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Learning Progressions in Science: A Summary of the Report from the Center on Continuous Instructional Improvement (CCII)

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Introduction

The efforts of CPRE's Center on Continuous Instructional Improvement (CCII) to review the status and quality of work on the concept of "learning progressions" in science education—to clarify the concept, to assess its promise for improving science instruction, and to suggest the kinds of further work required if the promise we see is to be realized—are relevant to the Board on Science Education's (BOSE) exploration of organizing K-12 science education around core disciplinary ideas. Certainly the identification of core ideas is relevant—in fact critical—to future work on learning progressions. We recently completed a report on learning progressions in science that was developed in consultation with a panel of science education researchers, developers, and other relevant experts working in this field, entitled: *Learning Progressions in Science: An Evidence-based Approach to Reform.*[1] We offer here an extrapolation from that report that attempts to draw its implications for potentially productive ways to think about core ideas and content and performance standards, as well as to summarize some of the report's relevant findings and recommendations.

Relationships Among Core Ideas, Standards, and Learning Progressions in Science Education

CCII's report, building on definitions in recent National Research Council (NRC) reports[2], takes the position that learning progressions should be defined as empirically grounded and testable hypotheses about how students' understanding and ability to use knowledge and skills in core school subjects[3] grow and become more sophisticated over time with appropriate instruction. Ultimately, progressions should be based on research about how students' learning actually progresses given such instruction, as opposed to simply selecting sequences of topics and learning experiences based on logical analysis of disciplinary knowledge and/or on personal experience and customary practice in teaching. Of course the initial hypotheses behind progressions may stem from these latter sources or from other ways of reasoning about learning, but our contention is that,

[1]Corcoran, T, Mosher, F. & Rogat, A. (2009). *Learning Progressions in Science: An Evidence-based Approach to Reform* (RR-63). Philadelphia, PA: Consortium for Policy Research in Education. [A PDF of the report is available at http://www.cpre.org/ccii/. Hard copies may be ordered by emailing Kelly Stanton at stantonk@gse.upenn.edu.] This report, and the work behind it, was supported by Pearson Education and the William and Flora Hewlett Foundation. All data presented, statements made, and views expressed in this report are the responsibility of the authors and do not necessarily reflect the views of the Consortium for Policy Research in Education, its institutional partners, or the funders of this study. This report has been internally and externally reviewed to meet CPRE's quality assurance standards.
[2] National Research Council (2007). *Taking Science to School: Learning and Teaching Science in Grade K-8*. Committee on Science Learning, Kindergarten through eighth grade. Duschl, R.A., Schweingruber, H.A., & Shouse, A.W., Eds. Washington DC: The National Academy Press.
[3] CCII is carrying out parallel work on the concept of progressions as it applies to mathematics and literacy.

whatever their source, hypothesized progressions should be refined by close and careful observation of students' learning in the context of instruction in real school settings, as well as in laboratory or clinical situations. Then their validity, usefulness, and generalizability (coupled with further refinement) should be tested in schools as widely and iteratively as possible. This work should be aimed at answering critical questions about construct validity: Do the hypothesized sequences describe those that most students actually follow given appropriate instruction? And about consequential validity: Does instruction based on these learning progressions produce better results for most students? The work also should capture and attend to evidence on the instructional experiences associated with desired progress and on the resources required to support such instruction.

If this work is pursued vigorously and rigorously the end result should be a solid body of evidence on what most students are capable of achieving in school and about the particular sequence(s) of learning experiences that lead to proficiency on the part of most students. However, we do not assume that there is likely to be only one best progression or pathway. The number and nature of productive pathways are likely to be influenced by differences in students, teachers, and settings and should be a matter of empirical study. Future design and experimentation will almost certainly modify and improve the pathways identified in the context of current practice.

There is an obvious relationship between this idea of progressions and the notion of core disciplinary or "big" ideas. While it might be the case that one could study learning progressions in the wild—growing as they will and ending up wherever they do— in the context of education the concept has a more teleological character. Attention is naturally focused on endpoints that society cares about and that schools consider to be important. That, in turn, helps to focus attention on the question of how students would get to these endpoints. What is the character of children's initial or early ideas about phenomena relevant to an endpoint, and what use do they make of those ideas? With experience and instruction, do those ideas and actions shift and/or develop toward the desired endpoints? If so, how, and if not, why? Can we envision a more efficient pathway to the endpoint? Some of our colleagues who work on progressions in science refer to these beginning and endpoints as the lower and upper "anchors" for their progressions. We prefer a label such as "target" for the upper end or goal since anchor tends metaphorically to weigh in the wrong direction, and it doesn't work particularly well for the initial or early states either.

Whatever the label, the "core ideas" construct clearly seems well-suited to serve as the endpoint for hypothesized progressions. Progression researchers/developers can use core ideas as a heuristic device to identify important, quasi-isolatable, sub-sections of a conceptual or practice domain and to focus attention on the sequence of understandings and practices that students might acquire or travel through on their way to attaining the target conceptual structure and related skills. In the progressions work, the significant strands or dimensions of development that, taken-together, lead toward the target tend to be called "progress variables." For example, if the target core idea were, say, the atomic theory of matter, one of the content progress variables might focus on students' ideas about the properties of materials and their determinants, and how those ideas may change over the school years. A parallel scientific practices progress variable might focus on their growing understanding of the ways properties can be measured and the advantages of more precise techniques and tools over reliance on simple sensory input. Clearly our use of words here like "important, significant, quasi-isolatable," and so on suggests questions that beg for more formal definitions and criteria rooted in and applied to concrete examples from the disciplines.

Still, in spite of the relevance of core ideas to the development of progressions, we feel that there also is a tension between the ways that these ideas are often thought about in the context of content and performance standards and the ways we might think about them after an extended program of progressions research and development of the sort we are recommending. As implied by the BOSE call for the August meeting, thinking about the core or big ideas in scientific disciplines and the related development of national or state standards have generally, at best, been the product of scientists and experienced educators thinking hard about the structure of scientific theory and reasoning in a particular field to identify the more fundamental concepts that generate explanations of the known empirical observations within the domain. There may be an attempt to avoid simple, and long, lists of facts and relationships and to seek parsimony by identifying more fundamental or generative concepts from which the specifics might be derived. Less ideally, the development of core standards can turn into a kind of log rolling or faux democratic process in which one's own favorites are included if one is willing to accept that others' are too. The result, as many have noted, is a curriculum that is a mile wide and not very deep.

In contrast, although work on progressions also may start with an attempt to identify the central ideas and practices of the discipline as a basis for choosing the targets of the progressions, it should move quickly to an empirical consideration of what children's and students' ideas relevant to these targets look like at points along the way, beginning in pre-school or even earlier[4]. Early on in this work it seems that one should ask whether there is, in fact, evidence that *any* students in the K-12 grades have attained levels of understanding and skill in the core ideas that would approximate the target as it might be framed in expert terms. How closely do at least some students get to such an approximation, how many do so, and what experiences or backgrounds appear to be associated with this accomplishment? Perhaps most importantly, how can one tell? What stands as evidence that students know and can do the desired things? What do we know about knowledge and skill transfer to new situations or the development of new knowledge? At the same time, as progression researchers/developers look vertically down grades and age levels toward the earliest configurations of knowledge that children have about the domain in question, and horizontally across the range of configurations individuals can exhibit at any age, they

[4] At one end, progressions start with children's beginning knowledge, which for young children might be the kinds of understanding of the natural world and ways of thinking about it that they are likely to have developed based on common human experience as mediated by the folk categories and explanations that are embedded in their culture and their native language. At the other end, progressions target an adequate understanding (that is one that would be recognized as a reasonable approximation of the way scientists currently see things) of how scientific disciplines explain and model the central phenomena of each discipline or interdisciplinary field and the ability to apply those understandings to solve problems and develop "new" knowledge. This target knowledge can also include an understanding of how science has come to and continues to build these explanations and models over time (i.e. an understanding of scientific practices: careful observation and measurement, devising and testing explanations against empirical evidence and alternative explanations, and the social norms of science–public logical argument, replication, verification, the willingness to abandon less effective explanations for better ones, and so on). We think there are no fixed rules for how to select the targets at the upper end. The primary point is that they should be central and important for explaining significant phenomena in a field or for understanding how explanations are developed, and they should be accessible to students within the normal course of their school experiences – the terms "big ideas" or "core concepts" are often used, as we have noted. Clearly questions of centrality, accessibility, and generativity are subject both to argument and to modification over time, especially with respect to accessibility; given that one hopes instruction will become more effective and make deeper understanding more accessible.

should ask whether: a) these configurations are characteristic of many individuals; b) they seem to represent an interpretable ordering (or sets of orders) that reflect levels of progress over the years, heading toward the recognized and desired approximations of the expert knowledge, and; c) the differences among individuals' concept and skill configurations at a given age or grade can be interpreted meaningfully as representing attainment of recognized levels of progress that those who already have attained the more desirable approximations would have passed through in earlier years.

No one has gone through this process of analysis and evidence gathering in any thoroughgoing way, but we would suggest that we should.. In doing so we may find that the approximations of the target conceptions or core ideas—rooted as they are in the evidence of what students actually can do when they fit the approximation—look rather different from, perhaps richer or maybe simpler and more bounded at the secondary level, but certainly more complete and textured than, the ones that would have been expected based solely on descriptions of the structures of knowledge and skill derived from advanced understanding of the discipline. We argue that such work will provide us with a more realistic description of what we should hope for in the way of higher and more generative achievement, and doing it will also provide evidence on how instruction can support students in moving along the path toward meeting those hopes.

To reprise: what we are arguing so far is that it certainly is useful to try to identify a coherent and parsimonious set of core ideas and skills based on an analysis of the contemporary structure of knowledge and practice in the disciplines that can represent what students should know and be able to do by the end of public schooling. However, it is not reasonable to expect that this set of core ideas will fully match how advanced scholars in the discipline understand them, so there must be some rule of reason for ratcheting back to some conception of what is "necessary for further study or for success in relevant sorts of jobs/job training," and that itself also raises empirical issues for deriving standards from pure disciplinary reasoning. But looking at such a process from the point of view of progressions, we then would argue that it is essential to view these targets as representing only the beginning of a process of empirical investigation of how (and whether) it is that students' learning can progress, with instruction, from their initial naïve understandings and explanations of relevant phenomena rooted in their home culture and native language, to something like the knowledge and skill characterized by the proposed targets. We suggest that in that process those targets themselves may be enriched and perhaps fundamentally changed.

In what follows we present excerpts from our report that elaborate some of these ideas, and then provide a brief look (see appendix A) at current and ongoing programs of research and development in science education that in some degree reflect the sorts of work we are advocating.

Findings on the Potential Benefits of Learning Progressions

Improved Standards

Can learning progressions help us develop new standards that would be more realistic and usable? Let's first consider how learning progressions and standards differ. Standards define common content and performance expectations for all students in particular grades or age groups. They are derived from analysis of the structure of the core school disciplines and from efforts to reach consensus about societal goals. The content standards tend to be aspirational, and the expected performance levels tend to be a negotiated balance between the desire to be rigorous and challenging and the need to be realistic in terms of likely failure rates on the assessments used to measure performance. In contrast, learning progressions represent hypotheses about how students' understanding actually develops given particular instructional experiences, and they can be tested and validated against further empirical observations of the order and rate in which students' understanding and skill do in fact develop given similar instruction. They also can be modified by evidence on what happens when instruction varies. Instead of making assumptions about what *should* happen, they focus on what *does* happen, given variation among students and their instructional opportunities.

While the state standards required by No Child Left Behind (NCLB) assume that all students should cover the same content in roughly the same time periods, and meet or exceed the same proficiency expectations at roughly the same time, learning progressions are open to the finding that students' rates of progress along the hypothesized pathways can vary. In this sense, learning progressions are consistent with the original conception of standards-based reform which holds that the same levels of proficiency should be set for all students, but that the time and resources needed for them to attain those levels would likely vary.[5] Current NCLB policy holds that by 2014 essentially all students should be expected at least to reach proficiency levels at the same times, grade by grade.

Standards tend to assume that the ultimate performance targets can be broken down logically—deductively—into chunks of earlier and later knowledge and skill that students should master in order and which then will add up to achievement of the desired proficiency. In contrast, learning progressions are based on empirical studies of how student thinking about a concept and/or mastery of a practice actually develops, with specified instruction. The levels of achievement identified in a progression represent the steps that student thinking typically goes through on the path to the desired understanding and skill. In progressions the earlier levels may reflect mistaken or imperfect understandings of the target concepts that have to be revised or abandoned before the student can move on, rather than, as standards seem often to conceive of them, correct but incomplete understandings that simply have to be supplemented in order to reach full understanding. For example, for a younger child "having weight" means "feels heavy—affects me by pushing/pulling on my hand." Later in a progression, students will come to understand that having weight (or by then, perhaps, "mass") means having some amount of matter that pushes on things, or resists being pushed, whether or not it is detectable "by me".[6] The student's concept of weight undergoes a reconceptualization rather than a simple additive modification (and that shift will be more meaningful to the student if it is mediated and motivated by concrete experiences with observation and measurement).

At this point in the development of thinking about progressions the language used to describe the levels of achievement or stages of progress that constitute steps in a progression is not as precise as we might hope it will become, particularly when we are trying to talk about levels as a general feature of progressions rather than about the specific evidence found for the levels in a particular progression. But the hope is that

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[5] Smith, M. & O'Day, J (1991). Systemic school reform. In S. Fuhrman & B. Malen, (Eds.) *The Politics of Curriculum and Testing* (pp. 233-267). Bristol, PA: The Falmer Press

[6] Wiser, M., Smith, C.L., Asbelle-Clark, J., & Doubler, S. (2009). Developing and Refining Learning Progression for Matter: The Inquiry Project: Grades 3-5. Paper presented at the Annual Convention of the American Educational Research Association; San Diego, CA.

these milestones would represent something more significant than just getting right answers to a few more test questions. This hope stems from a structural view of cognitive development which suggests that the development of student thinking may not be purely incremental but may proceed as a series of increasingly complex schemes for organizing understanding of the world which may be rather stable for periods of time but which eventually are modified or even broken down and rebuilt to take account of new evidence and new perceptions (including, of course, new inputs from instruction). The developers of learning progressions try to identify a limited set of these relatively more stable—even if still temporary—consolidations of students' thinking that most students are likely to experience in roughly the same order, and they seek to characterize the other, perhaps more diverse or less ordered, sets of experiences, perceptions, and partial understandings that underlie and are incorporated into these consolidations, as well as those that eventually lead to re-consolidations at later levels.

The proponents of learning progressions clearly are focused on teaching and learning—they assume that getting to the overall goals of schooling involves a journey, and they are concerned with providing maps that would enable teachers and students to tell where students are in that journey, not just in order to see whether they have arrived or fallen short, but rather to help them see where to go next or what has been missed. Progressions are aimed at producing a connected view of the development of students' thinking and skills, drawing a picture of the ways in which students place particular facts and concepts into a more general conception of how those facts and concepts are related, so as to support an understanding of how some aspect of their world works, however rudimentary that understanding may be in the earlier stages of their learning.

Currently most state standards have a somewhat different focus and structure. Most significantly, they tend to be framed in terms of the desired outcomes of learning without specifying much in regard to how those outcomes might come about or what time periods might be required for mastery by students who enter with different levels of understanding and skill—they focus on the products of students' thinking rather on the ways that thinking develops over time. State content standards try to specify what teachers should teach; performance standards specify how much or how well students should learn these things. They provide very little specification about how instruction mediates between the presentation of content and student outcomes. As a result, standards provide little guidance for teachers about what they should do to ensure that students meet or exceed the standards. Also, because the standards are often a negotiated list resulting from the experience, preferences, and influence of adult stakeholders and are seldom rooted in direct evidence of whether most children can learn everything expected within the time and resources schools provide, they often include many more topics at each grade than it is reasonable to think teachers and students can address at anything more than a superficial level. This provides teachers with considerable incentive to favor coverage over depth of treatment.

There is an obvious tension between thinking about the growth of students' learning as developers of learning progressions do and the way that writers of the current standards have been doing. Learning progressions certainly address the order in which students are likely to learn things, but they do not necessarily specify the ages at which particular milestones should, or are likely to, be reached. Under NCLB the state standards define grade level proficiency standards that essentially all students are expected to reach or exceed in their grade level cohorts by the year 2014. While the empirical data collected from research on learning progressions might provide evidence that most students would reach particular milestones by a given grade, they also may show that students differ widely in their rates of progress even though they may move through the stages of progress in more or less the same order. In fact, the empirical evidence assembled so far indicates that at any given grade the range of the students' positions on any given progression varies widely. One of the main points of focusing on progressions is to provide teachers with a conceptual structure that will inform and support their ability to respond appropriately to evidence of their students' differing stages of progress by adapting their instruction to what each student needs in order to stay on track and make progress toward the ultimate learning goals.

We recognize that the setting of grade level proficiency standards for all students is designed to avoid "the soft bigotry of low expectations" for traditionally low performing or disadvantaged students and that some will see a danger in an approach that recognizes, and accepts, that students' performance levels are likely in fact to range quite widely at any given time. They may fear that this would lead schools to accept a low expectations kind of tracking for low performing students. We think this danger can be avoided and that in fact progressions can offer a much more realistic and effective way of setting high standards for all students. Far from encouraging holding low expectations for some students, learning progressions, because they define a common path or typical paths and a set of identifiable performance levels for the development of knowledge and skill in core school subject areas, afford the possibility of defining standards by choosing which of the performance levels should be deemed adequate for the kind of functioning that should be expected of, say, a high school graduate.

In addition, the empirical work necessary to justify that a hypothetical learning progression provides an adequate description of the ways in which students' understanding and skill grow over time should also in the long run provide evidence of the kinds of instruction and experience that are associated with enabling students to move along the progression and the rates at which they can do that, given their starting points. "Adequate (yearly) progress" toward that standard could be defined meaningfully in terms of identifiable movement along the progression's performance levels. "Adequacy" could be defined at least in part empirically through studies of the amount of progress needed to ensure that an at-risk student located at an earlier performance level would reach the desired overall proficiency goals by the end of secondary school or by an empirically justified extension of that time. That amount or rate of progress in turn could be associated with empirical evidence about the levels of resources and pedagogical approaches that have enabled students who were at similar initial levels for a given age and grade to make progress at that rate. Furthermore, studies of learning progressions using alternative or innovative instructional regimes could be conducted to determine if they differentially affect the rate or nature of student development, and if they produce better results, the ultimate target could be raised with less concern that it would result in higher rates of failure. In this manner, research associated with learning progressions could result in higher standards that still would be fair for students and schools. There is currently little or no empirical justification supporting policy assertions about when schools should be successful in enabling all students to meet proficiency standards.

So standards could be set at realistically high levels and be empirically justified for most students while recognizing that, within reasonable limits, time and resources might have to vary to enable them to reach those standards. This would contrast with the current situation in which it seems that if students are to reach common grade level and graduation standards in common amounts of time and with similar resources, the standards have to be watered down to workable levels, but ones that probably are inadequate when judged by the demands of the world beyond school. Progressions offer the promise that standards based on them would be more transparent and harder to water down, since proficiency would be referenced to identifiable and understandable levels in the progressions and could be clearly compared with descriptions of the levels above and below them. Students who had not reached or exceeded proficiency could be characterized in terms of the levels they had reached, rather than described simply as being at “basic” or “below basic” levels. The clarity of the descriptions of the levels in learning progressions and the learning performances associated with them would also offer the possibility of gathering much stronger empirical evidence of what students who had reached a given level would be able to do in terms of applying their knowledge and skill to real world problems or to further learning. This again would provide a contrast with the obscurity of current standards’ proficiency levels and the lack of evidence that students who, say, just meet proficiency standards on current state assessments would be seen by competent observers to be proficient in any real world sense

A progressions approach also suggests a way to deal with another of the problems with our current approach to setting standards. This problem stems from the fact that standards often define grade-level expectations in terms of the content to be taught. But that means that teachers are faced with a situation in which they are expected to teach the same concepts and facts to all of their students, even while they recognize that their students will differ quite widely in the ways in which they can reason with and argue about those concepts and facts. The performance standards associated with this content, and the assessments associated with them, tend to confound knowledge of facts and vocabulary with scientific practices in ways that make it difficult to know exactly what is being assessed or how to respond constructively to students’ results to help them improve. By treating the development of concepts and practices as *analytically* distinguishable, but intertwined, pathways (each of them being what we and others would call “progress variables”), progressions can make this tension explicit and provide a basis for describing and assessing the empirically observable combinations of concepts and practices that actually show up in students’ understanding and in their work.

In practice this might mean that a teacher covering a particular topic in a grade would be able to see that some of her children were thinking about that topic in ways characteristic of “earlier” consolidations of the related content and practices progressions. If students were not able to show progress on practices in the context of that particular topic while she was teaching it, having the issue clearly identified in terms of the parallel progressions should make it possible for the teacher to help the students to focus on those practices in the context of their work with subsequent topics or content. The point is that the progressions can make the interactions between content and practices explicit in a way that current standards and assessments often do not, and this in turn provides direction for more effective instructional responses. We also would observe that the fact that progressions can make these distinctions explicit provides a much firmer grounding for thinking about skills (as in “Twenty First Century Skills”) in ways that are instructionally relevant, rather than thinking of them as things that can somehow be taught in their own right independent of particular content.

Improved Curricula

When it comes to curriculum, our main point is that everything we have just said above argues that learning progressions could provide much more useful frameworks for devising specific curricula than are provided by most current standards documents. To repeat—that is because progressions would be rooted in evidence gathered from real students in the course of instruction with real teachers, and provide descriptions of students' progress that specify the particular instructional approaches, or the range of approaches, that were associated with the described progress. Because they would be grounded and tested in real teaching and learning situations, they also hold the promise of providing more realistic pictures of the kinds of progress or growth students are likely to be able to show within the time and particular resource constraints available to schools and teachers. They could support realistic and parsimonious planning for what would be required to meet the needs of a given student population, and help to guide the development of fairer and more realistic accountability provisions for schools, teachers, *and* students. If learning progressions were derived from and tested against evidence of the association between the kinds of progress students make and the kinds of instruction they have experienced, as we are suggesting they should be, then they could provide a basis for specifying "curriculum frameworks" for determining what, and in what order and intensity, specific content and skills should be taught, They also would provide a basis for designing "instructional regimes" that would specify ways of responding pedagogically to individual students' or groups of students' particular stages of progress and learning problems. In this case we would be tempted to argue that we would not need a separate superstructure of "standards" at all—except for the function of identifying within the progressions or frameworks the levels that substantially all children would eventually be expected to reach.

Improved Assessments

Designing and validating assessment instruments focused on the identified levels of progress is part of the process of developing a learning progression. Developers of learning progressions specify learning performance indicators that exemplify how students are likely to think and what they are likely to know, understand, and be able to do (along with their likely misunderstandings as well) at particular points along the progression. These performances encompass levels of understanding and use for both conceptual knowledge and scientific practices that generate that knowledge—practices such as designing investigations, constructing models, critiquing explanations, making scientific arguments, or applying scientific concepts to non-standard problems. These learning performance indicators operationally define the levels of increased understanding and application that most students are likely to pass through on the path to achieving the learning target at the top of the learning progression. Testing the construct validity of learning progressions requires that assessments be designed to report validly on students' levels of progress in terms of the student performances associated with these learning performance indicators.

This requirement to discriminate reliably and validly between levels of performance rather than to discriminate among students—or to order them somehow—represents a subtle, but quite fundamental, shift in the purpose of assessment. Development of learning progressions requires extensive dialogue among science educators, learning scientists, and measurement specialists and should bring these communities together to develop more aligned curricula and assessment. In fact, in several of the cases we examined, assessment experts are working closely with science educators and learning scientists to design assessments that measure different levels of student understanding of specific science content. These assessments are intended to measure use of scientific practices (such as providing explanations or models or designing experiments to test them) as well as understanding of core concepts (such as the conservation of matter or buoyancy) and therefore define in explicit terms how students at each level will express their knowledge and skill. The learning performances defined in the progressions typically would require students to engage in more complex tasks and provide teachers with richer insights into student thinking than the assessment items typically used in state assessments.

Most importantly for the development of better assessments, learning progressions characterize how student performances change over time and describe how thinking will develop over time relative to specific starting and ending points. Thus the assessments based on a progression should provide more useful information than conventional standardized norm-referenced tests do about student progress toward specific learning goals. The assessments derived from learning progressions are likely to provide information that is more easily interpreted by teachers and potentially allow them make better informed and more precise decisions about student needs and how to respond to them instructionally.

Improved Instruction

Having a clear conception of the likely stages of students' progress ought in itself to be useful in guiding teachers on their instructional goals and choices, particularly as those would be reinforced by curricula and assessments informed by progressions. But the evidence generated during the development and testing of the hypothetical learning progressions concerning how they are influenced by instructional choices and experiences should provide even more direct support for teachers' choices about what to do when they see evidence of how their students are progressing and what particular difficulties they are facing. The empirical investigations that are required to inform the development of progressions and to confirm their usefulness also should provide the grounding for the pedagogical content knowledge that teachers need to guide their instructional choices. Teachers' acquisition of that knowledge could of course be facilitated through participation in pre-service education or professional development experiences that would be informed by, and designed in accordance with, the research that supports the development and ongoing validation of the progressions.

The Validation of Learning Progressions

During the panel meetings convened by CCII, a number of the participants (see appendix B for the list of participants) raised the issue of how learning progressions might be "validated," —that is, how evidence might be gathered to test the internal robustness of the hypothesized progression (construct validity) and the hypothesis that the use of a suggested sequence is effective at producing the desired outcomes (consequential validity). As noted above, we think a sensible way to think about learning progressions is to see them as being hypotheses about, or models for, the likely ways in which students' understanding of core scientific explanations and practices and their skills in using them grow over time with appropriate instruction and opportunities to learn. So, if these progressions are to be treated as hypotheses or small-scale theories about how students are likely to learn, it seems to us reasonable to treat the issue of validation in the same way one would treat the development and testing of any scientific hypothesis or theory.

In between children's entering understanding and the target knowledge and practices we hope they acquire by the end of secondary schooling, the learning progression hypothesis suggests that it should be possible to identify some finite set of partial, intermediate, or approximate conceptions of the target scientific explanations through which the students' understandings will build to reach that target. The strong version of the hypothesis would be that most students' understanding will move through these intermediate conceptions in roughly the same order, though perhaps at quite different rates (depending on instruction, ability, other experiences and exposure, including home opportunities, etc.). And for some more complex targets it may be that the intermediate steps involve collections of understandings that interact and support each other but which can be acquired in varying orders. The point would be that the hypothesized progression should be able to specify some way of identifying whether students have acquired each of these conceptions, as well as whether they can be expected to occur in some order or at some time in relation to each other. It also is reasonable to think of any particular progression as being made up of sets of component progressions, each of which could be specified in a similar way. And as these sub-progressions approach the scale at which they might be covered within the course of an instructional unit, or a week, they are more and more likely to include specification of the instructional approaches that are most likely to move a student from one level of understanding to the next (or to undo particular misconceptions that have been identified).

For purposes of validation, all of the above descriptions of the elements of a hypothesized progression can be treated as propositions that can be tested as part of the process of validating a progression. As with any scientific hypothesis or theory, we should not think that testing these propositions can establish the validity of a progression once and for all. Rather, the best we can do is to increase our confidence that the progression is a reasonable account of the ways students are really likely to learn, while recognizing that it could be subject to substantial revision or replacement given new evidence and/or a more inclusive or compelling alternative hypothesis.

The development of a progression tends to be, and perhaps must be, an iterative process involving forming a tentative hypothesis, testing it against further observations of instruction and students' learning, revising it, checking it again, and so on. In many ways this process is indistinguishable from what would be done to assess the validity of a progression. Nevertheless, at some point researchers and developers who have been devising progressions come to some relatively stable view about the key steps students' thinking and skills are likely to go through (and perhaps the misconceptions or particular difficulties they are likely to experience along the way). At a minimum, a hypothetical progression then has to specify the ways in which you could tell whether a student had reached a particular step in the progression (often called "achievement levels"), or where he or she was in that process. That is, the description of the steps needs to specify what people working on learning progressions tend to call the "learning performances" that students would be able to demonstrate if they had reached a particular step (or in some cases also the misconceptions, etc. that they would have at that point, or that might impede their movement to the next level). Those normally translate into even more specific instantiations in terms of assessment items, classroom learning tasks, or assignments.

Some working in this field would argue that the progressions, and the performances and assessments used to identify key steps in those progressions, should be pretty closely tied to curricular and instructional approaches that have been designed to promote student progress from point to point or that have evidence that they are associated with such progress. Among other advantages, knowing something about the instructional experiences students have had makes it possible to design performance expectations and assessments that tap more complex understanding and skills because one can make assumptions about the language and activities it would be fair to assume the students have been exposed to. Others prefer to work with data from students exposed to the normal range of curricula and instruction in our schools, so their progressions, learning performances, and assessments can have a more general application, but they also may be less precise, or have more difficulty in identifying and capturing performance, at the higher levels of the hypothesized progression. Whether instruction is specified or whether the progression involves a more general description of the likely stages of student progress, we think that the process of gathering evidence to validate or demonstrate the value of the progression should include attempts to specify what instruction the students have had, when their performances are being used as evidence that the progression describes the paths their learning has followed.

In any case, the logic of the progression hypothesis requires that when students' performances on the associated assessments, instructional tasks, assignments, etc. are sampled, one should not expect to see that students who were not able to demonstrate the expected learning performance thought to be earlier in the hypothetical progression were nevertheless able to succeed in performing in the way expected for a later point in the progression. If that should happen in more than a very few instances (some forms of performance may offer the possibility of succeeding "by chance," and that would introduce noise into this system), the progression or the design of the assessments, or both would have to be reconsidered and revised.

There are quite sophisticated statistical and psychometric techniques that can be used to design and test the development of assessment items and exercises to see whether the item difficulties and student performances order themselves in ways that are consistent with the predictions implied by the hypothetical progressions[7], and some form of this logic would seem to be essential for validating a progression—i.e. for increasing our sense of its credibility and usefulness. But there are other issues beyond the psychometric ones.

While a progression that is based primarily on evidence from cross-sectional sampling may be sufficient to inform the design of standards and assessments that are more instructive than many we have now, it does seem that the underlying logic of the concept would argue that the progressions should be seen in individual students' understanding as it grows over time—so that eventually there should be strong evidence from longitudinal studies that the hypothesized order of development holds. This is particularly true if the virtues of the hypothesized progressions for informing instruction are to be realized, since those virtues are likely to be seen most clearly when students' progress from step to step is observed very closely and attention is paid to what it is about the students' experiences that seems to help them in this progress. That kind of observation is likely to be crucial for building the kinds of pedagogical content knowledge that should be one of the beneficial outcomes of approaching instruction in terms of progressions.

Further, many of the ideas of progressions that are now being developed, particularly those that are strongly influenced by disciplinary ideas about what should be

[7] Wilson, M. (2005). *Constructing measures: An item response modeling approach.* Mahwah, NJ: Erlbaum

considered acceptable target understanding in the discipline’s terms, set out expectations for performance at the high end that may be realized by only a few students, if any, in the course of conventional instruction in our schools. In that case it will be very hard to provide validation evidence for whether and how those conceptions of advanced performance are reached or how they can be assessed. That implies, in such instances, that students not only need to be followed over time but also that associated instructional interventions will have to be devised in order to test whether there can be “existence proofs” that the higher levels of progress can be reached by more than just a few unusual or talented students.

At the risk of complicating the issue even more, it also became clear in our discussions that, in representing students’ progress as a relatively straightforward set of steps along a metaphorically linear path, learning progressions are making a useful but potentially misleading simplification. As we have discussed earlier, it is more reasonable to understand students as participating in multiple progressions simultaneously, and, in the case of science, these include related progressions in mathematical understanding, reading comprehension (which includes certainly general vocabulary and syntactical awareness), and the strands of scientific practices discussed above which, while they are pedagogically embedded in domain specific experiences, can be seen as having their own progressions. These all can hinder or facilitate the way specific understandings grow. This complexity complicates the picture of psychometric validation we painted earlier, since it reminds us that even if we think our hypothesized progression has a pretty clear logic, the assessment items and exercises we apply it to are likely to be affected by (“load on”) these other progressions as well, and sorting out that more complex set of interactions requires more careful reasoning and implies an even more iterative approach to “validation.”

Consequential Validation

Clearly, there is a good way to go before there are enough science learning progressions having strong evidence that they provide a credible description of the steps students are likely to go through in learning core understandings and skills so that such a collection of progressions could arguably provide the basis for designing a core school curriculum or for deriving from the progressions and the implied curriculum a better and more coherent set of state or supra-state standards and assessments. And it would be a step even further to claim that if such a set of progressions existed, they, and the curricula and assessments derived from them, would be able to inform teachers’ understanding of their students’ progress and problems in such a way that they could respond to that information with pointed instructional reactions that would enable their students to overcome their difficulties and stay on, or get back on, track, so as to meet learning goals, ensure higher levels of performance for all, and reduce gaps between the average level of performance of the student population as a whole and that of groups of students who were less likely to succeed in the past. But those are in fact the kinds of claims that are being made for the value of attending to and developing learning progressions. Those claims raise a general question of consequential validity for learning progressions—if we had enough of them, and they were well justified, would they in fact have these additional beneficial consequences for the education system?

At this point, this is among the most hypothetical of questions. But it does suggest a program of further work that would be necessary to add other levels of “existence proof” to the demonstration that a particular progression works as it is supposed to. It would seem to be a reasonable requirement for the validation of the general progression hypothesis to suggest that, once there were a few well-warranted progressions covering at least a significant sub-set of the generally agreed goals of science education, an effort should be made to convince some set of states to array their standards for the relevant strand(s) of science content and skill learning across the relevant range of grades to match the appropriate achievement levels with the grades (or with the specified order) suggested by the progressions. If they would not do that on a state-wide basis at first, they might be encouraged to promote such an approach in some set of their districts on an experimental basis. In addition, curriculum developers, and providers of professional development, should be encouraged to design approaches to assessment (or a curriculum-embedded search for evidence of student progress and problems), and appropriate pedagogical and instructional responses, keyed to the progressions, and then this whole "regime" should be evaluated, perhaps in competition with "business as usual" or with compelling alternative approaches, to see whether students do significantly better, learn more, close gaps, and so on. If this sounds like a long and recursive process of validation of the progressions hypothesis, it is—but it clearly is consistent with the level of effort, and the time, likely to be required for progressions to prove that they are able to make a significant difference in the effectiveness of the American education system.

Recommendations

We think it is useful and instructive to recognize what actually will be required to test any adequately complex approach to reforming and improving instruction. The learning progression hypothesis is one such approach, and we have only begun to work out what will be required to make it a compelling one. But we do think that we also have begun to make the case that it is an approach that deserves to be taken seriously and that it would justify the investment required to give it a full chance to prove its worth.

The CCII panel discussed the potential of learning progressions, the inadequacies and gaps in the work to date, and some of the challenges facing developers and potential users. They concluded that learning progressions held great promise as tools for improving standards, curriculum, assessment, and instruction. They agreed that it was important to advance the development of learning progressions in a manner that would produce the greatest benefit to educators in the shortest possible time. With this goal in mind, they recommended the following steps be taken by researchers, developers, policymakers, and education professionals:

- **Share the available learning progressions**. While the existing progressions cover only fragments of the K-12 science curriculum, and most have not extensive testing in classrooms, they still can provide useful information for groups working on state and national standards, and for developers working on curriculum and assessment as well. The existing progressions fill in only part of the picture, but, much like archaeologists reconstructing an ancient mosaic from fragments, standards setters and curriculum developers can do better work if they use the available progressions because they provide clues about the structure and sequence of the missing parts of the curriculum.[8]

- **Validate the learning progressions**. Funding agencies should provide additional support for research groups to validate the learning progressions they have developed so they can test them in practice and demonstrate their utility. Second party tests of the learning progressions may also be valuable.
- **Create existence proofs**. An effort should be made to collect evidence that using learning progressions to inform curriculum, instruction, assessment design, professional development and/or education policy results in meaningful gains in student achievement. This evidence is needed to respond to skepticism expressed by various stakeholders about the value and significance of learning progressions, and to justify further investments in their development.
- **Identify the core science ideas to be studied.** Funders such as NSF should work with scientists, researchers, and other relevant stakeholders to identify the core ideas that developers of the next set of learning progressions should be focusing on. Perhaps the next step in this process should be to agree on criteria for selection of those ideas.
- **Invest in development of progressions for the central concepts for K-12 science**. This follows directly from the previous recommendation. Researchers should be encouraged to pursue development of progressions that address the core concepts and that cover larger grade spans. The result would be a collection of progressions with greater relevance to the needs of schools and to the needs of those who design instructional materials and assessments.
- **Invest in the development of assessment tools based on learning progressions for use by teachers and schools**. There is a fundamental difference between assessments designed to distinguish how students perform compared to other students on general scales of “achievement” or ability and assessments designed to distinguish among particular levels in the development of student knowledge and stages of sophistication in their understanding and ability to apply knowledge.
- **Encourage collaboration among scientists, science education researchers, assessment experts, and cognitive scientists**. Inadequate communication among scientists, science education researchers, cognitive scientists, and assessment developers has been an obstacle to work on learning progressions.
- **Support more research on science learning**. We need research that enhances our understanding about how younger students learn and what they are capable of understanding. As noted above, we also need to understand more about how variations in cultural backgrounds and values affect the science learning of young children and how various classroom interventions can successfully accelerate their learning in science.

[8] Some observers of the development of learning progressions would point out that the relationship between progressions and curriculum should be a two-way street. We already have implied that a good progression might be indistinguishable from a good curriculum framework, and it ought to be the case that well-designed curricula or curriculum frameworks – ones that are thoughtful about the ways in which students are likely to learn and what experiences should help them to do so – in areas where progressions have not yet been developed and tested would represent first-order approximations of hypothetical progressions for those areas. Students’ experiences with such curricula would produce the evidence on which stronger progressions might be built (Lorrie Shepard, personal communication).

- **Study development of students from different cultural backgrounds and with differing initial skill levels.** We desperately need to understand how to accelerate the learning of students who enter school with lower literacy levels and also to understand how cultural backgrounds and early experiences affect developmental paths. Researchers recognize that the pathways described by progressions are not developmentally inevitable and that there may be multiple pathways to learning a given idea or practice, but the progressions' hypothesized achievement levels should provide useful *foci* for more constructive studies of how students' differences affect their learning, if and when they do.
- **Increase funding for the development and validation of learning progressions.** All of the above recommendations require funding. The present level of investment in this work is inadequate, and will not allow us to realize the potential benefits of these new tools.
- **Encourage states revising their standards to consider the evidence on learning progressions.** While the scope of the existing learning progressions in science and the evidence supporting the models of development they provide does not warrant mandating their use, states and districts revising their standards and trying to improve science teaching would benefit from considering the lessons they provide about the sequencing of the science curriculum, the inter-connections between conceptual understanding and practices, and the design of assessments.

Learning progressions have enormous potential, but as the recommendations listed above make clear, there is a great deal of work to be done to realize that potential. Still, if we are serious about eliminating achievement gaps and raising the levels of academic achievement in the United States, we must abandon the search for panaceas and quick fixes that has dominated contemporary discussions of school reform and engage in a serious research and development effort to provide our teachers with the tools they need to do the job. Investing in learning progressions would not solve all of our problems, but it would put us on the right path toward finding solutions.

Table of Learning Progressions in Science Discussed, Mentioned, and Identified by Panelists

Some learning progressions were noted by the panelists or identified by reviewing NSF awards for learning progressions in science (cells left blank indicate details about which we did not have information).

Learning progressions presented and discussed at the CCII meetings.

Focus Topic, Concept, or Practice	Developers*	Subtopics	Grades	State of Work	Basis of Development of the Framework	Development Purpose
Tracing carbon in ecological systems (one of four strands of environmental literacy)	Mohan, Chen, and **Anderson**, 2009	1) Carbon (generating organic compounds, transforming organic compounds; oxidizing organic compounds), 2) Water, 3) Biodiversity, 4) Connecting actions	Across Grades 4–12	A basic framework with achievement levels is in place for Carbon, with a set of psychometrically sound assessments that have helped to validate. Currently working on other subtopics but much more work is done on the carbon strand. Conducting classroom investigations to help validate the carbon strand. Validation not complete for any strand of this environmental literacy program, is far along for carbon.	Draws on research on student learning of the topics, but to a large degree is based on empirical work around assessments and inter-viewing students across many grades.	Understand how to help students develop deeper understanding of important concepts in environmental science so they can become environmentally literate citizens

***Bold=Panelist.**

Learning progressions presented and discussed at the CCII meetings, continued.

Focus Topic, Concept, or Practice	Developers*	Subtopics	Grades	State of Work	Basis of Development of the Framework	Development Purpose
Particle model of matter	Merrit, Shin, Namsoo, and **Krajcik**	Structure and Behavior of Atoms and Molecules (includes particle concept, movement, and conservation principles).	One eight to ten week unit at the middle school level	Curriculum is developed and some assessments developed allowing for determination of achievement levels. Working on developing more psychometrically sound assessments to validate. Validation not complete.	Based on prior research on student learning of the particle nature matter, but also based on assessments linked to curriculum and taken by middle school students.	Understand how students use the particle model of matter to explain phenomena can develop over time so can inform curriculum development and instruction around this topic.
Modeling across topics such as matter and energy (Modeling is fore grounded)	**Reiser** and colleagues	Important aspects of understanding and engaging in using models, (constructing, critiquing, and revising models) as well as important aspects of the nature of models (understanding that models are tools for making predictions and explanations)	Across Grades 4–8	Curriculum is developed. Have some assessments allowing for determination of achievement levels. Validation not complete.	Based on some research on students' understanding and use of models, but mainly based on assessments linked to curriculum and taken by elementary and middle school students.	Understand how students' ability to engage in modeling can develop over time so can inform curriculum development and nstruction in science.
Genetics and giving accounts of genetic phenomena using molecular, meiotic, and transmission genetic models	**Duncan**, **Rogat**, & Yarden	Central ideas thought to be important to understanding modern genetics.	Across Grades 4–12	The framework is being validated by a small longitudinal study. Has some learning performances and assessments are available, but they need psychometrically sound assessments to complete the validation.	Largely based on research on student understanding in the discipline, plus some empirical classroom-based research.	Help students learn genetics deeply so that they can go on to become genetically literate adults.

***Bold=Panelist.**

Learning progressions presented and discussed at the CCII meetings, continued.

Focus Topic, Concept, or Practice	Developers*	Subtopics	Grades	State of Work	Basis of Development of the Framework	Development Purpose
Strand maps for **chemical reactions** with predictions and explanations	AAAS Project 2061 (**Roseman**)	Important concepts about matter that are thought to be required to understand chemical reactions.	Across middle school grades	A sequence of ideas is developed. Working on developing assessments, has completed some statistical analysis of assessments to confirm potential relationships using Rasch analysis between concepts in strand maps. Validation not complete.	Largely built on examination of disciplinary knowledge	Help students develop deep understanding of matter with the aim of improving science literacy and influencing standards.
Data modeling and evolution	**Lehrer** and **Schauble**	Measurement; Change in individual organisms, change in populations, variability, ecology.	Across elementary and middle school grades	Have curriculum, conducting classroom studies. Have levels of achievement from studies, developing assessments that are psychometrically sound. Validation not complete. Does not has what most people consider a "curriculum." Model depends on intensive professional development of teachers.	Based on their own and others' research on student learning in the context of good instruction. The research conducted in the context of developing the assessment system also serves to inform revision of the LP.	Support teachers and students in adopting modeling approaches to ecology.

***Bold=Panelist.**

Learning progressions presented and discussed at the CCII meetings, continued.

Focus Topic, Concept, or Practice	Developers*	Subtopics	Grades	State of Work	Basis of Development of the Framework	Development Purpose
Explanations and ecology	**Gotwals** and Songer	Components of scientific explanations, ecology, classification, and biodiversity.	Across Grades 4–6	Have curriculum, conducting professional development with teachers around LP curricula, conducting classroom implementation studies, have levels of achievement from studies, have psychometrically sound assessments. Validation not complete, but is far along.	Worked with scientists to better understand the structure of how biodiversity is defined and used by scientists. In addition, worked from prior research (their own and others) on how students' understandings (and alternative conceptions) in ecology/biodiversity develop and how students develop the ability to construct scientific explanations. Also, based on data from assessments linked to the curriculum.	Help students develop the ability to construct scientific explanations about complex ecology and biodiversity situations/data without support. In addition, develop tools (curricula and professional development) that allow teachers to support students in their development.
Buoyancy (actually is a progress variable; or a greatly simplified LP)	Kennedy and **Wilson**, 2007	Concepts required to understand buoyancy such as mass, volume, density, etc.	One middle school unit	Was developed for a single unit curriculum on buoyancy. Psychometrically sound assessments developed. Achievement levels available.	Based on data from assessments linked to the curriculum.	Help students learn density and buoyancy-a difficult topic to learn; also develop assessments that can provide insight into proficiency in this topic.

***Bold=Panelist.**

Learning progressions presented and discussed at the CCII meetings, continued.

Focus Topic, Concept, or Practice	Developers*	Subtopics	Grades	State of Work	Basis of Development of the Framework	Development Purpose
Atomic molecular theory	Smith, Wisner, **Anderson**, and **Krajcik**, 2006	Concepts central to this theory such as particles, motion of particle, conservation, etc.	Across Grades K–8	Has a framework with proposed developmental sequence. Has learning performances based on a number of inquiry standards such as taking measurements, analyzing data, constructing explanations or making predictions. Has some assessments. Has not been validated, although different groups are working on this.	Based on research on student learning about matter and research in general about learning science. Some parts based on an analysis of the discipline.	NAS commissioned as example of a LP to help illustrate what an LP is and should look like
Evolution	Cately, **Lehrer**, and **Reiser**, 2005	Concepts central to this theory such as diversity, variation, structure/function; ecology/interrelationships; change; geological process.	Across Grades 1–8	Has a framework with proposed developmental sequence. Has learning performances with practices such as argumentation, mathematical modeling, measurement and representation. Needs additional development around genetics. Has some assessments. Has not been validated.	Based in part on research on student learning about evolution and general research about learning science.	NAS commissioned as example of an LP to help illustrate what an LP is and should look like.

***Bold=Panelist.**

Other LPs noted by Panelists or Identified by examining NSF awards.

Focus Topic, Concept, or Practice	Developers*	Subtopics	Grades	State of Work	Basis of Development of the Framework	Development Purpose
Force and motion	**Alonzo**	Relationship between force(s) and motion in one dimension; includes students' ability to predict forces, given motion and to predict motion, given forces.	One unit, at middle/high school level	Framework and associated assessments have been revised in response to several rounds of data collection and analysis. No longitudinal studies have been conducted.	Draws on the extensive literature base about student conceptions and learning, as well as interviews (both "think aloud" and clinical) and written assessments.	To support teachers' formative assessment practices during a unit on basic force and motion principles.
Nature of matter (Nanoscience literacy)	Stevens, Delgado, and **Krajcik**, 2009	Structure of matter, periodic table, and ionic forces (i.e., inter-atomic forces)	Across Grades 7–14	Hypothetical framework and an empirically-grounded framework derived from student assessments and interviews. Have instructional suggestions to help move students along progressions.	Builds off Smith et al. work on matter and examination of standards and discipline analyses, but also uses data from real students to refine and revise.	To support nanoscale science and engineering literacy.
Energy and inquiry	Goldberg and Hammer	Concepts central to thinking about energy	Across Elem. to middle	Have curriculum.	—	—
Evolution	1. Horwitz and colleagues (Concord); 2. Metz and colleagues	—	1. Grade 3–5 2. Early elem.	1. Curriculum and assessment. 2. Curriculum materials	—	—
Matter and inquiry	Doubler, Wiser, Smith, and colleagues	—	Upper elem. and middle	Have framework and some assessments, curriculum materials and professional development. Beginning to validate hypothetical LP.	—	—

***Bold=Panelist.**

Other LPs noted by Panelists or Identified by examining NSF awards, continued.

Focus Topic, Concept, or Practice	Developers*	Subtopics	Grades	State of Work	Basis of Development of the Framework	Development Purpose
Scientific reasoning in the physical sciences	Hammer	—	K–16	—	—	—
Laboratory experiences in life sciences	Dayton et al. (Terc)	—	Grades 1–13	—	Help establish a theoretical framework for developing research and development of LPs in laboratory experiences in the life sciences	—
Atomic theory	Stevens, Delgado, and **Krajcik**	Atomic composition and structure subatomic, inter-atomic interactions	Grades 7–14	Developed framework, assessments, empirical data to support framework. Have suggested instructional strategies to help move students.	Developed a hypothetical framework using lower anchors derived from the Smith et al. Used Standards and Benchmarks to identify big ideas and scientific practices.	To support and promote nanoscale science and engineering literacy.
Celestial motion	Plummer and **Krajcik**	Motion of the sun, moon, and stars	Elem to Middle grades	Developed framework, some curricular interventions, and some assessments.	Based on research on how students learn these topics and the authors' own research and analysis.	To support students' understanding of celestial motion.

***Bold=Panelist.**

Other LPs noted by Panelists or Identified by examining NSF awards, continued.

Focus Topic, Concept, or Practice	Developers*	Subtopics	Grades	State of Work	Basis of Development of the Framework	Development Purpose
Natural selection	Furtak	—	Grades 9–10 biology (IB, regular, ELL)	Two versions of learning progression developed: one based on student misconceptions with sample student responses, and the second based on a sequence of correct ideas. Has set of formative assessments and suggested feedback (including instructional activities). Currently being piloted.	Draws on literature about students' common misconceptions about natural selection, a pilot study of student ideas and Mayr's '5 facts and 3 inferences' about natural selection.	To develop teachers' pedagogical content knowledge, including their facility with formative assessment, surrounding the teaching of natural selection and evolution.
Developing an empirically-tested learning progression for the transformation of matter to inform curriculum, instruction and assessment design	Shin and **Krajcik**	Matter and its transformation 6–12 grade.	Across grades 6th through 12th	Have hypothetical framework and some associated assessments allowing for determination of achievement levels; piloting assessment items using quantitative and qualitative methodology; validation of assessment not complete.	Based on research on student learning about topics, as well as interviews and written assessments.	Characterize how students can develop understanding of the major constructs within the transformation of matter. Track whether students can make important connections between concepts that lie in multiple constructs

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Appendix B

Meeting Participants

Alicia Alonzo, Assistant Professor, University of Iowa
Charles (Andy) Anderson, Professor, Michigan State University
Tom Corcoran, CPRE Co-Director, Teachers College, Columbia University
Karen Draney, Senior Researcher, Berkeley Evaluation & Assessment Research Center
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Joseph Krajcik, Professor, University of Michigan
Richard Lehrer, Professor, Vanderbilt University
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James Pellegrino, Professor, University of Illinois-Chicago
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Meeting Chair, Joseph Krajcik
Meeting Lead Organizers, Aaron Rogat and Tom Corcoran