research process (e.g., Clements and Sarama 2004; Barrett *et al.* 2012), for the purposes of drawing on teachers' insights of their students' learning preferences. The teacher-researcher partnership includes jointly constructing a LP and assessment activities (e.g., Clements, Wilson, and Sarama 2004; Steffe 2004). In Steffe's (2004) research, the researcher and teacher were present during students' constructive activities; the teacher conducted the teaching episodes and posed questions to clarify students' thinking while the researcher analyzed and presented the results. The data collected from teaching episodes are often qualitative in nature, which provide for a detailed description of observed student learning.

Researchers of LP in science education typically gather data with a variety of tools and generally from two or more assessment instruments. These instruments serve to validate the LP, and more so than in math education, this leads to the use of a "Validation" model approach (Duschl, Maeng, and Sezen 2011). Sample sizes in the available literature range from a single classroom (in qualitative studies) to nearly 4,000 students (in quantitative studies) (e.g., Jin and Anderson 2012). Assessments may include multiple choice, ordered-multiple choice, and open-ended questions to solicit written and illustrated explanations, as well as clinical interviews. Where clinical interviews are employed, students are asked to answer questions related to the target topic, and the researcher follows with probing questions to gather data used to confirm or revise proposed learning models. This process is usually voice recorded. Generally, rigorous validity and reliability tests are conducted on the assessment instrument prior to its use.

Across math and science education, LP research is usually conducted in formal classroom settings. Math research conducted thus far tends to focus on the lower grades (e.g., 2–3) while science education focuses on middle to high school students (i.e., grades five and higher). Absent in this research are individual student characteristics such as demographics, race, and sex. Such data may be useful for a meta-analysis or for making generalizations across student groups. Another gap in the literature is a need for publications to expand on the conceptual process and decision making during the refinement and validation steps (Shea and Duncan 2013).

Considerations About Doing Learning Progressions Research

Developing a LP is an iterative process, as the progression is written and revised based on formative assessments of students' thinking and understanding about a concept (Alonzo and Steedle 2009). The revision of a LP, from its hypothetical to validated form, takes time (ranging from two to three years) and money. Thus, the value of LP 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). Some researchers are concerned that there are too few studies for a rigorous comparison of effective ways to implement LP (Clements and Sarama 2004).

In theory, LP have the potential to provide coherence to standards, curricula, and assessments (Corcoran, Mosher, and Rogat 2009; Alonzo 2012; Sztajn *et al.* 2012) by bringing together different stakeholders (e.g., science educators, learning scientists, and measurement specialists), but more research is needed to disentangle some conceptual and methodological issues. For example, 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. Other researchers have observed students' inconsistency in their reasoning process to solve problems with similar foundational concepts (e.g., Alonzo and Steedle 2009).

Findings Relevant to Geography Learning Progressions

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 LP related to map interpretation, spatial reasoning processes, and geospatial technologies. Since LP is grounded on theories of cognitive development and learning (Duschl, Maeng, and Sezen 2011), the geography education community has a foundation of research to build on. We know, for example, that:

- Student ability to read, interpret, and understand representations of spatial relationships such as maps follows a developmental sequence that is gradual, multifaceted, and complex (Liben and Downs 1989, 1997).
- Map learning is constructed from a combination of experience and formal instruction grounded in cartographic and cognitive developmental theories (Downs and Liben 1988).
- Children by the age of three develop a concept of what constitutes a map and, with age, they widen their understanding to include the relationship between the use of symbols on a map and the objects they represent in the real world (Downs and Liben 1988; Liben and Downs 1997; Bunch 2000; Ishikawa and Kastens 2005).
- Results from the 2010 NAEP test suggest students' understanding of and ability to use maps increases

with their grade level as they can use latitude to locate an island by grade 4, solve locational questions using latitude and longitude and interpret simple map scales by grade 8, and identify several basic map projections and interpret geographic data from more sophisticated representations like cartograms by grade 12 (National Center for Education Statistics 2011).

We also know that geospatial technologies such as geographic information systems (GIS) can facilitate the development of spatial-thinking skills. With teacher support and scaffolding, elementary school students can use the basic functions of a GIS (e.g., zoom, measure distance, query) to identify patterns (e.g., Keiper 1999; Shin 2007). At the high school level, some studies have examined how students, by learning various ways to collect, display, and analyze spatial data, develop techniques to work with large datasets (e.g., Koch and Denike 2007). We also know that students' ability to identify locations on a map improves when they are asked to explain their reasoning process (Kastens and Liben 2007). Research shows similar findings for mapping tasks such as route planning (e.g., Wigglesworth 2003; Golledge, Marsh, and Battersby 2008).

Although some research shows that students tend to develop higher levels of problem-solving ability with maps as they gain experience over time (e.g., Wiegand 2003; Huynh and Sharpe 2009; Huynh and Rangarajan 2013), researchers also report that students have misunderstandings about a range of geographic concepts across the K–16 continuum: representation and geometric relationships (Liben and Downs 1989); understanding scale, size relationships, and symbolic representation at the elementary level (e.g., Liben and Downs 1989; Uttal 1996; Kastens and Liben 2007); projections and coordinate systems in high school and college students (Liben 1978; Signorella and Jamison 1978); and GIS operations (e.g., buffer, overlay; Battersby, Golledge, and Marsh 2006). What remains unknown are the major hurdles to developing accurate comprehensions of geographic concepts and practices even as learners become more sophisticated with their thinking. Clarifying these fuzzy concepts serves as one of the main potential contributions of LP. All of this prior research provides a foundation upon which to explore LP related to understanding and communicating information using maps, geographic representations, and geospatial technology.

The development of LP in geography may be buttressed by findings on core concepts shared with mathematics and science. For instance, geography deals with important spatial concepts that are crosscutting and highly relevant for mathematical and scientific thinking, such as scale, spatial patterns, processes, and models. Geography plays an important role as it can provide context to student learning at a macroscopic level, which neatly aligns with the lower anchor of a LP, where students may learn best by investigating concepts in a large space. For example, in a water cycle LP, the introduction of a geographic concept of water distribution on Earth and its influence on and by people, could provide students with a large-scale understanding in the lower anchor.

With regard to the spatial concept of scale, students often have trouble explaining and understanding phenomena that they cannot see or readily experience in their physical space or reality. This general trend is exemplified in the learning of topics such as the carbon cycle (e.g., Mohan, Chen, and Anderson 2009), genetics (e.g., Duncan, Rogat, and Yarden 2009), and the nature of matter (e.g., Stevens, Delgado, and Krajcik 2010). Students also commonly find it difficult to reason at different scales of analysis (e.g., from neighborhood to community to region) (Duncan, Rogat, and Yarden 2009; Gotwals and Songer 2010). Research on a math LP involving measurement suggests that students have problems explaining and understanding fractions before grade 5 (Steffe 2004), but are able to measure linear units (straight and bent paths) and understand fractional units with support by grade 3 (Barrett *et al.* 2012; Barrett and Clements 2003). Together, these pieces of information have implications on when and how to teach the use of scale to calculate real distances from a map scale.

Another example is students' representation of real world objects. Mathematics education research finds that pre-K level children can create pictures by combining shapes in a trial-and-error process and by grade two can understand attributes of shapes in order to build composite pictures (e.g., Clements, Wilson, and Sarama 2004). In the case of illustrating the water cycle, elementary students' drawings of water features (e.g., rivers) are not necessarily connected to the physical features in the surrounding landscape. Representations of landscape features begin in two dimensions and then develop in later years to include horizontal and vertical dimensions (Gunckel *et al.* 2012). These separate studies add to geographers' understanding of when and how students learn about map elements in a composite map.

By building on what we know about student learning of big ideas across geography, math, and science,[2] we propose an example of a LP on map reading and interpretation for discussion (Table 2). The core ideas, those that are continually developed upon in higher grades, include crosscutting concepts between science and geography (patterns, scale, proportion, and quantity) and those more specific to geography (location identification, symbols, and representation). Its conception follows Approach 1, using milestones in standard 1 from the *Geography for Life: National Geography Standards* (Heffron and Downs 2012), and aforementioned findings as a framework. Table 2 is a hypothesized learning progression developed by drawing on focused research on student map learning. There is currently no data that supports or provides alternative ways to explain student thinking on the target topic.

Table 2. Draft learning progression based on Standard 1 from *Geography for Life* (Heffron and Downs 2012).

How to use maps and other geographic representations, geospatial technologies, and spatial thinking to understand and communicate information		
Level	**Description**	**Common errors/ misconceptions**
4	Students understand that there are spatial relationships and connections between phenomenon at the local to national to global scale. Communication of patterns are supported by analytic tools (e.g., computation of spatial analysis) to answer and ask questions.	Uncertainty of appropriate use of spatial analysis techniques. Communication of findings and explanation of cause and effect.
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.	Difficulty interpreting spatial patterns.
2	Students begin to recognize that maps can be real or imaginary. They understand that maps are not a 1:1 representation. Students can use their body to measure and understand distances (e.g., 1 foot size equals to 1 foot on the ground). The measurements provide a foundation to understanding different scale formats.	Phenomenon is isolated to a geographic space. Relationship between map and real distances distorted.
1	Students can map landmarks from a familiar environment (e.g., classroom or bedroom) on a large-scale map. The symbols used are iconic such that they resemble the landmark being mapped (e.g., green patches for grass).	Map is a true size representation of reality. Symbols are iconic and look like objects in reality.
0	No evidence of understanding.	

Building Research Capacity: The Path Forward

Research on LP offers a means for geography educators to determine how students learn geographic facts, concepts, and practices, and whether they are *on track* toward attainment of a particular standard or set of standards. At present, however, the available research base in geography education is primarily focused on students' understanding (or learning) of individual ideas or practices, but not on the relationships between different areas of content or types of practices learned progressively across grade levels. In light of the current knowledge base, a capacity building effort, known as GeoProgressions, will build the groundwork for systematic, coordinated efforts to create a series of LP keyed to national geography standards for grades K–4, 5–8, and 9–12. This effort includes four major activities:

1. *Symposium:* A symposium in early 2014 brought together geographers and LP experts to engage in dialogue aimed at formulating an initial research agenda on geography LP. Given the paucity of research in the geography community and different approaches to LP, the discussions explored current debates about the potential advantages and limitations of LP for improving the quality of geography education. The symposium produced a plan to develop a research handbook for planning and designing research on LP related to Geography Standards 1–3 (Essential Element 1: The World in Spatial Terms) from *Geography for Life* (Heffron and Downs 2012). Scheduled to be published in early fall 2014, the handbook will define the parameters for future research and include short- and intermediate-term benchmarks for assessing progress.
2. *Inventory and prospect study:* GeoProgressions will also produce an inventory and prospect study to determine the range of scholars conducting research that is relevant for understanding LP in geography. The study will provide data to assess the extent to which the system of researchers in geography education will be able to carry out future research on LP and where potential collaborators might be found in other fields. It will also identify potential research collaborators for future projects and training workshops.
3. *Researcher-training workshop:* In the fall of 2014 GeoProgressions will sponsor a researcher-training workshop with graduate students, early career scholars, and faculty mentors. The training will prepare graduate students and early career scholars to develop, test, and refine LP. The workshop design will include small teams of participants with mentors to formalize the data collection process (e.g., clinical interviews) and analysis (e.g., coding and statistical analysis) on LP related to the themes of Essential Element 1: The world in spatial terms across the fourth, eighth, and twelfth grades. By including all three standards in this essential element, it provides material for a more holistic approach to LP related to maps and spatial thinking. For this focused program, the goal is to train interested scholars and develop proposals for lines of research that will generate empirical evidence of how students think in relation to maps, mapping, and spatial communication by drawing on relevant research in the geography education literature. Over time, it is hoped that this process will produce a cadre of future researchers with strong research and analysis skills.

4. *Preparing for a national-level research project:* The resulting research plans and handbook will be leveraged bythe GeoProgressions project to coordinate future research activity in multiple locations. GeoProgressions will assist individual researchers to compile and synthesize the results of their data collection. This effort to scale-up research in LP is a strategy that builds on the outcomes of each preceding recommendation to pave a road map for geography education research on LP.

Conclusion

Although a small collection of geography research articles on student understanding of spatial concepts and map reading/interpretation hints at the emergence of a sequential LP, discipline-specific findings in geography are few and consensus is lacking. The authors provide an overview of LP and debates about its merits and limits ongoing in the math and science education communities. The value of a LP within geography education is a way to tie together fragmented research on a singular topic into one coherent hypothesis about how students learn. Within geography education research, much work and empirical studies in map learning provide a strong foundation upon which to create such a LP. This article shares a sample LP drawing from research studies on map learning and discusses plans to support a research community in geography. To do so, the authors present a long-range plan for coordinating LP research in geography. Some fruitful lines of research, particularly those mapped to the standards of *Geography for Life* (Heffron and Downs 2012) (e.g., student misconceptions or nature of thinking about a topic), will provide a foundational base for the discipline as well as researchers in math and science education.

Acknowledgments

We appreciate Rebecca Pendergast for her help with the figures and the insightful comments from the two reviewers as well as the editor.

Funding

This material is based upon work supported by the National Science Foundation under Grant No. DRL-1347859. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Notes

1. The National Science Foundation, through its Education and Human Resources Core Research program (Award DRL-1347859), has awarded a $292,491 grant to the Association of American Geographers (AAG) and Texas State University for a project designed to build capacity for conducting research on learning progressions in geography (http://www.aag.org/cs/geoprogressions).
2. The authors acknowledge that geography is a science, both physical and social science. Due to the way that school subject matters are broken into discrete courses, this article uses the terms *geography, math*, and *science* to represent to areas of LP research conducted. In no way do these terms exclude geography from the sciences.

References

Adadan, E., K. C. Trundle, and K. E. Irving. 2010. Exploring grade 11 students' conceptual pathways of the particulate nature of matter in the context of multirepresentational instruction. *Journal of Research in Science Teaching* 47 (8): 1004–1035.

Alonzo, A. C. 2011. Learning progressions that support formative assessment practices. *Measurement: Interdisciplinary Research and Perspectives* 9 (2–3): 124–129.

———. 2012. Learning progressions: Significant promise, significant challenge. *Zeitschrift für Erziehungswissenschaft* 15 (1): 95–109.

Alonzo, A. C., and M. Gearhart. 2006. Considering learning progressions from a classroom assessment perspective. *Measurement: Interdisciplinary Research and Perspectives* 14 (1–2): 99–126.

Alonzo, A. C., and J. T. Steedle. 2009. Developing and assessing a force and motion learning progression. *Science Education* 93 (3): 389–421.

Anderson, C. W. 2008. Conceptual and empirical validation of learning progressions: Response to "Learning progressions: Supporting instruction and formative assessment." Presented at the meeting on Advancing Research on Adaptive Instruction and Formative Assessment, sponsored by the Center on Continuous Instructional Improvement (CCII), Philadelphia, Pennsylvania.

Baroody, A. J., M. Cibulskis, M-L. Lai, and X. Li. 2004. Comments on the use of learning trajectories in curriculum development and research. *Mathematical Thinking and Learning* 6 (2): 227–260.

Barrett, J. E., and D. H. Clements. 2003. Quantifying path length: Fourth-grade children's developing abstractions for linear measurement. *Cognition and Instruction* 21 (4): 475–520.

Barrett, J. E., J. Sarama, D. H. Clements, C. Cullen, J. McCool, C. Witkowski-Rumsey, and D. Klanderman. 2012. Evaluating and improving a learning trajectory for linear measurement in elementary grades 2 and 3: A longitudinal study. *Mathematical Thinking and Learning* 14 (1): 28–54.

Battersby, S. E., R. G. Golledge, and M. J. Marsh. 2006. Incidental learning of geospatial concepts across grade levels: Map overlay. *Journal of Geography* 105 (4): 139–146.

Battista, M. T. 2011. Conceptualizations and issues related to learning progressions, learning trajectories, and levels of sophistication. *The Mathematics Enthusiast* 8 (3): 507–570.

Bednarz, S. W., S. Heffron, and N. T. Huynh, eds. 2013. *A Road Map for 21st Century Geography Education: Geography Education Research.* A report from the Geography Education Research Committee of the Road Map for 21st Century Geography Education Project. Washington, D.C.: Association of American Geographers.

Bruner, J. 1960. *The Process of Education.* Cambridge, Massachusetts: Harvard University Press.

Bunch, R. L. 2000. GIS and the acquisition of spatial information: Differences among adults and young adolescents. *Research in Geographic Education* 2 (2): 67–97.

Catley, K., R. Lehrer, and B. Reiser. 2005. *Tracing a Prospective Learning Progression for Developing Understanding of Evolution.* Paper commissioned by the National Academies Committee. Washington, D.C.: National Academy of Sciences.

Clements, D. H., and J. Sarama. 2004. Learning trajectories in mathematics education. *Mathematical Thinking and Learning* 6 (2): 81–89.

Clements, D. H., D. C. Wilson, and J. Sarama. 2004. Young children's composition of geometric figures: A learning trajectory. *Mathematical Thinking and Learning* 6 (2): 163–184.

Corcoran, T., F. A. Mosher, and A. Rogat. 2009. *Learning Progressions in Science: An Evidence-Based Approach to Reform.* CPRE Research Report #RR-63. Philadelphia, Pennsylvania: Consortium for Policy Research in Education.

Downs, R. M., and L. S. Liben. 1988. Through a map darkly: Understanding maps as representations. *The Genetic Epistemologist* 16: 11–18.

Duncan, R. G., and C. E. Hmelo-Silver. 2009. Learning progressions: Aligning curriculum, instruction, and assessment. *Journal of Research in Science Teaching* 46 (6): 606–609.

Duncan, R. G., A. D. Rogat, and A. Yarden. 2009. A learning progression for deepening students' understandings of modern genetics across the 5th–10th grades. *Journal of Research in Science Teaching* 46 (6): 655–674.

Duschl, R., S. Maeng, and A. Sezen. 2011. Learning progressions and teaching sequences: A review and analysis. *Studies in Science Education* 47 (2): 123–182.

Furtak, E. M., S. Roberts, D. Morrison, K. Henson, and S. Malone. 2010. Linking an educative learning progression for natural selection to teacher practice: Results of an exploratory study. Paper presented at the 2010 Annual Conference of the American Educational Research Association, Denver, Colorado.

Gagné, R. M., and L. J. Briggs. 1974. *Principles of Instructional Design.* New York: Holt, Rinehart & Winston.

Golledge, R., M. Marsh, and S. Battersby. 2008. A conceptual framework for facilitating geospatial thinking. *Annals of the Association of American Geographers* 98 (2): 285–308.

Gotwals, A. W., and N. B. Songer. 2010. Reasoning up and down a food chain: Using an assessment framework to investigate students' middle knowledge. *Science Education* 94 (2): 259–281.

Gunckel, K. L, B. A. Covitt, I. Salinas, and C. W. Anderson. 2012. A learning progression for water in socio-ecological systems. *Journal of Research in Science Teaching* 49 (7): 843–868.

Heffron, S. G., and R. M. Downs, eds. 2012. *Geography for Life: National Geography Standards*, 2nd ed. Washington, D.C.: National Council for Geographic Education.

Huynh, N. T., and N. Rangarajan. 2013. The effects of geospatial support tools on public administration education and practice. Paper presented at the 2013 Annual Meeting of the Association of American Geographers, Los Angeles, California.

Huynh, N. T., and B. Sharpe. 2009. The role of geospatial reasoning in effective GIS problem solving: K–16 education levels. *Geomatica* 63 (2): 119–128.

Ishikawa, T., and K. A. Kastens. 2005. Why some students have trouble with maps and other spatial representations. *Journal of Geoscience Education* 53 (2): 184–197.

Jin, H., and C. W. Anderson. 2012. A learning progression for energy in socio-ecological systems. *Journal of Research in Science Teaching* 49 (9): 1149–1180.

Kastens, K. A., and L. S. Liben. 2007. Eliciting self-explanations improves children's performance on a field-based map skills task. *Cognition and Instruction* 25 (1): 45–74.

Keiper, T. A. 1999. GIS for elementary students: An inquiry into a new approach to learning geography. *Journal of Geography* 98 (2): 47–59.

Koch, T., and K. Denike. 2007. Aaron's solution, instructor's problem: Teaching surface analysis using GIS. *Journal of Geography* 106 (2): 69–77.

Krajcik, J. S. 2012. The importance, cautions, and future of learning progressions research. In *Learning Progressions in Science: Current Challenges and Future Directions,* ed. A. C. Alonzo and A. W. Gotwals, pp. 27–36. Rotterdam: Sense Publishers.

Lee, H-S., and O. L. Liu. 2010. Assessing learning progression of energy concepts across middle school grades: The knowledge integration perspective. *Science Education* 94 (4): 665–688.

Liben, L. S. 1978. Performance on Piagetian spatial tasks as a function of sex, field dependence, and training. *Merrill-Palmer Quarterly* 24 (2): 97–110.

Liben, L. S., and R. M. Downs. 1989. Understanding maps as symbols: The development of map concepts in children. In *Advances in Child Development and Behavior,* ed. H. W. Reese, pp. 145–201. New York: Academic Press.

———. 1997. Can-ism and can'tianism: A straw child. *Annals of the Association of American Geographers* 87 (1): 159–167.

Mohan, L., J. Chen, and C. W. Anderson. 2009. Developing a multi-year learning progression for carbon cycling in socio-ecological systems. *Journal of Research in Science Teaching* 46 (6): 675–698.

Mojica, G., and J. Confrey. 2009. Pre-service elementary teachers' understanding of an equipartitioning learning trajectory. In *Proceedings of the 31st Annual Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education*, ed. S. L. Swars, D. W. Stinson, and S. Lemons-Smith, pp. 1202–1210. Atlanta, Georgia: Georgia State University.

Mosher, F. A. 2011. *The Role of Learning Progressions in Standards-Based Education Reform.* CPRE Policy Brief, September 2011 (#RB-52). Philadelphia, PA: Consortium for Policy Research in Education.

National Research Council. 2007. *Taking Science to School: Learning and Teaching Science in Grades* K–8. Washington, D.C.: The National Academies Press.

National Center for Education Statistics. 2011. *The Nation's Report Card: Geography 2010.* Washington, D.C.: Institute of Education Sciences, U.S. Department of Education.

Plummer, J. D., and J. Krajcik. 2010. Building a learning progression for celestial motion: Elementary levels from an earth-based perspective. *Journal of Research in Science Teaching* 47 (7): 768–787.

Schwarz, C. V., B. J. Reiser, E. A. Davis, L. Kenyon, A. Achér, D. Fortus, Y. Shwartz, B. Hug, and J. Krajcik. 2009. Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching* 46 (6): 632–654.

Shavelson, R. J., and A. Kurpius. 2012. Reflections on learning progressions. In *Learning Progressions in Science: Current Challenges and Future Directions,* ed. A. C. Alonzo and A. W. Gotwals, pp. 13–26. Rotterdam: Sense Publishers.

Shea, N. A., and R. G. Duncan. 2013. From theory to data: The process of refining learning progressions. *Journal of the Learning Sciences* 22 (1): 7–32.

Shin, E-K. 2007. Using geographic information system (GIS) technology to enhance elementary students' geographic understanding. *Theory and Research in Social Education* 35 (2): 231–255.

Signorella, M. L., and W. Jamison. 1978. Sex differences in the correlations among field dependence, spatial ability, sex role orientation, and performance on Piaget's water-level task. *Developmental Psychology* 14 (6): 689–690.

Simon, M. A., and R. Tzur. 2004. Explicating the role of mathematical tasks in conceptual learning: An elaboration of the hypothetical learning trajectory. *Mathematical Thinking and Learning* 6 (2): 91–104.

Smith, C. L., M. Wiser, C. W. Anderson, and J. Krajcik. 2006. Implications of research on children's learning for standards and assessment: A proposed learning progression for matter and the atomic-molecular theory. *Measurement: Interdisciplinary Research and Perspectives* 4 (1–2): 1–98.

Songer, N. B., and A. M. Gotwals. 2012. Guiding explanation construction by children at the entry points of learning progressions. *Journal of Research in Science Teaching* 49 (2): 141–165.

Songer, N. B., B. Kelcey, and A. W. Gotwals. 2009. How and when does complex reasoning occur? Empirically driven development of a learning progression focused on complex reasoning about biodiversity. *Journal of Research in Science Teaching* 46 (6): 610–631.

Steedle, J. T., and R. J. Shavelson. 2009. Supporting valid interpretation of learning progression level diagnoses. *Journal of Research Science Teaching* 46 (6): 699–715.

Steffe, L. P. 2004. On the construction of learning trajectories of children: The case of commensurate fractions. *Mathematical Thinking and Learning* 6 (2): 129–162.

Stevens, S. Y., C. Delgado, and J. S. Krajcik. 2010. Developing a hypothetical multi-dimensional learning progression for the nature of matter. *Journal of Research in Science Teaching* 47 (6): 687–715.

Sztajn, P., J. Confrey, P. H. Wilson, and C. Edgington. 2012. Learning trajectory-based instruction: Toward a theory of teaching. *Educational Researcher* 41 (5): 147–156.

Uttal, D. H. 1996. Angles and distances: Children's and adults' reconstruction and scaling of spatial configurations. *Child Development* 67 (6): 2763–2779.

Wiegand, P. 2003. School students' understanding of choropleth maps: Evidence from collaborative mapmaking using GIS. *Journal of Geography* 102 (6): 234–242.

Wigglesworth, J. C. 2003. What is the best route? Route-finding strategies of middle school students using GIS. *Journal of Geography* 102 (6): 282–291.