Learning progressions – descriptions of increasingly sophisticated ways of thinking about or understanding a topic (National Research Council, 2007) – represent a promising framework for developing organized curricula and meaningful assessments in science. In addition, well-grounded learning progressions may allow for coherence between cognitive models of how understanding develops in a given domain, classroom instruction, professional development, and classroom and large-scale assessments. Because of the promise that learning progressions hold for bringing organization and structure to often disconnected views of how to teach and assess science, they are rapidly gaining popularity in the science education community. However, there are significant challenges faced by all engaged in this work. In June 2009, science education researchers and practitioners, as well as scientists, psychometricians, and assessment specialists, convened to discuss these challenges as part of the Learning Progressions in Science (LeaPS) conference. The LeaPS conference provided a structured forum for considering design decisions entailed in four aspects of work on learning progressions: defining learning progressions; developing assessments to elicit student responses relative to learning progressions; modeling and interpreting student performance with respect to a learning progressions; and using learning progressions to influence standards, curricula, and teacher education. This book presents specific examples of learning progression work and syntheses of ideas from these examples and discussions at the LeaPS conference.
LEARNING PROGRESSIONS IN SCIENCE
LEARNING PROGRESSIONS IN SCIENCE

Current Challenges and Future Directions

Edited by

Alicia C. Alonzo
Amelia Wenk Gotwals
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**Melissa Braaten** is an assistant professor in the School of Education's Department of Curriculum and Instruction at the University of Wisconsin-Madison. Her research interests include teacher learning in collaborative inquiry groups, ambitious science instruction that is responsive to students, the construction of explanatory models in school science, and the use of classroom discourse to create generative and equitable learning environments. Earlier in her career she was a middle school and high school science teacher in Tennessee, Texas, and Washington. She received her Ph.D. from the University of Washington.

**Derek Briggs** is Chair of the Research and Evaluation Methodology Program in the School of Education at the University of Colorado at Boulder, where he also serves as an associate professor of quantitative methods and policy analysis. His research agenda focuses on building sound methodological approaches for the valid measurement and evaluation of growth in student achievement. Examples of his research interests in the area of educational measurement include (1) characterizing the gap between validity theory and practice in the context of high-stakes standardized testing and (2) developing and applying psychometric models to assess learning progressions.

**Lea Bullard** is a doctoral candidate in science education at the University of Michigan and a research assistant at the University of North Carolina at Wilmington. Her professional work is focused on assessing student learning outcomes in higher education. Her personal research interests center on the nature and evaluation of visitor learning in science museums.
Kristina Chapple, Ph.D., provides research support for the creation and maintenance of assessments throughout the Cisco Networking Academy ecosystem. She works closely with subject matter experts, providing them with the statistical and measurement tools to create tasks, combine tasks on exams, and evaluate the tasks and exams after implementation. She is interested in item response theory, form linking and balancing, and other issues related to the implementation of large-scale assessments.

Younyoung Choi is a Ph.D. candidate in the Department of Measurement, Statistics, and Evaluation at the University of Maryland at College Park. She received her Master’s degree in the Department of Measurement, Statistics, and Evaluation at the same university and a Bachelor of Arts from the Department of Psychology at Sungkyunkwan University in South Korea. She is interested in developing simulation/game-based assessments using the Evidence Centered Design framework and investigating statistical methodologies to assess learners’ progressions using Bayesian Networks.

Beth A. Covitt is a research assistant professor in the Environmental Studies Program at the University of Montana. She conducts learning progression research addressing students’ understanding of water in environmental systems and students’ use of science in socio-ecological decision-making. Dr. Covitt also conducts science teacher professional development with elementary and middle school teachers in Montana.

Aaron Crawford is a graduate student in the Division of Psychology in Education at Arizona State University. His current research areas include methodological studies, item response theory, Bayesian networks, and structural equation modeling. He received M.A. and B.S. degrees in psychology from the University of North Florida.

Kristen DiCerbo is an evaluation specialist at Cisco Learning Institute. Her research interests include understanding how students learn technical skills, researching instructional practice around the world, and using new and different techniques to explore teaching and learning. This research occurs primarily in the context of the Cisco Networking Academy Program. Dr. DiCerbo received her M.Ed. and Ph.D. in educational psychology from the School Psychology Training Program at Arizona State University. She continues to teach a course on individual intellectual assessment at Arizona State. She received her B.A. in psychology and sociology from Hamilton College. Prior to joining Cisco Learning Institute, she worked as a school psychologist.

Susan J. Doubler co-directs the Center for Science Teaching and Learning at TERC and is Associate Professor of Education at Lesley University. Her work focuses on the interface between science education and the use of technology to further inquiry-based learning. She is currently leading two projects funded by the
NSF: The Inquiry Project, an effort to develop and study a learning progression about matter for grades 3–5, and Talk Science, an effort to develop web-based professional development resources aligned with the Inquiry curriculum and focused on productive classroom talk. She recently co-led the development of a web-based science leadership program for K-8 teachers and the development of a fully online master’s program in science education. Before coming to TERC and Lesley University, she was an instructional specialist and teacher in the Winchester (MA) Public Schools.

Jacob Foster is Director of Science and Technology/Engineering at the Massachusetts Department of Elementary and Secondary Education. In this role he oversees the state’s science and technology/engineering standards and curriculum framework, state-funded professional development opportunities, and support for districts. Dr. Foster has been a member of the writing team for the National Science Teacher Association’s Anchors project, has served on a design team for the NRC’s Conceptual Framework for New Science Standards, and is on the writing team for the Next Generation Science Standards. Previously Jacob worked with the Coalition of Essential Schools on school reform and conducted school reviews as part of Massachusetts’s accountability system. He has taught high school physical and earth sciences. In addition, he has served as a middle school science coach and science teacher educator. Dr. Foster earned a B.A. in earth science from Hampshire College and an M.A. and Ph.D. in science education from the University of Michigan.

David Fortus is a senior scientist at the Weizmann Institute of Science in Israel. He is interested in ways to improve middle school science education and to motivate middle-schoolers to continue studying science in high school. At present he is involved in the publication of a coordinated and comprehensive middle school science curriculum and a study of the reasons why students’ motivation to learn science declines from the end of elementary school and throughout middle school.

Erin Marie Furtak is Assistant Professor of Education specializing in science education at the University of Colorado at Boulder. As a former public school teacher, Dr. Furtak’s research focuses on the development of teachers’ knowledge and practices to support reform-oriented science teaching. Currently, she is (1) exploring how learning progressions about natural selection can support teacher learning communities as they develop, enact, and revise common formative assessments and (2) relating teacher enactment of formative assessment to student learning. Her projects have been supported by the Alexander von Humboldt Foundation, the Knowles Science Teaching Foundation, the Spencer Foundation, and a CAREER grant from the NSF.

Amelia Wenk Gotwals is an assistant professor of science education at Michigan State University. Her research interests include examining the ways that students and teachers develop more sophisticated understandings and abilities. Specifically,
she is interested in the development, evaluation, and assessment of learning progressions in science and ways to assess complex reasoning in authentic scientific situations. In addition, she is interested in investigating how teachers develop assessment literacy, specifically, how teacher candidates can learn to gather evidence of student understanding and use this evidence to modify their teaching practices. Her work has been funded by the NSF and the Spencer Foundation, through a Spencer Dissertation Research Fellowship.

Kristin L. Gunckel is an assistant professor of science education at the University of Arizona. She received her Ph.D. from Michigan State University. She is co-leader of the water cycle learning progression strand in the Environmental Literacy Project and the Reasoning Tools for Understanding Water Systems Project. In addition to learning progressions, she is also interested in elementary science teacher education.

Hui Jin is an assistant professor at The Ohio State University. Her research interests include learning progressions, students’ informal explanations and causal reasoning, conceptual change theories, and qualitative research methodology. She received her Ph.D. from Michigan State University.

Lisa Kenyon is an associate professor in the Department of Biological Sciences in the College of Science and Mathematics and the Department of Teacher Education in the College of Education and Human Services at Wright State University. Her research focuses on engaging students and teachers in scientific practices such as explanation, argumentation, and scientific modeling—specifically, examining how students use their epistemologies of science to support these practices. Her current focus on scientific modeling includes two main areas: (1) developing a learning progression for upper elementary and middle school students and (2) supporting preservice teachers’ pedagogical content knowledge for scientific modeling. Other research interests include curriculum design, project-based inquiry, and teacher professional development.

Joseph Krajcik, Professor in the College of Education at Michigan State University (MSU) and Director of the CREATE for STEM Institute, focuses his research on exploring the impact of designing innovative classroom environments in which students find solutions to important intellectual questions that subsume essential learning goals. He has authored and co-authored over 100 manuscripts and makes frequent presentations focused on his research, as well as presentations that translate research findings into classroom practice, at international, national and regional conferences. He is a fellow of the American Association for the Advancement of Science (AAAS) and the American Educational Research Association (AERA), served as president of NARST, and received guest professorships from Beijing Normal University and the Weizmann Institute of Science. In 2009, Ewha University in Korea named him a distinguished fellow. Prior to coming to MSU, Joe spent 21 years at the University of Michigan.
AUTHOR BIOGRAPHIES

Amy Kurpius, M.S., has been working in the field of higher education for more than 10 years. Her work experience includes project management, research evaluation and analyses, grants management, and financial administration. Her education work has focused on professional and executive education, learning progressions and formative assessments in K-8 science and mathematics education, performance assessment in pre-college and higher education, and admissions assessments of achievement and ability. She has consulted with organizations such as the Council for Aid to Education, the College Board, Indiana University, Organization for Economic Co-Development, Stanford University, Teachers College, and the University of Pennsylvania.

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Lindsey Mohan is an adjunct research scientist at Michigan State University. She received her Ph.D. in educational psychology from Michigan State University. Through her work with National Geographic Society, Lindsey developed video-based professional development on the Environmental Literacy Teacher Guides series and is currently working on carbon-cycling learning progression research with the Environmental Literacy Project. She has also conducted research documenting exemplary teaching and exceptional classroom dialogue in science.
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Julia Plummer is an assistant professor at Arcadia University where she coordinates the science education program. Prior to this position, Dr. Plummer spent more than a decade teaching children and adults in planetariums. Her research interests include investigating the design of learning environments for developing students’ understanding of astronomy and the practices of science as applied to astronomy, in both classroom and informal environments. She is also interested in the role of curriculum and professional development in educators’ beliefs about astronomy education. Dr. Plummer has conducted a series of studies that have led to the development of an initial framework for a K-8 observational astronomy learning progression. She has co-authored a middle school astronomy curriculum published through It’s About Time.

Brian J. Reiser is Professor of Learning Sciences in the School of Education and Social Policy at Northwestern University. Dr. Reiser’s research examines how to make scientific practices such as argumentation, explanation, and modeling meaningful and effective for classroom teachers and students. This design research investigates (1) the cognitive and social interaction elements of learning environments supporting scientific practices and (2) design principles for technology-infused curricula that embed science learning in investigations of contextualized data-rich problems. Dr. Reiser leads the MoDeLS (Modeling Designs for Learning Science) project, developing an empirically-based learning progression for the practice of scientific modeling, and BGuILE (Biology Guided Inquiry Learning Environments), developing software tools for supporting students in analyzing biological data and constructing explanations. Dr. Reiser is also on the leadership team for IQWST (Investigating and Questioning our World through Science and Technology), a collaboration with the University of Michigan developing a middle school project-based science curriculum. Dr. Reiser was a founding member of the first graduate program in Learning Sciences, created at
Northwestern, and chaired the program from 1993, shortly after its inception, until 2001. He was co-principal investigator in the NSF Center for Curriculum Materials in Science, exploring the design and enactment of science curriculum materials, and served on the NRC panels authoring the reports *Taking Science to School* (2007) and *Conceptual Framework for New Science Education Standards* (2011).

**Daisy Wise Rutstein** is a graduate student in the Department of Measurement, Statistics and Evaluation at the University of Maryland, College Park. Her interests include Bayesian networks and cognitive diagnosis modeling.

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**Richard J. Shavelson** is the Emeritus Margaret Jacks Professor of Education and Professor of Psychology (by courtesy) at Stanford University, and former I. James Quillen Dean of the School of Education at Stanford and Senior Fellow in Stanford’s Woods Institute for the Environment. He is currently director of research and development at SK Partners, LLC. He served as president of AERA; is a fellow of AAAS, AERA, the American Psychological Association, and the American Psychological Society; and is a Humboldt Fellow (Germany). His current work includes assessment of undergraduates’ learning using the Collegiate Learning Assessment, accountability in higher education, assessment of science achievement, the validity of learning progressions, the enhancement of women’s and minorities’ performance in organic chemistry, and the role of mental models of climate change on sustainability decisions and behavior. Other work includes studies of computer cognitive training on working memory, fluid intelligence and science achievement; the scientific basis of education research; and new standards for measuring students’ science achievement in the NAEP (the nation’s “report card”). His publications include *Statistical Reasoning for the Behavioral Sciences, Generalizability Theory: A Primer* (with Noreen Webb); *Scientific Research in Education* (edited with Lisa Towne); and *Assessing College Learning Responsibly: Accountability in a New Era* (2010).

**Carol L. Smith** is Professor in the Department of Psychology, University of Massachusetts at Boston, where she has been since receiving her Ph.D. in developmental studies from Harvard University in 1976 and completing postdoctoral research at the Massachusetts Institute of Technology (MIT) in 1978. She is a cognitive developmental psychologist whose work on conceptual change
in science education exemplifies part of the research basis for learning progressions. Over the past 30 years she has studied the conceptual changes that occur as children develop their ideas about matter as well as their ideas about scientific models and knowledge construction in science. She has also collaborated with teachers, scientists, and science educators to create innovative teaching units for elementary and middle school students and to study their effectiveness in facilitating conceptual restructuring compared with more traditional teaching approaches. Most recently, she worked on a team that synthesized current research in order to propose a long-term learning progression for matter and served on the NRC’s Committee on Science Learning, K-8, which authored Taking Science to School. She is currently collaborating on two longitudinal studies—one with elementary school students (on matter) and the other with college students (concerning their conceptions of science).

**Nancy Butler Songer** is Professor of Science Education and Learning Technologies in the School of Education at the University of Michigan and the Director of the Center for Essential Science (www.essentialscience.umich.edu). Her research is focused in two areas: (1) addressing 4–10th grade urban students’ underperformance in science through the design and evaluation of curricular units and emerging technologies focused on complex reasoning in science and (2) designing and evaluating assessments to measure complex learning in science. She has a Ph.D. in science education from the University of California, Berkeley, a M.S. in Molecular/Developmental Biology from Tufts University, and a B.S. in Biological Sciences from the University of California, Davis. She was awarded a Presidential Faculty Fellowship from President William J. Clinton in 1996 and is a Fellow of the AAAS.

**Jessica Thompson** is a research assistant professor in the College of Education at the University of Washington. Her research focuses on engaging underserved students in science and on supporting science teachers in working toward ambitious and equitable pedagogy. Dr. Thompson was awarded an American Association of University Women Dissertation Fellowship, the 2007 Selma Greenberg Dissertation Award, and a 2010 Knowles Science Teaching Foundation (KSTF) Fellowship. The KSTF is supporting a project that examines co-learning of high-leverage practices between teacher candidates and cooperating teachers. With funding from the Carnegie Foundation and the NSF, she has spent the last five years working on the development of tool systems designed to advance early career science teachers’ pedagogical reasoning and practice (see http://tools4teachingscience.org/). For the last three years she has also run a video club, in partnership with local school districts, that supports in-service science teachers in examining links between practice and student learning.

**Patti West** is an employee of Cisco Systems. She is an educational specialist on the Cisco Networking Academy Learning Systems Development team. Her interests include the application of latent variable psychometric and Bayesian inference models to inform the design and development of curriculum, assessment and learning games.
Mark Wilson is Professor in the Graduate School of Education at the University of California, Berkeley. He is a Fellow of the American Psychological Association and Founding Editor of the journal Measurement: Interdisciplinary Research and Perspectives. He is currently the President of the Psychometric Society. His interests in measurement range from reforming the approach to measurement in education and, more broadly, across the social sciences, to innovations in mathematical and statistical modeling for measurement to the policy and practical issues involved in educational and psychological assessment.

Mark Windschitl is a professor of science teaching and learning at the University of Washington. His research interests deal with the early career development of science teachers—in particular their trajectories toward ambitious and equitable pedagogy. His research group has developed a set of high-leverage practices for K-12 science instruction and a set of discourse tools that allow beginners an entry point into expert-like dialogic interactions with young learners. This work is supported by a 5-year grant from the NSF. Work from this and related projects has appeared in the American Educational Research Journal, Teachers College Record, Cognition and Instruction, Phi Delta Kappan, Science Education, and in white papers commissioned by the NRC and the National Academy of Science. Dr. Windschitl is the PI on a Noyce Teaching Scholars grant and has supported approximately 30 teachers in that program in their transitions to urban schools. He also co-administers the Annenberg Fellowship program—also known as the Rhodes Scholarships of Teaching—for teachers at the UW. He is the recipient of the 2002 AERA Presidential Award for Best Review of Research, the co-author of the chapter on science teaching in the new AERA Handbook of Research on Teaching, and the 2011 recipient of the Iowa State University Outstanding Alumni Achievement Award.

Marianne Wiser is Associate Professor and Chair of the Psychology Department at Clark University. She has degrees in physics and engineering and in physical oceanology from the University of Liege, Belgium, and a Ph.D. in cognitive and brain science from MIT. Her areas of research are science learning and teaching in elementary and middle school; the development of physical concepts, numeracy, and notations in young children; and the role of language in science learning. Her work in science education focuses on learning progressions of matter and energy for the elementary grades. She is working with a team of researchers, curriculum developers, and teachers from Tufts University, University of Massachusetts Boston, and TERC. She is also collaborating with colleagues at Clark University on an oral language curriculum for early elementary school based on science learning progressions and language development research. She has been a consultant for the College Board as part of a team that redesigned the AP Physics assessment using an evidence-centered model; for NRC on how to organize science standards around core ideas; and for the Massachusetts Department of Education on how to revise science standards around learning progressions.
FRAMING SECTION
 INTRODUCTION

Leaping Into Learning Progressions in Science

Learning progressions—descriptions of increasingly sophisticated ways of thinking about or understanding a topic (National Research Council [NRC], 2007)—offer a promising framework for bringing coherence to multiple facets of the educational system. Learning progressions, which articulate cognitive models of the development of student understanding, have the potential to inform the design of standards, large-scale and classroom assessments, curricula, and teacher professional development. As such, the science education community has taken considerable interest in learning progressions. However, as with any new research agenda, there are challenges. If these challenges are not addressed, they may thwart the promise that learning progressions hold.

Many journal articles and conference presentations gloss over the challenges authors and presenters have encountered in their work. In contrast, this book emphasizes that such challenges in learning progression work need to be a central part of the conversation. The chapters in this book recognize that, in order for learning progressions to fulfill their promise, the community must undertake a critical examination of the challenges in defining, assessing, modeling, and using learning progressions. Therefore this book explores learning progression work through an examination of some of its most important challenges.

This chapter introduces the book. First, we discuss why learning progressions have generated so much interest in the science education community. Next, we describe the current challenges in learning progression work and our impressions of the field. We conclude by outlining the book’s structure and discussing our expectations of how the book may advance learning progression work.

THE PROMISE OF LEARNING PROGRESSIONS

Students in the United States (US) consistently perform worse on international standardized tests of science achievement than their peers in other countries. US students perform relatively well in fourth grade. However, by the eighth grade their level of performance drops considerably and remains low throughout compulsory schooling (Gonzales et al., 2004; Schmidt, McKnight, & Raizen, 1997). In addition, there is increasing concern that schools in the US do not adequately teach students the scientific knowledge and skills needed for success in the workforce (National Academy of Sciences, National Academy of Engineering & Institute of Medicine, 2007).
One possible explanation of these disconcerting findings is that K-12 science education in the US is unfocused, with many topics presented in a disconnected and shallow fashion (Valverde & Schmidt, 1997). US science textbooks address many more topics than textbooks in other countries (Linn, Tsuchida, Lewis, & Songer, 2000) and do so in a superficial and unsystematic manner, such that content is not presented in a logical order and does not build from year to year (Roseman, Kesidou, Stern, & Caldwell, 1999). Thus US students lack the opportunity to develop the coherent understandings and skills needed to develop scientific literacy.

The idea of preparing students to be scientifically literate is not new. In its 1990 report, *Science for All American*, the American Association for the Advancement of Science [AAAS] argued that students should acquire deep understandings of big ideas in science in order to understand socio-scientific issues such as global warming, population growth, nuclear energy, and public health. Although this argument was widely accepted by the science education community, two decades later we still do not have a clear understanding of how to achieve science literacy through science education.

Learning progressions have the potential to organize standards, assessments, and instruction in a way that promotes scientific literacy. Current standards and curricula prioritize the structure of the scientific disciplines, using a top-down approach that creates logical (from scientists’ perspective) sequences of ideas. Learning progressions, which use both top-down and bottom-up design approaches, can combine ideas about scientific domains with understandings of how students learn. Thus learning progressions provide a significantly different perspective from that of other currently available frameworks for organizing standards, assessments, and instruction.

Learning progressions prioritize big ideas that are generative and merit extended periods of study. As part of the top-down design approach to learning progressions, scientists and science educators select these big ideas from the core knowledge needed for understanding socio-scientific issues and achieving scientific literacy. However, this logical decomposition of big ideas may not necessarily reveal the paths students take as they learn scientific content. Therefore, the bottom-up design approach to learning progressions promotes the organization of content based on students’ thinking as they develop more sophisticated understandings. Students’ progression from naïve to more sophisticated understandings may not be linear or easily described. An investigation of the “messy middle” (Gotwals & Songer, 2010, p. 277) of students’ learning may thus provide powerful information for formative assessments (e.g., Alonzo, 2011), curriculum development (e.g., Wiser, Smith, & Doubler, this volume), and standards (e.g., Foster & Wiser, this volume).

The top-down and bottom-up processes of developing learning progressions require varied expertise. Learning progressions draw on existing work that has not before been brought together in a coherent and systematic manner. In addition, learning progressions require collaborations to generate new knowledge needed to advance the field even further. In the past, scientists and science educators have articulated core ideas in science that are generative and allow students to integrate
knowledge that produces powerful explanations of socio-scientific phenomena (e.g., AAAS, 1990; NRC, 1996, 2007). However, while they have identified goals for scientifically literate citizens, they have not taken the bottom-up design approach described above; thus they have failed to identify and/or prioritize the ways students achieve these goals.

Cognitive and learning scientists have conducted research on how children learn in specific domains and have studied the ideas students bring to school. However, much of this research has been conducted outside the classroom, with limited success in transferring the knowledge acquired to learning environments. In addition, assessment experts have researched ways of ascertaining what students know, and psychometricians have developed sophisticated models of students’ responses to assessments. Yet, since there has been little communication between science educators and these measurement experts, new techniques have not been systematically applied to science education (NRC, 2001). Hence the research on learning progressions represents a systematic effort to synthesize the ideas from multiple strands of research into frameworks for scaffolding students in the deep understandings required for scientific literacy.

Learning progressions hold great promise for the science education community. They can harmonize and coalesce multiple aspects of the educational system by their focus on a common framework that is informed by core socio-scientific ideas and by knowledge of how students learn. Standards and large-scale assessments have identified which science topics to teach and curricula have outlined how to teach these topics. However, while students’ misconceptions have informed curricula and standards documents (e.g., AAAS, 1990, Davis & Krajcik, 2005), learning progressions go further in that they focus on how students learn these topics (Alonzo, 2011). In the study of learning progressions, students’ ideas become, for the first time, an essential component of a framework that guides these multiple aspects of science education.

CONSIDERATION OF CHALLENGES IN LEARNING PROGRESSION WORK

Despite the exciting potential that learning progressions offer, we realized that many researchers lacked a shared definition of learning progressions and a shared vision of their critical features. Therefore we organized an interactive poster session at the 2008 annual meeting of the American Educational Research Association (AERA) entitled Diverse Perspectives on the Development, Assessment, and Validation of Learning Progressions in Science. In this session, our goal was to highlight both the promise that learning progressions held and the lack of a shared definition of this concept. While there were similarities in the work on learning progressions presented at this session, there were also significant differences in how researchers conceptualized and used learning progressions. We observed that researchers who took diverse approaches to the development of learning progressions and associated curricula and assessments were using the same language to describe dissimilar studies of and experiences with learning progressions. In addition, these researchers were conducing learning progression
work using very different methods. We also realized there was little communication among learning progression researchers about their efforts and results.

The interactive poster session allowed us to make comparisons among multiple projects in terms of how learning progressions are conceptualized. However, AERA poster sessions are not conducive to the deep discussions needed to move the field forward. And, as is typical of most conference presentations, the posters presented at the AERA session tended to highlight the successes—rather than the challenges—of learning progression work.

Following the AERA symposium, we organized the Learning Progressions in Science (LeaPS) conference (funded by the National Science Foundation [NSF]) that was held June 24–26, 2009, in Iowa City, IA (http://www.education.msu.edu/projects/leaps/). Eighty-two science educators, scientists, curriculum developers, assessment specialists, psychometricians, policy makers, and teachers attended the conference, where presentations were made and discussions were held about learning progression work with a specific focus on its challenges.

We structured the conference around four strands of learning progression work:

1. Defining learning progressions (the construct of learning progressions and the conceptualization of student progress);
2. Developing assessments to elicit student responses relative to a learning progression (the multiple ways to elicit evidence of students’ knowledge and practices);
3. Modeling and interpreting student performance relative to a learning progression (the inferences made about students’ learning progression levels based on their responses to assessment tasks); and
4. Using learning progressions (the many ways learning progressions may influence science education, including the design of standards, curricula, and teacher education).

These strands of learning progression work usually overlap and therefore cannot be pursued independently. However, separation of the strands reduces the complexity of the issues involved and allows for a more organized conversation about the challenges of learning progression work.

The LeaPS conference provided a structured forum for discussing the challenges associated with these four strands of learning progression work in both plenary and strand-specific sessions. The plenary sessions offered participants the opportunity to learn about the ongoing work of addressing challenges in the four strands. Three plenary sessions highlighted work in the defining, assessing/modeling, and using strands. Richard J. Shavelson gave a keynote address in a fourth plenary session. In addition, a graduate student poster session showcased the work being undertaken by early-career scholars across the four strands. Each LeaPS conference participant selected one strand and attended strand-specific work sessions. Strand leaders facilitated working sessions in each strand. In these sessions, participants shared their work, discussed strand-specific issues, and suggested ways of addressing strand challenges. The strand leaders shared key ideas from the strand-specific
work sessions at a final plenary session that allowed all participants to hear the ideas from the four strands.

It is important to note that the ideas generated at the LeaPS conference do not represent a consensus of all participants. While many ideas had wide agreement, our intent as conference organizers was not to push for consensus. We agree with the report from the Consortium for Policy Research in Education (CPRE; Corcoran, Mosher, and Rogat, 2009) that states that, at this stage, learning progressions are “… potentially important, but as yet unproven tools for improving teaching and learning… developing and utilizing this potential poses some challenges” (p. 5). However, in contrast to the meetings convened by CPRE, which resulted in this widely cited report, the main purpose of the LeaPS conference was not to achieve consensus. Rather, since learning progression work is still in its early stages, we thought it was important to explore a diversity of approaches. Forcing consensus too early may limit the successes that could come from learning progression research. Thus the main contributions of the conference, and, we hope, this book, are the descriptions of challenges researchers face in learning progression work and the approaches they develop to work with and around these challenges.

THE CURRENT STATE OF LEARNING PROGRESSIONS

Since the LeaPS conference, learning progressions have grown in popularity. Articles about learning progressions have appeared more frequently in journals. For example, the Journal of Research in Science Teaching devoted a special issue to learning progression research (Hmelo-Silver & Duncan, 2009). Besides funding much of the learning progression research, the National Science Foundation recently sponsored a “footprint” conference1 to assess learning progression work in science and learning trajectories in mathematics and to make recommendations for future work. In addition, learning progressions have begun to influence national policies. The NRC (2010) included “prototype” learning progressions in its draft framework for the development of science education standards. Although the final version of its Framework for K-12 Science Education (NRC, 2011) did not include these learning progressions, research on learning progressions informed much of the new design of the Framework, and this document calls for increased learning progression research that may inform the development of future standards.

Learning progression research has advanced considerably in the last five years. Many researchers, educators, and teachers now recognize the potential of learning progressions throughout the educational system. However, challenges remain that require resolution before learning progressions can be effectively incorporated into a comprehensive framework for science education. Shavelson and Kurpius (chapter 2) discourage pushing learning progressions in science education prematurely into “prime time”; they caution that additional learning progression research is still required. We view this book as a significant contribution towards addressing these challenges such that learning progressions can fulfill their promise for widespread impact on science education.
CREATION AND STRUCTURE OF THE BOOK

Selecting and Reviewing the Exemplar Chapters

This book evolved from presentations and discussions at the 2009 LeaPS conference. For formal presentation at the conference (including both plenary sessions and strand-specific sessions), we selected 23 proposals from the 38 proposals submitted. Of the 23 conference presentations, we selected 12 presentations for inclusion in this book. We asked two author groups to combine the ideas from their presentations into joint chapters. Therefore, conference presentations resulted in 10 of the 12 “exemplar” chapters that highlight research in the four strands of learning progression work. Thus, the overall acceptance rate from conference proposal to book chapter was 32%. We solicited two more exemplar chapters in order to describe the use of learning progressions in standards development and in large-scale assessment. Consistent with instructions for the conference proposals, we asked the authors to feature challenges from their work on learning progressions as an integral and focal part of their chapters.

After at least one exchange of editorial comment and feedback with each chapter author, we sent all exemplar chapters to three or four external reviewers. We provided these reviewers with a vision statement for the book that highlighted the theme of challenges in work on learning progressions. We asked the reviewers to evaluate how well the chapters identified challenges in learning progression work and how critically the chapters considered the work presented. In addition, we asked the reviewers to rate the clarity and coherence of the writing, to give the chapters an overall rating, and to make comments pertinent for revisions. We asked the authors to respond to the reviewers’ comments and to make revisions as needed. We reviewed the revised chapters before accepting them for inclusion in the book.

Reviewing the Other Chapters

In addition to the 12 exemplar chapters, the book contains this introductory chapter and two framing chapters. There is also a synthesis chapter for each strand and a conclusion chapter. Strand leaders wrote the synthesis chapters that were revised in a feedback process with the book’s editors.

Format of the Book

Section I: Framing section. After this introductory chapter (chapter 1), two framing chapters (chapters 2 and 3) set the tone for the book. Shavelson and Kurpius (chapter 2) recommend that a cautious view should be taken of the recent excitement generated by learning progressions in science education. They argue that researchers in science education should critically examine learning progression work to ensure that the resulting products (learning progressions and associated tools) live up to their promise. Krajcik (chapter 3) responds to this recommendation and describes learning progression research that can advance science education.
Following the Framing Section, there are four sections based on the four strands of learning progression work (Defining, Assessing, Modeling, and Using) used at the LeaPS conference. Each section has four chapters: three exemplar chapters on strand-specific challenges in learning progression work and one chapter that synthesizes ideas from the exemplar chapters and the discussions at the LeaPS conference.

**Section II: Defining learning progressions.** Chapters 4–7 describe the challenges associated with defining learning progressions. Defining learning progressions involves identifying a big idea or core concept and being explicit about what progresses as students develop more sophisticated knowledge and/or practice. There is significant variation in how different projects define learning progressions. Learning progressions have been developed for both content and scientific practices; thus what constitutes “progression” differs by project. The chapters in this section describe how students learn to provide scientific accounts of water and carbon in socio-ecological systems (Gunckel, Mohan, Covitt, & Anderson); how students learn to coordinate observations and explanations of celestial motion (Plummer); and how students learn to engage in scientific modeling practices (Schwarz, Reiser, Acher, Kenyon, & Fortus). Chapter 7 synthesizes these challenges and highlights the often implicit decisions made in defining learning progressions.

**Section III: Assessing learning progressions.** Chapters 8–11 describe the challenges associated with developing assessments that elicit student responses relative to learning progressions. Learning progression assessments are created and used for different purposes—for example, to validate the learning progressions or to evaluate student learning using formative and summative classroom assessments as well as large-scale assessments. In all learning progression assessments, the goal is to develop tasks that may be used to validly and reliably place students at a given level of a learning progression. The chapters in this section describe challenges in the following contexts: gathering evidence about students over a wide age range and across cultures and languages (Jin & Anderson); designing assessment tasks based on a learning progression that contains both content and practices (Gotwals, Senger, & Bullard); and working within (or possibly changing) existing large-scale assessment systems whose purposes and existing structures are not necessarily aligned with the purposes and design of learning progression assessments (Alonzo, Neidorf, & Anderson). Chapter 11 synthesizes these challenges in learning progression assessments and examines other issues in the design of such assessments.

**Section IV: Modeling learning progressions.** Chapters 12–15 describe the challenges psychometricians face when modeling (and interpreting) student performance relative to a learning progression. Because learning progression researchers have a more complex view of student thinking than the “gets it”/“doesn’t get it” perspective, new measurement approaches may be required to interpret student responses to assessment items with respect to the underlying learning progression. The learning progression chapters in this section explore measurement models based on Bayesian Networks (West et al.), Attribute Hierarchy Modeling (Briggs & Alonzo), and Item Response Theory (Wilson).
Chapter 15 synthesizes these modeling efforts and identifies common themes. This chapter also examines the role of grain size and misfit in modeling student responses with respect to learning progressions and explains the importance of including considerations of modeling in all aspects of learning progression work.

Section V: Using learning progressions. Chapters 16–19 describe challenges in the use of learning progressions for various purposes. Researchers have proposed that learning progressions can be used as tools in the development of standards and curricula and in teacher preparation and professional development. However, guidelines for translating learning progressions into tools for specific purposes and audiences are still being developed. The chapters in this section explore the requirements of and challenges inherent in this work: designing curricular resources to support student progress with respect to a learning progression (Wiser et al.); designing learning-progression-based tools useful for supporting development of ambitious teaching practices (Furtak, Thompson, Braaten, & Windschitl); and using learning progressions in the design of state standards (Foster & Wiser). Chapter 19 synthesizes these challenges in using learning progressions and describes themes and issues related to learning-progression-based products. This chapter also argues for the development of learning-progression-based tools, discusses the role of misconceptions in learning progression levels, and addresses the decision of when learning progressions are ready to use.

Section VI: Concluding section. In Chapter 20, the book’s editors summarize the four strands of learning progression work. The chapter also identifies major cross-strand themes in order to make recommendations for how learning progression work might advance through more collaborative research, contributions to policy conversations, and interactions with other stakeholders. The editors emphasize that while the book focuses on the challenges of learning progression work, the science education community should not lose sight of the promises that learning progressions hold. It is only by addressing these challenges that learning progressions can have a significant impact on science education.

GOAL OF THE BOOK

As work on learning progressions is still in its early stages, it is doubtful that all the ways of defining, assessing, modeling, or using learning progressions have been identified. In fact, it is important to explore multiple options for addressing learning progression challenges. Therefore, our hope is that this book, with its focus on identifying and addressing such challenges, will stimulate further interest in learning progression research and model ways of addressing challenges in this complex work.

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Our advisory board members and our strand leaders played critical roles in structuring this book through their conference assistance and their chapter contributions. Each advisory board member provided guidance about a particular learning progression strand: Carol L. Smith (Defining), Charles W. (Andy) Anderson (Assessing), Mark Wilson (Modeling), and Joseph Krajcik (Using). The strand leaders guided discussions at the LeaPS conference and wrote synthesis chapters. Alicia Alonzo and Amelia Wenk Gotwals were strand leaders for the Assessing and Using strands respectively. Lindsay Mohan and Derek Briggs were strand leaders for the Defining and Modeling strands, respectively.

In addition, LeaPS conference participants—see Appendix A—contributed to the discussion of challenges in learning progression work. Their ideas influenced the chapter authors and helped shape the synthesis chapters. Comments by chapter reviewers greatly improved the book. These reviewers are listed in Appendix B. In addition, we thank Marcia Halvorsen, whose careful language editing helped us achieve consistency in the chapters and comprehensibility of complex ideas. We also thank David Zinn, who created the LeaPS logo.

NOTES

1 Charles Anderson, Principal Investigator; DUE-1132562.
2 Julia Plummer also contributed to the Defining Learning Progressions synthesis chapter.

REFERENCES


RICHARD J. SHAVELSON AND AMY KURPIUS

REFLECTIONS ON LEARNING PROGRESSIONS

[The Center on Continuous Instructional Improvement] views learning progressions as potentially important, but as yet unproven tools for improving teaching and learning, and recognizes that developing and utilizing this potential poses some challenges.

Corcoran, Mosher, and Rogat (2009, p. 5)

Learning progressions have captured the imagination and the rhetoric of school reformers and education researchers as one possible elixir for getting K-12 education “on track” (Corcoran et al.’s metaphor, 2009, p. 8). Indeed, the train has left the station and is rapidly gathering speed in the education reform and research communities. As we are concerned about this enthusiasm—and the potential for internecine warfare in a competitive market for ideas—we share the Center on Continuous Instructional Improvement’s view of the state-of-learning-progressions as quoted above. Even more, we fear that learning progressions will be adapted to fit various Procrustean beds made by researchers and reformers who seek to fix educational problems. We believe that learning progressions and associated research have the potential to improve teaching and learning; however, we need to be cautious—learning progressions are especially vulnerable to data fitting in the manner depicted in the Non Sequitur cartoon (Figure 1). As with any innovation, there are both promises and pitfalls associated with a learning progression reform agenda. Moreover, we fear that the enthusiasm gathering around learning progressions may lead to preferential treatment of one solution when experience shows single solutions to education reform come and go, often without leaving a trace. The best of intentions can go awry.

With this preamble, it is understandable that the LeaPS conference1 organizers—Alicia Alonzo and Amelia Gotwals—would invite this chapter’s first author to keynote the conference as a friendly curmudgeon who would raise issues and concerns about the ability of learning progressions to keep the train “on track.” As veterans of formative assessment, learning progressions, and cognitive research on learning and memory, we have learned firsthand how tricky it is to attempt to model cognition and the multitude of differences among individuals. For example, in his doctoral dissertation, Jeffrey Steedle (2008; see also Steedle and Shavelson, 2009) revealed how fragmented students’ knowledge structures are in explanations of force and motion. Knowledge comes in pieces that seem to be cobbled together in a particular context that calls for a particular explanation; this cobbled-together
explanation may or may not align neatly with a learning trajectory (e.g., diSessa, 1988). More problematic, imposing a particular learning trajectory on data leads to misinterpretations and mis-prescriptions for teaching. As we discuss in this chapter, there is likely no single linear path within and across students’ knowledge structures that has the potential to provide a tidy learning progression and prescriptions for teaching.

We have learned from experience how appealing and (superficially) compelling innovative teaching practices can be, especially when implemented by teachers who have their own conceptions of teaching and learning. Research in the Stanford Education Assessment Laboratory (SEAL) on formative assessment, which incorporated a learning progression for students’ learning about sinking and floating, led to the following conclusion that appeared in a special issue of the journal *Applied Measurement in Education*:

After five years of work, our euphoria devolved into a reality that formative assessment, like so many other education reforms, has a long way to go.
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before it can be wielded masterfully by a majority of teachers to positive ends. This is not to discourage the formative assessment practice and research agenda. We do provide evidence that when used as intended, formative assessment might very well be a productive instructional tool. Rather, the special issue is intended to be a sobering call to the task ahead. (Shavelson, 2008, p. 294)

We have also discovered how learning progressions can derail the train by reinforcing naïve conceptions and by prematurely imposing constraints on instruction and cognition that ultimately may not be advantageous. For example, with respect to naïve conceptions, the SEAL research on sinking and floating followed a middle school science inquiry unit (Pottenger & Young, 1992) that was sequenced in a manner consistent with scientists’ evolving explanations of sinking and floating: from mass to volume to volume and mass to density to relative density. One major, unintended consequence of the curricular learning progression approach was that the unit reinforced the mass explanation of sinking and floating, complicating subsequent conceptual development and conceptual change.

With respect to the premature imposition of constraints on instruction, SEAL research (discussed below) tested competing models of cognitive progression—a learning progression and a knowledge-as-pieces conception of growth (Steedle & Shavelson, 2009). We found that constraining students’ ideas to the learning progression led to clumping incommensurate beliefs about force and motion into a single level. Using the learning progression in teaching, then, might work for some students identified at a given level but not other students with a similar level diagnosis. The evidence, rather, supported the knowledge-as-pieces conception in which students cobble together sets of beliefs into a “model” that they use to explain a phenomenon in a particular situation; the cobbling might lead to a different model of the same phenomenon when surface features of the situation change.

In the remainder of the chapter we first present a simplified view of how the field of learning progression conceptualization and research is evolving along two strands: (a) curriculum and instruction and (b) cognition and instruction. Given the possibility of fragmentation, this view may say more about the perceivers than the perceived; we leave that judgment to the reader. We then discuss each strand, drawing lessons learned and proposing approaches for further research. Finally, we try to put the pieces together in a summary.

Before proceeding, it seems appropriate to attend to definitional matters. Along with a number of others who also attended the LeaPS conference, we had the good fortune to serve on the Planning Committee for the Science Framework for the 2009 National Assessment of Educational Progress (NAEP). We described a learning progression as “a sequence of successively more complex ways of reasoning about a set of ideas” and stated that learners move from novice to expert after extensive experience and practice. We added that “learning progressions are not developmentally inevitable but depend on instruction interacting with students’ prior knowledge and construction of new knowledge.” Moreover, we recognized that there was no one “correct order” of progression. We also noted that learning
evolves in a “succession with changes taking place simultaneously in multiple interconnected ways.” Finally we warned that learning progressions are “partly hypothetical and inferential since long-term longitudinal accounts of learning by individual students do not exist” (National Assessment Governing Board [NAGB], 2008, p. 90). We believe that this description constituted a reasonably accurate characterization of learning progressions and what was known in 2006 when the framework was being written.

Corcoran et al. (2009), reporting for a committee of researchers engaged in work on learning progressions, provided a more recent yet consistent definition of learning progressions based on a National Research Council (2007) report: “empirically grounded and testable hypotheses about how students’ understanding of, and ability to use, core scientific concepts and explanations and related scientific practices grow and become more sophisticated over time, with appropriate instruction” (p. 8). Corcoran et al. (2009) also noted that the hypotheses describe pathways students are likely to follow as learning progresses, with the number and nature of such pathways empirically testable and influenced by instruction. These learning progressions are based on “research… as opposed to selecting sequences of topics and learning experiences based only on logical analysis” (p. 8).

There seems to be considerable overlap in the two definitions. Both characterize learning progressions as the sequence or growth of successively more complex ways of reasoning about a set of ideas. They both recognize the centrality of instruction in the evolution of the progressions. They both recognize that such growth is not simple but may take complex forms as learners move from novice to expert. And both definitions recognize the hypothetical character of learning progressions and the need for a strong research base on which to justify policy recommendations for widespread use of such progressions.

It is the hypothetical and under-researched nature of learning progressions that frightens us. It is premature to move learning progressions into prime time, as seems to be happening; significant empirical research is required to establish these progressions. When we think of each set of core ideas that might be the focus of learning progression research and subsequently incorporated into teaching and learning, the amount of research required is staggering. Moreover, by the time this research is completed, the policy and reform circus will have long ago taken down its tents and headed for another apparently greener pasture. Just what are we embarking on and recommending? Might it be premature? Or might we recognize the hypothetical nature of learning progressions, call for more research, but push ahead with the empirically-based revision of progressions in the meantime? That is a question we pose to our community as we move forward.

TWO ROADS TO LEARNING PROGRESSIONS

Robert Frost’s (1916) well-known poem “The Road Not Taken” describes the choice a traveler faces when meeting a fork in a wood:
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Two roads diverged in a yellow wood,
And sorry I could not travel both
And be one traveler, long I stood
And looked down one as far as I could
To where it bent in the undergrowth.
Then took the other, as just as fair,
And having perhaps the better claim,
Because it was grassy and wanted wear;
Though as for that the passing there
Had worn them really about the same.

... Somewhere ages and ages hence:
Two roads diverged in a wood, and I—
I took the one less traveled by,
And that has made all the difference.

Like the traveler in the poem—although more simply—we face a choice between two roads: interrelated roads traveled by learning progression reformers and researchers. One appears more worn, but like the roads in Frost's poem, both are really worn about the same. It is the choice that makes all the difference.

We call the first road the curriculum and instruction road and the second road the cognition and instruction road. Fortunately, we are more than one traveler and do not have to choose (or should not choose) at a glance. President Obama's stimulus package (e.g., see http://www2.ed.gov/programs/racetothetop-assessment/index.html accessed November 3, 2010) has the potential to allow researchers and reformers the pursuit of both in order to see if, in fact, one of the two roads makes all the difference, whether both do, or whether neither does.

The Curriculum and Instruction Road

The curriculum and instruction road may be characterized by the development of instructional units on, say, living organisms (Lehrer & Schauble, 2000) or sinking and floating (Shavelson, Yin, et al., 2008); K-8 curricular specifications for, say, atomic structure (Smith, Wiser, Anderson, & Krajcik, 2006); or even content specifications spanning K-12 science (e.g., Valverde & Schmidt, 1997).

To be sure, cognition is not omitted from the curriculum and instruction road. Yet we believe that curriculum and instruction progressions are based largely on logical analysis of content structure—perhaps a kind of spiral curriculum as envisaged by Jerome Bruner (1960) in The Process of Education. This logical content analysis is combined with what we call “psychologizing” as to how students might develop ideas cognitively. Yet such psychologizing is always limited to the person engaged in this process. When concrete data are brought to bear on the cognitive processes students employ, complication and surprises arise. This is evident as students “think aloud” when they wrestle with solving a problem or explaining why things sink and float.
Perhaps an example of a learning progression that follows the curriculum and instruction road would be helpful. In SEAL research on the use of formative assessment in teaching about sinking and floating (e.g., Shavelson, Young, et al., 2008), we posited a learning progression that followed the series of investigations described in *Foundational Approaches in Science Teaching* (Pottenger & Young, 1992; see Figure 2). The dependency of the learning progression on teaching and learning is evident in the performance of two students, one from a “successful” guided-inquiry teacher (Gail) and another from an “unsuccessful” open-ended discovery teacher (Ken). Gail’s student appears to follow the learning progression; Ken’s student does not. Rather, Ken’s student is mired in the conception that heavy things sink and light things float. That is, Gail’s guided-inquiry teaching provided empirical support for the learning progression, but Ken’s open-ended discovery teaching did not.

![Figure 2. Learning progression for sinking and floating differs for two students: one student taught by a “successful” guided-inquiry science teacher (Gail) and one student taught by an “unsuccessful” open-ended discovery science teacher (Ken). From “On the Role and Impact of Formative Assessment on Science Inquiry Teaching and Learning,” by R. J. Shavelson, Y. Yin, E. M. Furtak, M. A. Ruiz-Primo, C. C. Ayala, D. B. Young, M. L. Tomita, P. R. Brandon, and F. Pottenger in Assessing Science Learning: Perspectives from Research and Practice by J. E. Coffey, R. Douglas, and C. Stearns (Eds.) (p. 34), 2008, Arlington, VA: National Science Teachers Association. Copyright 2008 by the National Science Teachers Association. Reproduced with permission of National Science Teachers Association via the Copyright Clearance Center.](image-url)
With a few exceptions, learning progressions following the curriculum and instruction road have not been empirically validated, at least in the strong sense that each learning progression posited has been researched, replicated, and validated as described by Corcoran et al. (2009). Empirical validation of learning progressions might be obtained through cognitive workshops, short essays, predict-observe-explain probes, teaching experiments, and the like that elicit students’ explanations of natural phenomena (e.g., why do things sink and float?). Indeed, SEAL research suggests that context—in this case teacher and teaching method—will greatly influence the validity of a learning progression interpretation of student performance.

Even though learning progressions following the curriculum and instruction road have seldom been adequately validated empirically, we need to follow this road to the development of learning progressions for a number of reasons. Logical analysis and psychologizing can only take us along the road; empirical research can help guide us. But given the immensity of the curriculum, how might we accomplish the kind of self-correcting research needed to fine-tune and validate learning progressions? We don’t know, but we have a proposal—one that might be surprising. We believe that teaching experiments and action research with collaborating teacher and researcher teams might amass the evidence and provide the practical wisdom needed to study and refine learning progressions. (Our proposal contrasts with that of Shavelson, Phillips, Towne, and Feuer, 2003, who argue that such experiments are only a beginning and need to be replicated on large scale). We envision such teams working on particular progressions, learning what does and does not work, fine-tuning the progressions, and making their findings available to others working on the same progression. In this way, we might expand both our knowledge of developing and validating learning progressions and our practice in using them. If we assemble a critical mass of teams working on important learning progressions, we might jump start the research and development agenda and create enough replications to evaluate the validity and utility of the proposed progressions. We would then be in a position to know if this is a road worth taking as we logically analyze and psychologize learning progressions. All of this might then lead to new and improved methods for studying learning progressions, which seem a practical necessity.

The Cognition and Instruction Road

While the curriculum and instruction road begins with a logical analysis of content, the cognition and instruction road begins with a psychological analysis of cognition underlying content—what does it mean to understand core ideas in science? How can we use knowledge about cognition to build instruction that improves the chances of all students learning at high levels?

There is a long tradition in the psychological analysis of cognition related to subject-matter learning; studies by David Ausubel (1963), Robert Gagne (1965), Jerome Bruner (1966), and Robert Glaser (1963) are early examples. The goal
of this work is to map the growth of cognition as a student learns about particular concepts, such as force and motion. That is, what does the path look like as a student, over time, moves from naïve conceptions of force and motion to expert conceptions consistent with the understanding accepted by the scientific community? Most importantly, what do the paths look like between novice and expert, and how might they inform curriculum, teaching, and assessment?

More recently, Mark Wilson (2009) and Alicia Alonzo and Jeffrey Steedle (2009) have mapped learning progressions from a cognitive perspective. A third example, a learning progression for force and motion—specifically for explaining constant speed—is shown in Table 1. The progression describes what the student knows and can do when confronted by force and motion phenomena, more specifically when a force is and is not present, and when the object is and is not in motion. That is, the learning progression maps a cognitive progression for “understanding” force and motion from naïve (Level 1) to expert (Level 4).

Table 1. Force and Motion Learning Progression.

<table>
<thead>
<tr>
<th>Level (Facets)</th>
<th>Description and Expected Responses to Item Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 (00)</td>
<td>When balanced forces act on an object, the object is either at rest or moving with a constant speed. When unbalanced forces act on an object, the object's speed changes.</td>
</tr>
<tr>
<td></td>
<td><em>Balanced force:</em> When balanced forces act on an object, it is either at rest or moving with a constant speed.</td>
</tr>
<tr>
<td></td>
<td><em>No force:</em> After a force is removed, an object slows down because of friction, which acts in the direction opposite motion.</td>
</tr>
<tr>
<td></td>
<td><em>Constant motion:</em> An object is moving with constant speed when forces are balanced.</td>
</tr>
<tr>
<td></td>
<td><em>No motion:</em> An object remains at rest when a horizontal force is equal to an opposing force.</td>
</tr>
<tr>
<td>3 (00, 70)</td>
<td>When balanced forces act on an object, the object is at rest or slowing down. An unbalanced force in the direction of motion is needed to maintain constant speed. Speed is proportional to applied force.</td>
</tr>
<tr>
<td></td>
<td><em>Balanced force:</em> When balanced forces act on an object, it is either at rest or slowing down.</td>
</tr>
<tr>
<td></td>
<td><em>No force:</em> After a force is removed, a force continues to act on an object as it slows down.</td>
</tr>
<tr>
<td></td>
<td><em>Constant motion:</em> A constant net force or unbalanced force on an object maintains constant speed.</td>
</tr>
<tr>
<td></td>
<td><em>No motion:</em> Same as level 4.</td>
</tr>
<tr>
<td>2 (90)</td>
<td>No motion implies that no force is acting on an object. Exception: gravity may act on objects at rest. Motion implies that a force is acting on an object.</td>
</tr>
<tr>
<td></td>
<td><em>Balanced force:</em> Same as level 3.</td>
</tr>
<tr>
<td></td>
<td><em>No force:</em> Same as level 3.</td>
</tr>
<tr>
<td></td>
<td><em>Constant motion:</em> Same as level 3.</td>
</tr>
<tr>
<td>1 (00)</td>
<td>If an object is pushed horizontally and remains at rest, there must be a greater force keeping the object at rest.</td>
</tr>
<tr>
<td></td>
<td><em>Balanced force:</em> When balanced forces act on an object, it is moving at a constant speed.</td>
</tr>
<tr>
<td></td>
<td><em>No force:</em></td>
</tr>
<tr>
<td></td>
<td><em>Constant motion:</em> Same as level 3.</td>
</tr>
<tr>
<td></td>
<td><em>No motion:</em> An object remains at rest when a horizontal force is not great enough to overcome a larger frictional force, gravity, or the inertia of the object. The force of gravity is not equal to the upward force on an object at rest on a surface.</td>
</tr>
</tbody>
</table>

An issue with this kind of learning progression is whether it accurately reflects cognition. Put another way, does students’ knowledge actually grow in this linear, progressive way? Put still another way, does the progression provide a valid and practically useful way of portraying the pathway of cognitive development? By valid we mean whether students’ knowledge actually grows in this way. By useful we mean that if their knowledge does grow this way, can the progression inform curriculum development, classroom teaching, and assessment?

There is another way to conceive of the pathway from naïve to expert understanding of a core science conception. It builds on two principles in cognitive science. The first principle is that knowing and doing are embedded in a cognitive network. The second principle is that memory is reconstructive. Together these principles lead to the hypothesis that when confronted by a natural phenomenon and posed a problem, students will construct an explanation that is context-dependent, drawing on bits and pieces of knowledge embedded in a memory network to reconstruct their knowledge and, thus, to provide an explanation. Note that if students at different places in the evolution from naïveté to expertise have bits and pieces of knowledge organized in a coherent linear manner, their cobbled-together explanations would most likely follow a linear learning progression, such as the one shown in Table 1.

But suppose students’ knowledge is not so orderly. Suppose they have bits and pieces of loosely related knowledge about force and motion in their cognitive networks, garnered from extensive personal experiences and brief classroom encounters. In this case, their explanations will most likely be quite context-specific; if superficial characteristics of the problem change, we suspect students would change their explanations in ways not explicated by the learning progression in Table 1. Progress might not be neat and linear, although our statistical and qualitative modeling might force it, Procrustean style, into something neat and linear. Rather, progress from novice to expert might be better conceived as somewhat hectic and non-linear. If we conceive of memory as a complex network, at various times a student might make progress by building up bits and pieces of knowledge about force and motion into a small subnet, but other bits and pieces might still be unconnected. Of course, students might vary on which subnets they develop and which bits and pieces of knowledge lie scattered in memory. Depending on the context of a force and motion problem, an appropriate subnet might be accessed by one group of students but not by other groups.

If knowledge comes in bits and pieces, then the knowledge appears organized and coherent only when a high level of competence is reached. Anything less than expertise gives rise to multiple “mental models” and explanations for the same underlying phenomenon by the same person under different contexts. And if this is so, prescriptions based on a linear learning progression might not be accurate; if inaccurate, they might be heuristic at best and misleading at worst.

Jeffrey Steedle’s (2008) doctoral dissertation provides examples of our concern. He examined the extent to which students’ responses to force and motion test items fit a learning progression. He made this examination for three different learning
progressions dealing with conceptions in force and motion, including constant speed as shown in Table 1. He used multiple-choice item data where the alternatives included naïve conceptions or “facets” of understanding from Jim Minstrell’s Diagnoser (Minstrell, 2000). In a Bayesian latent class analysis of the data, comparing models based on the learning progressions and models based on “knowledge in pieces” in a cognitive network, Steedle and Shavelson (2009) report:

Students’ actual response patterns aligned with the proposed learning progressions for two sorts of students: those whose understanding is (nearly) scientifically accurate and those [naïve students] who believe that velocity is linearly related to force. Learning progression diagnoses for these levels could be interpreted validly (with few caveats), but diagnoses for the other levels could not because students diagnosed at those levels are not expected to consistently express the ideas associated with their learning progression levels … This suggests that it is not feasible to develop learning progressions that can adequately describe all students’ understanding of problems dealing with Explaining Constant Speed. Finally, an analysis of relationships between learning progression levels and facet classes indicated that the confirmatory [learning progression] model failed to make important distinctions between latent classes that the exploratory [knowledge in pieces] model made. (p. 713)

Therefore, Steedle and Shavelson (2009) conclude:

Students cannot always be located at a single level of the learning progressions studied here. Consequently, learning progression level diagnoses resulting from item response patterns cannot always be interpreted validly. It should be noted that the results presented here do not preclude the possibility that some individuals systematically reason with a coherent set of ideas. These results do, however, provide strong evidence that there are few substantial groups of physics-naïve students who appear to reason systematically about the forces acting on objects with constant speed. Further, these results corroborate findings from other physics education research indicating that many physics-naïve students should not be expected to reason systematically across problems with similar contextual features. (p. 713)

There is, then, evidence gathered on the cognition and instruction road that gives us pause as we proceed in the pursuit of learning progressions. This evidence suggests re-thinking how we conceive of learning progressions or even if learning progressions are the “right” way to think about the growth of students’ knowledge. Indeed, the evidence supports the not-so-tidy definition of learning progressions used in the NAEP 2009 Science Framework (NAGB, 2008). Progressions are not developmentally inevitable but depend on instruction interacting with students’ prior knowledge and new knowledge construction; there is no one “correct order” for the progression. That is, progressions evolve in a succession of changes that take place simultaneously in multiple, interconnected ways. Progressions are, to date,
partly hypothetical and inferential since long-term longitudinal accounts do not exist for individual learners.

Perhaps conceiving of knowledge growth as a learning progression, let alone attempting to order levels in a learning progression, needs some re-thinking. Rather, conceiving of knowledge growth as a hectic, opportunistic, constructive process of cobbling together bits and pieces of knowledge, as Steedle’s (2008) dissertation suggests, might prove to be beneficial as we attempt to assist teachers in building students’ understanding of the natural world. Then we would need to figure out how the bits and pieces evolve into coherent models of the natural world with instruction.

CONCLUDING COMMENTS

The first author was asked to act as a friendly curmudgeon at the LeaPS conference in order to raise issues and ask questions as the learning progression train gathers steam and leaves the station. If we have accomplished anything, it has been to be curmudgeon-like. Our overriding concern is that an inadequately tested idea for improving curriculum, teaching, and assessment is being moved into prime time prematurely. We state this concern with full recognition that the learning progression concept has legs. If the concept is not developed in practice, it will languish in researchers’ arcane journals. Nevertheless, we warn that there is the potential that a premature rush to implementation may result in more unintended mischief than intended good at this point.

We must, for example, guard against fitting our data to a preconceived notion of a learning progression. Rather, in a Popperian sense, we should seek disconfirmation; only when we fail should we move the progression into prime time. Even at this point, we need to monitor how well the progression works and agree to modify it as evidence demands.

We also need to make a concerted effort to gather evidence from the field that learning progressions embedded in curricular materials are operating as intended. We posed one possible approach that would move this agenda forward—that of teaching experiments and action research conducted by collaborating teacher-researcher teams. Such teams, on a large scale, might gather the empirical evidence and provide the practical wisdom needed to refine and improve learning progressions. Teams can work on particular progressions, learn what works and what does not, fine-tune the progressions, and make their findings available to others working on the same progression. We trust that those conducting learning progression research will think of other ways to address this area of concern.

A concerted effort should also be made to ensure that cognitive interpretations of learning progressions are accurate, useful, and lead to intended learning with minimal unintended consequences. Learning progressions may not be nice and linear. Teachers need to know this as researchers pursue heuristic representations of progressions to assist in practice, with an expectation of evolution and correction through research and practice over time. It seems that progress from
novice to expert may not be linear but may be better conceived as a wandering journey through a complex memory network comprised of bits and pieces of information. Students might be nested in non-linear subnets for particular contextual representations of a problem. Steedle’s (2008) research suggests a methodological approach for guarding against imposing theory on data by testing theory—our notion of a particular learning progression—with data. Both substantive psychological theory building and research into learning progressions are needed urgently for the most important science conceptions in the curriculum. A concerted research effort is needed. We again trust that those in the learning progression community will think of other ways to address this area of concern.

We have one final curmudgeonly thought. Whatever we come up with as a learning progression research and development agenda for reform, it must take into account the capacity of teachers to implement. The four million teachers in the United States are not, in general, like the teachers who volunteer to work with researchers in developing and testing cutting-edge ideas. It is well known that the former group of teachers lack, on average, the critical content knowledge needed to use learning progressions. They also lack the time needed to acquire that knowledge so that they may address the challenges that emerge when students do not nicely and neatly follow the prescriptions of the progressions and the textbooks. Whatever we do needs to take this reality into account; teacher professional development may not be extensive enough to address this challenge. So, finally, we trust that learning progression researchers will also think of ways to address this area of concern.

In closing, we have discussed two roads taken in the pursuit of learning progressions. In truth, the two roads don’t diverge in a yellow wood nearly as much as Frost’s roads. Rather, they continually intersect at the point of instruction. So the final challenge is to merge these roads as a major highway of coherent research to support the policy engine that is now steaming down the track… can we even catch up before it derails?

ACKNOWLEDGEMENTS

We would like to thank Alicia Alonzo and Amelia Gotwals for inviting the first author to address the Learning Progressions in Science (LeaPS) conference. We would also like to thank Jeffrey Steedle and Alicia Alonzo for their comments on earlier drafts of this chapter. They made invaluable suggestions. Any errors of omission or commission are, of course, ours.

NOTES

1 The Learning Progressions in Science (LeaPS) conference took place from June 24–26, 2009, in Iowa City, IA.
2 Incidentally, Bruner (1966) had a particular version of psychologizing in building curriculum. Curricular materials should move from initially enactive (physical manipulation) to iconic (mental image of physical manipulating) to symbolic (symbol replaces mental image).
REFERENCES


THE IMPORTANCE, CAUTIONS AND FUTURE OF LEARNING PROGRESSION RESEARCH

Some Comments on Richard Shavelson’s and Amy Kurpius’s “Reflections on Learning Progressions”

Amelia Wenk Gotwals and Alicia Alonzo asked me to write a response to “Reflections on Learning Progressions” by Richard Shavelson and Amy Kurpius (chapter 2). I am pleased to contribute these remarks to further the discussion on learning progressions.

Shavelson and Kurpius, who describe themselves as “friendly curmudgeons,” begin their reflections by warning the community not to adopt simple solutions by forcing data to fit learning progressions. This is a wise caution since force fitting of data, before we have learned all that we can from this research paradigm, will prove fatal to learning progression research. Such research will improve the learning and teaching of science only if the community conducts careful, systematic, and unbiased research.

When I first entered the world of education research in the mid-1980’s, misconceptions research was in full bloom and, as learning progressions do now, offered the promise of guiding research in science education and of helping students learn science. Unfortunately, although some researchers conducted excellent research and advanced our knowledge, everything was interpreted as a misconception. Laundry lists of misconceptions were published and presented at conferences. If students gave incorrect responses to assessment items or in interviews, the conclusion was that they held a misconception about the idea. Any response that did not match canonical science was considered a misconception. Many researchers failed to recognize that students may have simply been unfamiliar with the particular idea being assessed or that the items used to assess understanding were poorly written. I raise this issue because it represents a good illustration of what Shavelson and Kurpius refer to as “Procrustean bed” methodology—when researchers force a pattern onto data to fit the main idea of science education research.

To avoid such force fitting of data to learning progressions, the community needs to critically monitor and evaluate its own work. Without such self-evaluation, like Shavelson and Kurpius, I fear that an abundance of learning progressions will be developed that has not been carefully researched. As a result, learning progression research will fail to produce findings that promote learning of core ideas in science.
Learning progressions, like formative assessment, appeal to researchers, practitioners, and policy makers. However, this appeal should not allow for superficial development of ideas. Nor should it prevent systematic research and development to occur so that learning progressions can quickly be developed and used in schools. Individuals who conduct learning progression research know the difficulties and challenges of the work, especially since clear procedures for developing and testing learning progressions are underspecified. Of course, as Shavelson and Kurpius state, a challenging situation exists because policy makers, curriculum designers, and teachers wish to use learning progressions to guide assessment and curriculum materials development and instruction.

Creating learning progressions, unfortunately, requires years of systematic research. One major premise of learning progression work is that it requires empirical accounts of how students learn. Although some research findings exist that the community can draw upon in the design of learning progressions, much more is needed. As Shavelson and Kurpius state, while some initial learning progressions are based on research findings, these learning progressions require further development. Until the results from systematic research are available, the gaps in our knowledge need to be filled with our best guesses. I agree with this approach; however, in the absence of such research, rationales based on theoretical foundations for decisions need to be provided when articulating levels of learning progressions.

Although the community should heed this warning by Shavelson and Kurpius, it also needs to move forward. Because the support of students’ learning of science has never taken a developmental perspective, science learning has suffered. Learning progressions focus the science education community on how ideas gradually become more sophisticated over time based on coherent unfolding of ideas, instruction, and prior experiences. Science education would benefit from a developmental perspective that extends beyond thinking about how science ideas progress based on the logic of the discipline to include how students can reason with core ideas based on the examination of more targeted experiences under optimal teaching and learning conditions.

Let’s look at an example to see the value of learning progressions in designing curriculum materials. It is not unusual for curriculum materials to introduce ideas about the water cycle before students develop understandings related to the particle model of matter. Although students can certainly learn about the water cycle in a descriptive sense without understanding the particle model of matter, they cannot provide a causal mechanism that explains the water cycle in the absence of the particle model. Unfortunately, curriculum materials and teachers too quickly introduce the particle model, failing to build an evidence-based model that has explanatory power. What is so unfortunate about this instructional approach is that students perceive and memorize the particle model as fact rather than as a framework that can provide causal accounts of phenomena encountered in their daily lives. However, if instruction could help students develop the beginnings of a particle model, learners could use this model to explain phase changes. Then, when students
explore ideas related to the water cycle, the particle model is reinforced and more connections are made. At this point, students develop a more integrated understanding that allows them to offer more sophisticated causal accounts of other everyday phenomena. This is the power behind learning progressions. Those of us in the community should not let this power slip away because of sloppy and rushed research.

As someone whose expertise is in curriculum development and the design of learning environments, I realize that the water cycle could drive the learning of the particle model of matter. I am not criticizing this approach since there are many contexts that could be used for learning core ideas; however, my point is that instruction cannot simply provide students with a model and expect them to see its power to explain phenomena. Instruction needs to help learners develop understanding of the model and see the potential the model has as a causal mechanism to explain and predict phenomena.

Learning progressions move away from the one-paragraph/one page description of content ideas that too often are presented in science education. Rather, learning progressions provide curriculum designers with the tools needed to purposefully build upon students’ current understandings in order that they will form richer and more connected ideas over time (Margel, Eylon, & Scherz 2008; Merritt, Krajcik, & Shwartz, 2008). Curriculum materials, as Shavelson and Kurpius state, must not only build from the nature of the discipline but also from what is known about how students learn and reason. Fortunately, such materials are beginning to appear, for example, in research by Hannah Margel and her colleagues (Margel et al., 2008), Andy Anderson and his colleagues (Mohan, Chen, & Anderson, 2009) as well as in my work with various colleagues (Krajcik, Reiser, Sutherland, & Fortus, 2008; Merritt, 2010; Merritt et al., 2008). These materials were carefully researched in classrooms to examine if and how they support student learning. In many respects, these materials were developed as teaching experiments (the term used by Shavelson and Kurpius). I do not claim that one curriculum fits all teaching situations or that curriculum materials are an essential aspect of learning progression research. Rather, it is my contention that curriculum developers can take advantage of learning progression research to design curricula with a developmental focus. Such a focus can provide learners with opportunities to build more connected and sophisticated understandings as they examine related ideas in new and more complex situations.

This narrative, which describes how I envision the essence of the learning progression approach, matches the descriptions of learning progressions by Shavelson and Kurpius (chapter 2) and by Corcoran, Mosher, and Rogat (2009). A learning progression provides a sequence of successively more complex ways of reasoning about a set of ideas as learners move from novice to experts as they engage in key learning experiences (National Assessment Governing Board, 2008). Perhaps science education has created a theoretical and research paradigm that can drive the learning of science in the years ahead. However, the research community needs to ensure that good development and research work continue.
Next I highlight some important aspects of the design and research of learning progressions that, although presented in the Shavelson and Kurpius chapter, require further articulation.

First, learning progression work is based on a solid foundation of theoretical ideas. In some respects, researchers are in a unique position as far as science education since the cognitive and learning sciences communities have provided key theoretical underpinnings for learning progressions. *Taking Science to School* (National Research Council, 2007) and *How People Learn* (National Research Council, 1999) articulate what is known in the field about student learning. Never before has the science education community possessed such a solid and robust understanding of how to advance student learning.

The structure of expert knowledge as tightly connected around core ideas that drive thinking, observing, and problem solving is a key that informs learning progression research. This understanding suggests that only a few learning progressions for core/big ideas in the disciplines require careful development. The National Research Council identified a few core ideas that drove their work in the design of the new conceptual framework for K-12 science education.¹ This does not mean that there is only one trajectory for each core idea since learning is influenced by instruction and personal experience. However, to help students develop and refine their ideas, a few hypothetical learning progressions for core ideas should be developed. Thereafter classroom research/teaching experiments should further refine and articulate each learning progression. Unfortunately, very little empirical work is available to help guide the design of learning progressions around these big ideas. For instance, I question if the idea of density should form a learning progression.² If this is the case, then researchers need to learn how to support students in building the idea of density by determining which key phenomena, experiences, and analogies are useful to this learning. For the project Investigating and Questioning our World through Science and Technology [IQWST] Krajcik, Reiser et al. (2008) describe an activity a classroom teacher created that seemed useful for developing middle school students’ understanding of density. In this activity, there are two boxes of equal size: One is filled with Styrofoam packing peanuts and the other with books. Although the box with the books has much greater mass than the box with Styrofoam packing peanuts, their volumes are the same. The teacher then invites different students to lift the boxes. This multimodal...
experience helps students build connections they will remember. The teacher uses this activity to help students realize that two variables, mass and volume, are important in the density of materials. Building this understanding is critical to understanding density. This example points to an important research component in developing, refining, and articulating learning progressions: Once learning progressions are developed, the community needs to conduct research to gather learning data for various segments of the progressions. If density is part of the learning progression on the properties of materials, then it is essential to identify key instructional activities that can develop student understanding.

Second, I agree with Shavelson and Kurpius that learning progressions are not linear, that students need to revisit ideas under new contexts to refine their understanding, and that ideas often link across learning progressions. For instance, ideas related to force and interactions intersect with learners' understanding of ideas related to transformations of matter. Without building certain key ideas in forces and interactions, a learner can only proceed so far in understanding transformations of matter and can only develop a descriptive model of transformation instead of a mechanistic model.

In my view, there are four requirements for learning progressions. First, the big idea should be identified and explained. This step involves unpacking the big idea (see below for additional ideas about unpacking). Second, the learning progression should be clearly described at each level. This description should explain the student reasoning expected at each level, prerequisite understandings that often are part of the previous level, and the links to related ideas. Research-based articulations of the difficulties and challenges learners experience as they move to higher levels are essential. As Anderson (2008) notes, the levels should relate logically from the learner’s perspective not necessarily based only on the logic of the discipline. As part of considering the learner’s perspective, we should also examine how students learn and how to identify the content they find engaging. Third, each learning progression should include psychometrically validated assessment items that can identify students at a particular level. Fourth, each learning progression should include classroom-tested instructional components—key phenomena, analogies, and tasks—to use in advancing learners to the next level of understanding. These instructional components are not curriculum materials, but they provide teachers and curriculum developers with instructional components that are useful for building curriculum materials.

A learning progression for the particle nature of matter will require that students understand that gases are matter and as such have mass. It has been well documented that many middle school students do not think of gases in this way. An instructional activity for this learning progression could be to ask students to determine the mass of a filled CO2 cartridge, empty the CO2 cartridge, and then to determine its mass again. The change in mass of the cartridge is evident. But one example or illustration is never enough to build understanding. This also works with a filled gas tank for a barbeque grill. Anyone who has filled a barbeque gas tank knows that the filled tank is much heavier than the empty tank. However, the difference in weight between the filled and empty tank comes to a surprise to many. Other ideas might work as well.
For instance, I spoke with Dr. Phil Johnson, a science educator and divisional director for postgraduate education at Durham University in England, about his work on learning progressions. He described how students determine that the mass of a closed system does not change when a substance transforms from the liquid stage to the gaseous stage (P. Johnson, personal communication, November 5, 2010). The critical point I am trying to make is that although there could be several key instructional activities to help students move from one level to the next, there is probably a finite set. These key instructional components are linked to the current level and to assessments associated with the learning progression and show how to support students moving to the next level.

These learning progression activities for the particle model of matter contain critical instructional components that support students constructing understanding to move to the next level. If such instructional components are not addressed, in my opinion, learning progression work is vacuous, as a learning progression by itself cannot support teachers or curriculum. I know a difference of opinion exists in the learning progression community about the value of these instructional components and whether they should be considered part of the learning progression or if they are instead part of a teaching progression. However, without them, I do not see how researchers could validate a learning progression; in my work, these instructional components are essential in learning progressions. In testing a learning progression, researchers need to examine how students progress when opportunities to learn arise; otherwise, research measures the result of instruction that is based, not on how students develop ideas across time, but on curriculum materials that may be less than optimal for supporting learning (Roseman, Stern, & Koppal, 2010). In some sense, the conversation about whether these instructional components are/are not aspects of the learning progression is misguided. To validate a learning progression, opportunities to learn are necessary.

The work by Anderson and colleagues on a learning progression for environmental literacy (e.g., Mohan et al., 2009) illustrates the importance of conducting learning progression work in classrooms that target big ideas. Many high school students don’t achieve upper levels of environmental literacy because they lack the opportunity to learn the big ideas in the learning progression with the typical high school curriculum. However, high school students who have participated in teaching experiments have experienced coherent instruction take a different path and reach higher levels of performance. Hence, the validation of learning progressions should take place in environments where students have opportunities to learn the ideas in the learning progressions. The challenge is to develop learning environments in which the components work together—the learning progression, assessments and instruction. In the absence of one, you cannot make progress with the others. Other colleagues (e.g., Richard Lehrer and Leona Schauble) argue for the importance of linking professional development to learning progressions. I agree with the important role that professional development plays in helping teachers learn the new practices that learning progressions require. Without professional development, it is unlikely we will see such practices in classrooms.
Like good curmudgeons, Shavelson and Kurpius set up two non-intersecting roads traversed in learning progression work—the curriculum and instruction road and the cognition and instruction road. (My background and work on the design of curriculum materials and learning progressions seems to place me along the curriculum and instruction road). But I fear that Shavelson and Kurpius have over-simplified the situation. A number of researchers have created a third road that merges the first two roads—the cognition, curriculum, and instruction superhighway (see below).

In IQWST (Krajcik, Reiser et al., 2008), my colleagues and I think seriously about what students need to learn (Krajcik, McNeill, & Reiser, 2008). We rigorously address content ideas by identifying and unpacking science standards. Unpacking refers to breaking apart and expanding various concepts to elaborate the intended content. In unpacking a science standard, in addition to examining the importance of the content, we look at how students reason and how they use knowledge. We examine common student difficulties, prior understandings needed to build the target understanding, and aspects of prior conceptions that may pose difficulties. Thus unpacking a science standard helps articulate its content and helps identify the reasoning and use of knowledge appropriate for learners.

Once the key science ideas are identified and unpacked, we develop “learning performances” to articulate the cognitive tasks that students should accomplish with this content. The development of learning performances is a critical step because science standards are typically presented as declarative statements of scientific facts that do not specify the type of reasoning students should engage in with ideas. My work with Namsoo Shin and Shawn Stevens uses a similar process of unpacking, but we refer to learning performances as “claims” and identify the evidence students must show the claim is met (Shin, Stevens & Krajcik 2010).

Several other groups (e.g., Duncan, Rogat, & Yarden, 2009; Songer, Kelcey, & Gotwals, 2009) create learning progressions that blend key science ideas and practices with students’ reasoning. Although these researchers may appear to be on the curriculum and instruction road, their work suggests they have split off somewhat from that road. They seem to be taking a new road that intersects both the curriculum and instruction road and the cognition and instruction road. Still other researchers (e.g., Lehrer & Schauble, 2008) appear to be transversing the cognition and instruction road as they unpack what it means to model with various mathematical ideas such as probability. Schauble and Lehrer also follow the same road that Anderson, Duncan, Songer, and I have taken (Krajcik, Reiser et al., 2008). This road is neither the curriculum and instruction road nor the cognition and instruction road but rather a blend—the cognition, curriculum and instruction superhighway. These research efforts represent the third road that Shavelson and Kurpius envision. The works cited clearly show this new road is already under construction and is being used. It is not yet the superhighway the field needs, but researchers are laying its foundation by blending the work of diverse groups who have expertise in the cognitive and the learning sciences, science or mathematics, science/mathematics education, and the teaching and learning of science/mathematics. Researchers are blending knowledge of learning, classrooms,
psychometrics and the sciences in order to explain and advance student learning. The community still has a long way to go to complete this superhighway, but this work is currently underway laying a foundation for improving teaching and learning.

As Shavelson and Kurpius envision, the curriculum and instruction and the cognition and instruction roads have come together, and the learning progression community needs to follow this road to make the type of progress the field needs. However, it will take the work of diverse individuals to build these learning progressions. My work with learning progressions (e.g., Shin & Krajcik, 2008) suggests that the psychometric expertise that individuals such as Mark Wilson and Jim Pellegrino bring to the construction site is required. The National Science Foundation (NSF), which is concerned with bringing psychometricians and science educators together, sponsored a parallel workshop to the LeaPS conference (see Duncan & Krajcik, 2008) to help young scholars in the field develop psychometric expertise.

Shavelson and Kurpius make several points in their closing remarks that I wish to re-emphasize. I agree that the community needs to prevent force-fitting data to preconceived notions about learning progressions. This won’t be easy to avoid, and the community must be self-critical to avoid this tendency. In addition, the community should gather evidence from a variety of classrooms in which curriculum materials and instruction follow ideas linked to levels of a learning progression to determine if the learning progression operates as intended. This is challenging work since few curricula based on learning progressions now exist. When such research doesn’t exist, it needs to be conducted or researchers and designers need to take their best guess based on theory and experience to design materials. Through testing these materials, researchers will learn how students’ understandings develop. The NSF should also offer strong support of systematic and long-term research on learning progressions. If the current round of funding is not continued in future cycles, knowledge for the field will be developed, but it will be limited. Learning progression research, by its very nature, is longitudinal and it is unlikely that researchers will design optimal progressions and associated curriculum and assessment materials on their first attempt. Researchers will learn much from the data they collect that will feed back into revising the learning progression. Moreover, because learning progressions depend on instruction interacting with learners’ prior knowledge, students who advance to higher grades, having experienced instruction in earlier grades based on learning progressions, should reason about phenomena differently compared to learners who have not had such instruction.

Finally, the idea of teaching experiments is consistent with the work in IQWST and the work by Andy Anderson, Ravit Duncan, and others. Working closely with teachers and researchers with different areas of expertise is critical to developing learning progressions and materials that can change how learning occurs in the classroom. Research teams should consist of individuals with expertise in teaching, psychometrics, the cognitive and learning sciences, science education, and the science disciplines. In addition, more teachers should be involved with these teaching experiences so that we can see how these ideas scale and if they can be used in a variety of classrooms.
The chapter by Rich Shavelson and Amy Kurpius points to some important considerations. Generally a curmudgeon is defined as a difficult, cantankerous person or a killjoy—a person who spoils the joy or pleasure of others. Despite their use of the word as a self-description, it certainly does not apply to Shavelson and Kurpius. To me, they are thoughtful and friendly critics or commentators who highlight some important ideas that advance the work of learning progressions. If at one time there was a curriculum and instruction road and a cognition and instruction road, they have now merged as a third road—the super highway. But like any road, and especially a super highway, it takes money, time and the collaborative efforts of individuals with diverse expertise to construct.

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NOTES

1 http://www7.nationalacademies.org/bose/Standards_Framework_Homepage.html

2 Wilson (this volume) proposes one possibility for a larger learning progression that includes students’ developing understanding of density.

REFERENCES


