THE JUNCTURE OF SUPPLY AND DEMAND FOR INFORMATION: HOW AND WHEN CAN LEARNING PROGRESSIONS MEET THE INFORMATION DEMANDS OF CURRICULUM DEVELOPERS?

The authors consider the information demands of a group of curriculum developers in an effort to understand the potential utility of learning progressions for the design of science curricula. Analysis centers on the design and development processes of a well-established science curriculum group at the Lawrence Hall of Science that is currently creating the ***Seeds of Science/Roots of Reading*** program. A general model of the design and development process is presented and analyzed using a socio-technical framework. Consistent with this framework, two key components of the curriculum development process are identified: technical decisions and regular points of conflict. For each, information about student learning used by the curriculum developers is identified. This defines a subset of the information demands of curriculum developers and permits the authors to describe the juncture between information currently supplied by learning progressions and these information demands. Suggestions are made for expanding the information presented in learning progressions.

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Introduction

Learning progressions have received considerable attention by researchers in science and mathematics education for their promise in promoting conceptual clarity around key principles of a domain (Wilson, 2008) and for their potential to guide curricular programs that foster systematic development of sophisticated science content understanding and reasoning skills (Songer, Kelcey, & Gotwals, in press). Learning progressions can be viewed as a way of organizing information about student learning. In particular they are stores of information that describe increasingly sophisticated ways students may think about or understand a topic (National Research Council, 2007).

In order for learning progressions to be useful, they must meet users' information needs. Several recent publications inquire into the utility of learning progressions for practitioners involved in teaching and in assessing students' learning (Alonzo & Gearhart, 2006; Smith, Wiser, Anderson, Krajcik, 2006). While discussion of learning progressions' utility for teaching and assessing student knowledge and skills overlaps significantly with their usefulness for curriculum developers, the latter group presents unique information needs. It is important to investigate these needs in order to understand the role learning progressions can play in supplying information in the curriculum design and development processes.

The purpose of this project is to describe the information requirements (*information demand*) of science curriculum developers and use this information to better understand the most valuable characteristics of learning progressions (*information supply)* from a developer's unique perspective. The questions we seek to answer are two-fold: (1) What portion of curriculum developers' information needs can be met by learning progressions as they are currently conceived? and (2) What additional features would improve the utility of learning progressions for curriculum developers?

Method

Viewing learning progressions as systems that store and organize information about student learning, we borrow from the information systems and engineering literatures to create a framework for describing their optimal design from the standpoint of science curriculum developers. In particular, we appropriate the notions of information requirements determination (Brown & Ramesh, 2002; Byrd, Cossik & Zmud, 1992). *Information requirements determination* is noted as the most critical stage in the development of information systems. Loosely, it is a process for assessing the functionality required for a proposed system as viewed by the system's prospective users (Brown and Ramesh, 2002). Several types of information are typically collected, including: users' goals for the system, the processes of the users, users' data needs as well as any design constraints and behaviors of the users. The accuracy and completeness of such an assessment is often a pivotal determinant of its ultimate success. Where such an assessment takes place early on in the development of the information system, the overall quality of the eventual system is likely to be improved. As a result, development costs associated with the system stand to be decreased.

The focus of the present effort is on the information requirements or needs of science curriculum developers where they relate to student learning. In what follows, we first present the design and development process used by a group of curriculum developers within the University of California at Berkeley's Lawrence Hall of Science. We apply a framework for describing design efforts that accounts for the typical technical decisions and conflicts relating to student learning that occur at each stage of the curriculum designers' work (Lu, Cai, Burkett & Udwadia, 2000; Mumford &Weir, 1979). We also describe the information the curriculum developers utilize in each case to provide a sense of their information needs.

To conclude, we look for overlap, or juncture, between the information needs of the curriculum developers with regard to student learning (*information demand*) and the information presented by learning progressions (*information supply*). The juncture between the two sets – information needed by curriculum developers (*demand*) and information supplied by learning progressions – provides the basis for our claims regarding the requirements currently met by learning progressions. Relevant information needs that remain unmet in the current understanding of learning progressions are then described as we make recommendations for further research and additional features of learning progressions.

Design and Development Process: Decisions and Conflicts Arising at each Stage

Stage I	***Stage II***	***Stage III***	***Stage IV***	***Stage V***
Initial Design	Pilot Development & Implementation	REVISION A Field Test Development & Implementation	REVISION B Final Version	Production/ Distribution
		Summative Assessment Development	Summative Assessment Development	

In this section the major milestones of the curriculum development process are described as they are carried out in the new integrated science-literacy curriculum *Seeds of Science/Roots of Reading* from the Lawrence Hall of Science. We note the activities that lead to each milestone and identify two aspects of the process: (a) the pivotal decisions that must be made regarding student learning and (b) the typical conflicts that arise in each case. These are set out in order to identify key moments in the development process in which information regarding student learning is central.

The *Seeds/Roots* development process is iterative. Five general steps lead to development of the project's integrated science-literacy units. These steps include the initial conceptual design, development and testing of the pilot version of the given unit, revision of the pilot unit, and development of the field test version of the unit. Results from the field test are then reviewed by the development team in order to support revision of the curriculum and development of the validation version which is released for a final trial in classrooms across the country. More detailed descriptions follow.

Initial Design

The primary objective of the first stage in the development process – the initial conceptual design – is to set out the conceptual territory of the unit under design. A team of developers, usually working in concert with scientists from relevant fields, reaches an initial agreement over the big ideas to be treated in the unit. In addition, the smaller, constituent concepts that support students' understanding of the bigger science concepts taught in the unit are identified and articulated.

The group employs a range of resources for making decisions. As a first step toward this goal curriculum developers research existing standards relating to the topic – state standards, the Project 2061 Atlas and Benchmarks, and National Science Education Standards for example – in order to build an understanding of the academic or school-based expectations for students. An initial review of the education, human development and cognitive psychology literatures is also conducted. This review is focused on student misconceptions and other difficulties students may face in the topic area. In addition to supporting decisions about the breadth and depth of the prospective unit, these documents inform first judgments about the difficulty level that is appropriate for a given grade level. Practicing scientists contribute their perspectives on which big ideas are reflective of the current state of their fields, presenting developments and research directions that have not yet been treated by other science curricula. Often the practicing scientists are also university professors, and so they can contribute additional information about the concepts with which their own students struggle, or that they feel are addressed poorly in K-12 education. Finally, the commercial publisher weighs in, with opinions about what topics might fill a "gap" in the market. Combined, such efforts generate an initial understanding of the school-based expectations for curricula as well as the most current directions of relevant branches of scientific research.

Several key decisions must be made at this first stage of the development process. And as suggested above, this first set of decisions all impact the depth and breadth at which science topics will be addressed in the unit under development. The decisions must take into account existing standards, the amount of time teachers are likely to be willing and able to devote to the topic, the importance of the ideas relative to others generally taught in the grade and standards of later grades, the developmental appropriateness of different topics, and the relative importance of concepts in the world of practicing scientists, among other considerations. An important component of these conversations are the group's first attempts to also prioritize the unit's concepts into one of three categories – concepts students should master, those students should be familiar with, and those to which students should simply be exposed. (Wiggins & McTighe, 1998) With classroom time constraints, classifying content in these categories inevitably creates challenges and conflicts.

Pilot Development and Implementation

Once the conceptual outline is established, a pilot version of the unit is outlined and tested. In this stage the conceptual outline is transformed into a proposed sequence of lessons, and these lessons are tested in one or more local classrooms. The goal at this stage is to produce a sequence of lessons that address the conceptual progression of the unit, and also function "successfully" in the classroom. The development is relatively fluid and iterative at this point: although developers begin with an outline of the entire unit, they note students' responses to the pilot lessons in the classroom and make changes in the draft curriculum outline.

A smaller group of curriculum developers – usually a pair – takes primary responsibility for the development and implementation of the pilot version of the unit in collaboration with at least one classroom teacher. The larger group of developers continues to offer input and review results of the pilot. This larger group provides a knowledgeable and yet slightly removed perspective. Their role is to probe, critique, and challenge assumptions in a way that the more involved developers may not have the distance to do. Also, an assessment specialist begins developing student assessments, which are implemented as pre- and post-tests. Information at this point comes from the documented reflections of the curriculum developers and the collaborating teacher, collection of student work, and the student assessments. During the pilot development and implementation stage, key decisions include initial selection of activities (based on the conceptual territory established in the first phase) and "midstream" revisions to the planned sequence in the face of student and teacher responses to the activities. For example, the developers may add activities or revisit a topic when there is evidence that students are struggling to understand.

Revision – Field Test Development and Implementation

In the field test development stage, the results of the pilot test are incorporated into the production of a field test version of the unit that is implemented in a nationwide field trial by a diverse group of classroom teachers. At this stage the unit is "written up" into a formal teacher's guide. The primary goal at this stage is to identify problems with the unit when implemented by classroom teachers, in order to inform the final revision for publication.

The larger curriculum development team is reconvened for several meetings in which the results of the pilot test are analyzed. Teacher and developer reflections are considered, along with the results of student assessments. The team may also revisit the original research into standards and misconceptions at this point. After the large team meeting, the field test version is then drafted. The assessment specialist develops a revised version of student assessments to use in the field trial. Finally, during the implementation, a science advisor also reviews the teacher's guide for science content and provides feedback.

The team meeting to review pilot findings is sometimes called the "Fence Posts Meeting", meaning that the group agrees to a set of "fence posts" that defines the territory of the field test unit. Decisions made in the initial conceptual development phase are revisited and the unit learning goals are revised based on the findings from the pilot test. Conflicts can occur related to the need to alter (usually to reduce) the conceptual territory addressed by the unit. Conflicts can also occur between the conceptual goals for the unit and other factors. For example, there may be an activity that is highly engaging and well loved by students and teachers, but if the activity does not align sufficiently with the conceptual focus of the unit to be worth the investment of time, it may have to be cut. At this phase, there is a need to take some risks, as this will be the last chance to get input from real teachers in real classrooms before the published version of the unit is developed. Developers will thus sometimes err on the side of including too much in the unit in terms of concepts covered.

Revision – Development of Finalized Unit

At this stage the goal is assembly and review of information generated during the field test stage to support production of a final published unit that can be successfully used in the classroom. The larger curriculum development team, including assessment specialists, is again convened for a series of meetings in which different sources of evidence from the field test are reviewed. The evidence includes daily and end-of-unit surveys completed by the field test teachers; science content review provided by a scientist advisor; results of student assessments; and analysis of student work. The analysis of content standards is also usually revisited. After the series of team meetings, the unit is rewritten by a pair of curriculum developers. Often there is significant change between the team of developers that developed the field test version and the team of developers that produces the published version. This diversity of viewpoints is considered to be a strength in the process and ensures a multiplicity of perspectives.

The decisions and conflicts at this stage are very similar to those made at the field test development phase, except at this point there is more information (because the unit has been implemented by a broad array of teachers), and the stakes are higher (because this is the last chance to make changes before publication). At this point significant cuts are often made to the conceptual territory covered in the lesson, and occasionally additions. For example, in a field test for a unit called "light energy," many field test teachers complained that the unit did not address color, and thus did not help them address science standards they need to cover. Although it had originally been decided that color could not be addressed with sufficient depth and thus should be left out, a compromise was made and several lessons about color were incorporated into the final unit.

Summative Assessment and National Trial

While much of the team's energy is focused on designing and testing the curriculum's lessons, a small subgroup is typically engaged at the field test stage to begin development of the unit's summative assessments. Because the *Seeds of Science/Roots of Reading* curriculum integrates inquiry science instruction with literacy instruction, the summative assessment system includes assessments that address science content knowledge, scientific inquiry skills, knowledge of the nature and practice of science as well as others addressing different aspects of literacy – comprehension of informational text, science vocabulary and science relevant genres of writing. In what follows we focus on the development of the science content knowledge assessments.

The summative assessment team generally follows the BEAR assessment method (Wilson, 2005). The group's initial work is made up of conversations and research into the existing literature to develop a draft set of progress variables that describe the likely levels of student understanding as they progress from less to more sophisticated. Once the progress variables have been drafted team members draft sets of sample items that give students opportunities to show what they know about the unit's topic area. The group uses these items to conduct think-alouds with students, documents corrections that need to be made to existing items and often the progress variables themselves, and ultimately drafts additional questions that are tested through think-alouds as well.

Partnering with the assessment specialist on the team, participants then reflect on the results from the student interviews, the progress variables themselves and past conversations to select the set of items to be used in a final trial of both the curriculum and the assessments themselves. This step in the development process entails recruitment and selection of 8 – 10 classrooms of students across the country to take the newly developed pre-test, follow the full curriculum and then take the post-test. Student responses are returned to the Lawrence Hall of Science for analysis by the assessment specialist, who analyzes the results to understand item functioning and test form characteristics, presents the data to staff and again works with members of the curriculum development team to create the final summative test forms.

The group's theories of how students are likely to progress in their understanding of the unit's content are foundational to the items that are eventually written and tested, and a significant amount of time is put into their critique and revision. Staff involved in development of the summative items ensure the progress variables reflect the content and emphases of the unit. Where possible, the group also uses existing descriptions of students' likely development through the unit's content. In some cases these descriptions are available and made explicit in the research literature. In other cases descriptions must be pieced together from results and conclusions found in past studies. Though it is still somewhat rare, it is increasingly the case that the group is able to use existing, relevant, learning progressions on one or more of the unit's focus topics. In all cases, the group usually runs into difficulty applying these available resources without some or a great deal of modifications. This is usually the case because of the group's interest in creating progress variables and items that are good reflections of the curriculum's lessons, as well as the breadth and depth at which it addresses the content.

Several decisions that require information about student learning must be made in the course of the assessment development process. Disagreements typically arise over the content of the levels of the progress variable – particularly the endpoints or highest levels – as well as the order of the levels, and the sorts of items that stand to best identify students working at particular levels of the progress variable. Extensive conversations over the relationship, or 'fit', between the progress variables and the curriculum itself are also common.

Information Requirements

After describing the major decisions and conflicts arising at each step of a sample curriculum development process, we next present the sorts of information commonly relied on in each case and also consider additional information that could be utilized but is not yet available. While there are many decisions and points of conflict in the curriculum development process, we focus on three topics that make up an important subset of the decisions and conflicts developers face: the curriculum's *breadth, depth,* and the *priority* given to its learning goals and content. These topics, or areas of information need, are fruitful for further discussion of curriculum developers' information requirements with regard to student learning. Each area of information need is profiled below with its corresponding decisions and conflicts, and accompanied by descriptions of information typically used to resolve conflicts and generate decisions, and speculation as to what information learning progressions could provide that would improve such efforts.

Breadth of Science Content

Decisions regarding…	Information Needs
Breadth	• Identify moments where convergence or divergence of concepts is likely • Describe likely trajectories through key topics • Describe shape or topography of learning in single and related topic areas • Communicate relationships between topics/learning progressions -- serial, parallel, cyclical, or nested relationships.

As noted, decisions about the optimal number of topics and learning goals in a given unit are made and revisited throughout the curriculum development process. Members of the curriculum development team reflect on student results and teacher feedback from their pilot and field tests of the draft curriculum, they access state and national standards, talk with science advisors and discuss among themselves the best number and combination of concepts to be learned in a given unit. In many cases the sources and people consulted offer conflicting views on what should constitute the endpoints of instruction.

What learning progressions can contribute. Current knowledge regarding student learning is pivotal to these decisions. In this regard there may be several roles for learning progressions at this stage of the curriculum development process. For instance, where learning progressions set out the likely trajectories of students as they move from less to more sophisticated understanding of a given concept or set of concepts, they clarify the growth required to reach the endpoints of understanding. This alone is a support in decision-making about breadth as such a description can serve to check unrealistic expectations, and help developers better focus on what is truly important to cover in the given unit. Additionally, learning progressions that convey more information about the critical moments in students' likely trajectories as well as those providing information about the intricacies of the shape or topography of student learning could be used to better support decision-making among practitioners. Four examples are presented here.

First, it is largely recognized within the curriculum development team that student learning rarely, if ever, occurs in a linear fashion. It does not seem to progress along a ladder, from one stage to the next. (Fischer *et al.*, 2003; Fischer, 2008;NRC, 2007) Rather, student learning can assume many shapes over time. In many cases, it seems to be web-like, with students making progress along a number of strands simultaneously. While there may be moments in students' careers when such strands are independent of others, there also seem to be critical points at which they are integrated. In such cases, students may realize that what they know about several topics, animal adaptations, evolution and extinction, and pre-historic conditions on earth, can all be integrated to make conclusions about a topic that may be novel to them —whales, for example.

Second, it is also imaginable that this process of integration could be turned on its head with students gaining an understanding of a key concept in sufficient depth that they can use it to help explain and make sense of other areas of science. For instance, students can learn about the idea of systems, and experience the power of using their understanding to accelerate their learning about the human body, a nearby pond, or phases of the moon.

Both of the above scenarios present critical moments in student learning. Information about such moments – the windows in students' careers when such convergence or divergence are likely to occur, and which student experiences or prior knowledge is likely to generate such convergence or divergence – could go a long way in supporting effective decisions regarding the ideal breadth of curricula. Learning progressions that offer such information about student learning would be valuable.

Third, in addition to generally being a non-linear process, student learning is often discontinuous. It has been classically described as a series of growth spurts and plateaus (Draney, 1996; Reznick & Goldfield, 1992; Ruhland & van Geert, 1998). One might imagine something like a step or staircase function as a better description of student growth in such cases, rather than a continuous function with a steady slope. Under ideal conditions, students' skills and understanding can leap forward at a fast rate. (Fischer, Yan & Stewart, 2003) And after such a spurt, their growth may slow, forming a plateau.

This has ramifications for practitioners. It is likely that the best time to increase students' breadth of understanding is after such a spurt, during moments of plateau. Where she has reached a plateau, the student has mastered the target concepts and is ready to begin applying them to novel contexts. She is ready to begin thinking of new ways to increase the breadth of her understanding by applying what she has learned to new topics. In this regard, there is added benefit to learning progressions that are not only organized vertically, along the Y-axis, but also have a horizontal component. Such a learning progression might suggest a range of related topics that students at the highest levels of understanding, for example, are likely to be successful with as they apply their new skills or understanding. Students that have mastered specific approaches to modeling the behavior of particles in different phases of matter, for instance, may then be likely to have success at broadening their understanding by thinking about the behavior of particles in other situations – simple cases of chromatography, for example.

Optimally, whatever the student is doing or learning to gain a breadth of understanding could potentially fuel the next spurt within the same topic area or in related topic areas. And this suggests a fourth example of the need for more in-depth and sophisticated information regarding student learning: It would be valuable to have a sense for some of the concepts most likely to drive students' next spurt. In this case a single given learning progression may be insufficient. Instead, in this context it may be necessary to draw from several learning progressions that are interrelated or describe growth within several topics that tends to take place in a parallel fashion. It could be advantageous for curriculum developers to have available 'sets' of learning progressions that stand in a serial, parallel, cyclical or even a nested relation to one another (*see* Fischer, 2008; Wilson, 2008).

Depth of Science Content

Decisions regarding…	Information Needs
Depth	• Likely trajectories through key topics • Well defined endpoints for various levels of understanding • Shape or topography of learning in specific topic areas • How non-linear, discontinuous dynamics impact the shape or pattern of student learning over time

A core aim of the *Seeds/Roots* approach is to support children in becoming young experts in science, ideally surpassing the everyday understandings of adults – much in the way a third grader might know much more about dinosaurs, dinosaur anatomy and history than their parents. But there are obvious trade-offs involved in creating units that cover material in the in-depth fashion necessary to make such a goal possible. As mentioned above, the majority of these trade-offs involve cutting back on the breadth of material covered in a unit.

Reaching agreement on the depth at which students should learn particular concepts involves developers in decisions and conflict over the ideal endpoints for students as well as developers' ideas about what experiences and supports students need to reach those end-points. Curriculum developers on the team utilize input from teacher surveys, student data from pilot and field trials, available state and national standards documents, science advisors and relevant research literatures to define these endpoints and make decisions regarding the optimal depth at which concepts should be covered. Existing learning progressions stand to support decisions regarding depth where they help developers define such endpoints and detail the steps typically taken by students along the way.

What learning progressions can contribute. Having access to information about likely student trajectories through material and detailed endpoints students have typically reached in the past stands to deepen developers' conversations and provide an improved evidence base for decisions regarding both depth and breadth. But again, curriculum developers could benefit even more from learning progressions that accurately reflect and forecast to some extent the 'messy' patterns presented by student learning over time. As suggested above, learning is rarely a 'steady march' upward during which landmarks (stages in a given learning progression) are seen once only on their path to expert knowledge. We know, for example, that students' semester, or school year, even their academic career is marked by periods of construction and collapse as they approach mastery over new ideas and skills only to temporarily fall back to old ideas and make missteps. Decisions regarding the optimal depth or breadth of a curriculum would benefit from a clearer understanding of how these non-linear, discontinuous dynamics impact the shape or pattern of student learning over time.

This is particularly true as students' conceptual understanding is generally unsteady in the early stages of learning something new. Their skills can shift in complexity from one moment to another, depending on the novelty of the context, supports present, their motivation, fatigue and numerous other factors. (Fischer, 2008) Over time, such a dynamic can give rise to a scallop-like pattern: the student starts with a low level of understanding, builds up her understanding or skill within a particular, well-defined context, only to have her understanding collapse as she attempts to apply it in a novel situation (Fischer, 2008). This may happen repeatedly and is a normal part of learning. Yet this sort of information about the shape of student learning is not currently available to curriculum developers as they make decisions about depth and breadth of coverage, and as they make decisions regarding the number of times a given curriculum needs to cycle back and give students additional opportunities to deepen and solidify what they have learned. Developers as well as teachers could potentially benefit were information stored and communicated through learning progressions that conveyed these sorts of likely dynamics of students' performance.

Priorities of the Curriculum

Decisions regarding…	Information Needs
Priority	• Likely trajectories through key topics • Description of how students *should* progress through science content to ensure later success • Clarification of endpoints of student learning • A detailed map of what students are likely to have learned in their career up to a given point and the steps they are likely to take well into the future • Indication of which concepts are generative of further learning in the same or other strands.

As part of the effort to clearly prioritize the big ideas and their constituent science concepts presented in the unit, the curriculum development team uses the backwards design system (Wiggins & McTighe, 1998), cataloguing concepts as either important to be exposed to, important to know, or important to master.

Decisions over the priority that should be given to concepts are typically justified by reference to state and national standards, the role of ideas or concepts in supporting development of additional or deeper understandings in other topics learned in the grade band, the relative importance assigned to the concepts by scientists in the field based on the work being done now or likely to be done in the future, as well as what teachers across the country are expected to teach about and local context (living where hurricanes occur presents a greater priority on learning about this weather phenomenon). In this regard, much of the information used to make decisions and settle conflicts over the priority given to concepts within a given unit also involves clarification of endpoints for student learning: in order to be successful in subsequent units or even subsequent grades, what should students be able to *do* after completing the unit?

What learning progressions can contribute. Because the curriculum developers draw on several information sources for input – communities of practicing scientists, state and national standards, cognitive psychology and education literatures, etc. -- they often end up choosing between competing claims about what should be prioritized and why. This requires that they integrate the information they have from various, forming their own judgments. Learning progressions, conceived as stores and systems of information about student learning, could have a valuable role to play in justifying or guiding decisions about the priority of concepts presented in the classroom. While learning progressions certainly can describe students' likely trajectories through key topics, they also could be assembled to reflect a broad consensus view of how students *should* progress through science content. They might identify essential landmarks or concepts that really must be mastered to succeed in later grades, along with noting concepts or skills that are less significant but stand to add more nuance to students' ideas. Such a consensus would presumably involve the best or most informed conclusions of the communities of educators, cognitive psychologists, psychometricians, practicing scientists and policy makers, among others.

Second, and this is a topic that may apply to all the decision points discussed in this paper, there is a sense in which the horizon of time that is considered during many conversations should be broad while also being specific. That is, given that most discussions regarding prioritizing the concepts to be treated in a given lesson hinge on claims about what students will need to know as the unit progresses or as they move to the next major grade band (6^{th} -8^{th} or 9^{th} through 12^{th}), it may benefit the development process if developers had access to a more detailed map of what students are likely to have learned in their career up to that point and the steps they are likely to take well into the future. This perhaps speaks to the need for national standards. But in cases where learning progressions provided such a wide range of information about the past as well as the likely future, decisions could be made that better capitalize on what students already know and what they will need to be ready for.

Third, there is now some agreement that many concepts are *generative* in the sense that they help students to learn more about a given topic or several other topics (NRC, 2006). Decisions about prioritizing content could be supported where developers are able to identify these concepts, assign them higher priorities and have students investigate them in ways that magnify their generative impact. This again touches on a rationale for employing several learning progressions at any given time. For instance, the new *Seeds of Science /Roots of Reading* curriculum focuses on three strands of science learning – science content, scientific inquiry and the nature and practices of science. In our experience we have a sense that these strands are interconnected – that learning in one strand can support and potentially drive learning in another. Where the relationships between learning progressions are researched and made explicit, developers decisions over priority of content could capitalize on them, ultimately leading to a more coherent and potentially accelerated curriculum.

In this article we have attempted to lay out the basic steps involved in the design and development process used by a group of curriculum developers within the University of California at Berkeley's Lawrence Hall of Science – the *Seeds of Science/Roots of Reading* program. This was presented as part of an effort to make clear the sorts of decisions and conflicts that typically arise in the process. We focused on three key topics in this regard – (a) decisions and conflicts over *breadth* of the curriculum being developed, (b) its *depth*, and (c) decisions about the given *priorities* for student learning. In addition, the sorts of information commonly relied on in each case was presented while also considering additional information that could be utilized but is not yet available. In the conclusion that follows, we use the preceding discussion to begin identifying the overlap, or juncture, between the information needs of the curriculum designers with regard to student learning (*information demand*) and the information currently offered by many learning progressions (*information supply*).

Conclusion

Some learning progressions offer a linear, vertically oriented picture of student trajectories through science material. For many of the developers' information needs, this presentation of student progress is sufficient. But as we have tried to emphasize in the preceding section this is not always the case. Keeping these comments in mind, two questions arise. First, what content do learning progressions currently present that helps meet the information needs of curriculum developers? And second, how can the type of information currently offered by learning progressions be expanded to the benefit of practitioners such as curriculum developers? In what remains we summarize the findings from the preceding discussion to briefly respond to each of these questions in turn.

What information do learning progressions present in their current state that helps meet the information needs of curriculum developers?

We recognize that existing learning progressions are diverse and that any attempt to characterize all of them will likely be lacking in one way or another. But in general, it seems safe to say that most, if not all learning progressions, summarize students likely or beneficial trajectories as they achieve increasingly sophisticated understandings of particular topics. Such information is useful to curriculum developers in each of the key moments of the curriculum development process noted above. It is useful for making decisions about the optimal breadth of a given curricular unit where it serves to inform expectations and help curriculum developers better focus on what is important to cover in a unit, given the concepts students will be moving on to cover in the future. Such linear descriptions of the changes student understanding goes through are also useful for making decisions about the depth at which particular concepts should be taught in a given curricular unit for similar reasons. Lastly learning progressions can be useful for supporting decisions and resolving conflicts over how concepts should be prioritized where they help to clarify the endpoints for student learning, identifying what students should know and be able to do at the end of a grade or grade band in order to have the prerequisites for success in subsequent steps of their academic career.

How can the types of information currently offered by learning progressions be expanded to the benefit of practitioners?

Several suggestions have been made here regarding ways to expand the types information offered by learning progressions. Many of these suggestions begin with the assumption that student learning is typically non-linear, potentially discontinuous and presents a complicated topography. Other suggestions made in this paper hinged on the premise that there are critical moments in student learning – moments where students are likely to be integrating what they have learned (convergence) or are learning they can apply a single skill or concept in several novel contexts (divergence). In both cases, the claim is that foreknowledge of the likely patterns, dynamics and critical points of students' learning could support developers in making decisions about the optimal breadth, depth and priorities of curricula.

With these ideas in mind, Important future directions for learning progressions research could include (a) creation of learning progressions that identify more accurately the likely "topography" of student progress (e.g., plateaus, collapses); and importantly (b) investigation of potential relationships between learning progressions (e.g., science content and science inquiry, or related areas of science content). In both cases, there will be a need for more sophisticated ways of modeling students' growth. Such research could have great potential to improve curriculum development and consequently better support student learning.

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