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Measuring Progressions: Assessment Structures Underlying a Learning Progression

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Abstract: This article describes some of the underlying conceptualizations that have gone into the work of the BEAR Center in the development of learning progressions. The core of all of these developments has been the construct map, which is the first building block in the BEAR Assessment System (BAS). After introducing the concept of a learning progression, the article summarizes the elements of the BAS, emphasizing the central concept of a construct map. The article then describes a series of several different ways to see the relationship between the idea of a construct map and the idea of a progression (which I call the ''assessment structure''), and also gives illustrative examples from recent BEAR projects. The article then discusses some strengths and limitations of these conceptualizations, focusing on both educational and measurement issues. The article concludes with some general reflections. © 2009 Wiley Periodicals, Inc. J Res Sci Teach 00: 1–15,

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The idea of a learning progression is one that is undergoing swift development at the current time. However, it is really just the latest manifestation of a much older idea, that of regularity in the development of students as they learn a certain body of knowledge or professional practice. Devising means of measuring a student's location within or along a learning progression is a crucial step in advancing the scientific study of learning progressions, and for finding educationally useful applications of the idea. In this article, one particular approach to measurement, called the BEAR Assessment System (BAS; Wilson, 2005; Wilson & Sloane, 2000), is used as a lens through which to portray a perspective on the many possible ways that learning progressions could be conceived of and measured. In this article, the manner in which the measurement approach supports the learning progression is referred to as the *assessment structure* for the learning progression. Of course, there are other measurement approaches that one could take, but these are outside the scope of this current effort.

The article begins with a brief note about the concept of learning progressions and adds some notes about assessment perspectives on learning progressions. It then summarizes the elements of the BAS, emphasizing the central concept of a construct map, which is the focus of the rest of the article. It then describes a series of several different ways to see the assessment structures—the relationship between the idea of a construct map and the idea of a progression—and gives examples from current and recent BEAR work. It then discusses the strengths and limitations of these conceptualizations, focusing on both educational and psychometric issues. The article concludes with some general reflections.

Learning Progressions: Links to Assessment

In general, this article will follow the definition of learning progressions as given in the lead article in this issue (Duncan & Hmelo-Silver, 2009). The purpose of the current article is to attempt to lay out some possible patterns of relationships between learning progressions and a concept that has been developed within a measurement and assessment framework, the concept of the construct map. This will be defined in some

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detail in the next section of the article, but suffice it to say at this point that a construct map is intended to be a somewhat less complex concept than a learning progression, and is designed to help conceptualize how assessments can be constructed to relate to theories of cognition.

Although the idea of a learning progression has links to many older and venerable ideas in education, the history of the specific term ''learning progression'' in the context of science education is a relatively brief one (CCII, 2009), starting with the publication of an NRC report (2006). That report was focused on assessment in K-12 education, and hence the connections to assessment have been there right from the start. Nevertheless, given the brief time-span since then, there is not a great deal of extant literature regarding the relationship between the two, although this may well change in the near future. A second NRC report (2007) also featured the concept, and enlarged upon classroom applications. Several assessment initiatives and perspectives are discussed in these reports, including references to the seminal 2001 NRC report *Knowing What Students Know*. Among the assessment programs highlighted there, probably the most prominent is the work on *progress variables* by the Australian researchers Masters and Forster (1996), and the closely related work on the somewhat more elaborated BAS (Wilson, 2005). In this article, I will draw on the latter as the core set of assessment perspectives and practices to relate to learning progressions.

In order to illustrate certain aspects of the relationship between learning progressions and assessment, I will use a visual metaphor that superimposes images of construct maps on an image of a learning progression. This image of the learning progression is shown in Figure 1, where the successive layers of the ''thought clouds'' are intended to represent the successive layers of sophistication of the student's thinking, and the increase in the cloud's size is intended to indicate that the thoughts become more sophisticated later in the sequence (e.g., they have wider applicability later in the sequence). The person in the picture is a someone (a science educator, a science education researcher, an assessment developer?) who is thinking about student thinking. In other circumstances (e.g., Wilson, 2005), I have called this person the ''measurer,'' though not here, as the ideas being examined in the article are mainly at an early point in the development of assessments, focusing on the first of the building blocks. It is important to recall that this learning progression is in the researcher's thoughts, and that it represents a hypothesis about the students' thoughts that will be examined empirically, eventually.

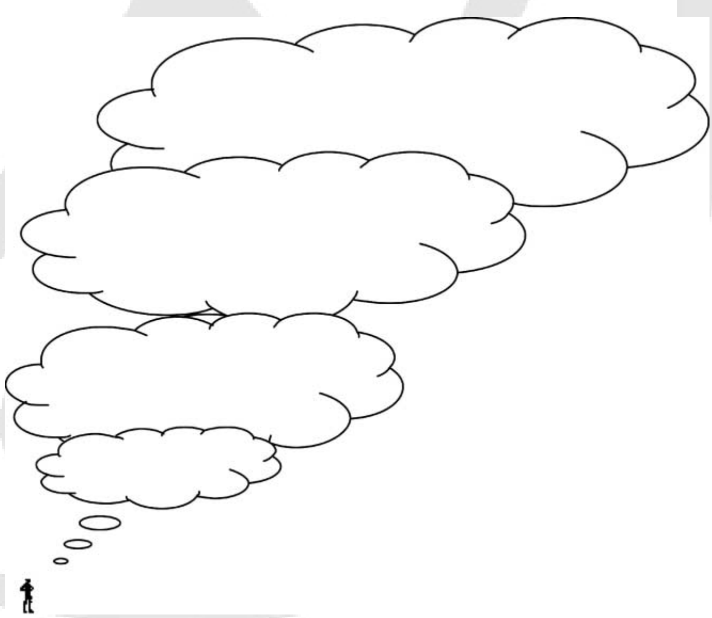

Figure 1. An image of a learning progression.

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The BEAR Assessment System

The BAS is based on the idea that good assessment addresses the need for sound measurement through four principles: (1) a developmental perspective, (2) a match between instruction and assessment, (3) the generating of quality evidence, and (4) management by instructors to allow appropriate feedback, feed forward and follow-up. These four principles, plus four building blocks that embody them, are shown in Figure 2. Below we take up each of these principles and building blocks in turn, emphasizing the first. See Wilson (2005) for a detailed account of an instrument development process that works through these steps.

Principle 1: A Developmental Perspective

A "developmental perspective" regarding student learning means assessing the development of student understanding of particular concepts and skills over time, as opposed to, for instance, making a single measurement at some final or supposedly significant time point (for earlier perspectives on this see Hewson, 1992 and Posner, Strike, Hewson, & Gerzog, 1982). Establishing appropriate criteria for taking a developmental perspective has been a challenge to educators for many years. What to assess and how to assess it, whether to focus on generalized learning goals or domain-specific knowledge, and the implications of a variety of teaching and learning theories all impact what approaches might best inform developmental assessment. One issue is that as learning situations vary, and their goals and philosophical underpinnings take different forms, a "one-size-fits-all" development assessment approach rarely satisfies educational needs. Much of the strength of the BAS comes in providing tools to model *many different kinds of learning theories and learning domains*. What is to be measured and how it is to be valued in each BEAR assessment application is drawn from the expertise and learning theories of the teachers, the curriculum developers, and the assessment developers involved in the process of creating the assessments.

Building Block 1: Construct Maps. Construct maps (Wilson, 2005) embody this first of the four principles: that of a developmental perspective on assessment of student achievement and growth. A construct map is a well thought out and researched ordering of qualitatively different levels of performance focusing on one characteristic. Thus, a construct map defines what is to be measured or assessed in terms general enough to be interpretable within a curriculum and potentially across curricula, but specific enough to guide the development of the other components. When instructional practices are linked to the construct map, then the construct map also indicates the aims of the teaching. Construct maps are one model of how assessments can be integrated with instruction and accountability. They provide a way for large-scale assessments to be linked in a principled way to what students are learning in classrooms, while at least having the potential to remain independent of the content of a specific curriculum.

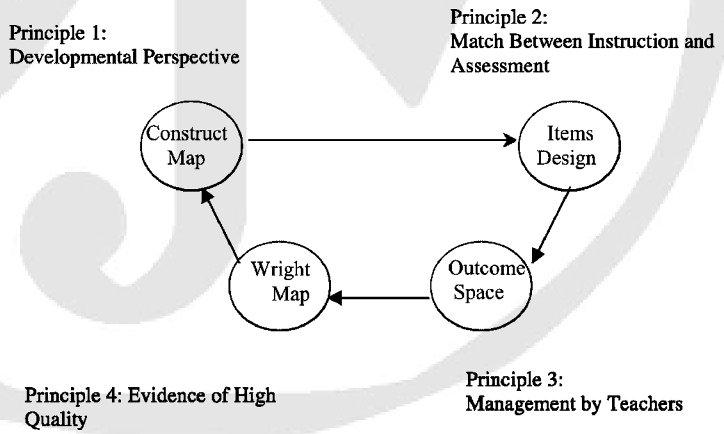

Figure 2. The principles and building blocks of the BEAR Assessment System.

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This approach assumes that, within a given curriculum, student performance on curricular variables can be traced over the course of the curriculum, facilitating a more developmental perspective on student learning. Assessing the growth of students' understanding of particular concepts and skills requires a model of how student learning develops over a certain period of (instructional) time. A growth perspective helps one to move away from "one shot" testing situations, and away from cross-sectional approaches to defining student performance, toward an approach that focuses on the process of learning and on an individual's progress through that process. Clear definitions of what students are expected to learn, and a theoretical framework of how that learning is expected to unfold as the student progresses through the instructional material (i.e., in[Q3] terms of learning performances), are necessary to establish the construct validity of an assessment system.

The idea of using construct maps as the basis for assessments offers the possibility of gaining significant *efficiency* in assessment: Although each new curriculum prides itself on bringing something new to the subject matter, in truth, most curricula are composed of a common stock of content. And, as the influence of national and state standards increases, this will become more true, and also easier to codify. Thus, we might expect innovative curricula to have one, or perhaps even two variables that do not overlap with typical curricula, but the remainder will form a fairly stable set of variables that will be common across many curricula.

Construct maps are derived in part from research into the underlying cognitive structure of the domain and in part from professional judgments about what constitutes higher and lower levels of performance or competence, but are also informed by empirical research into how students respond to instruction or perform in practice (NRC, 2001). To more clearly understand what a progress variable is, consider the following example.

The example explored in this brief introduction is a test of science knowledge, focusing in particular on earth science knowledge in the area of "Earth and the Solar System" (ESS). The items in this test are distinctive, as they are ordered multiple choice (OMC) items, which attempt to make use of the cognitive differences built into the options to make for more valid and reliable measurement[Q4] (Briggs, Alonzo, Schwab, & Wilson, 2006). The standards and benchmarks for "Earth in the Solar System" appear in Appendix A of the Briggs et al. article (2006). According to these standards and the underlying research literature, by the 8th grade, students are expected to understand three different phenomena within the ESS domain: (1) the day/night cycle, (2) the phases of the Moon, and (3) the seasons—in terms of the motion of objects in the Solar System. A complete scientific understanding of these three phenomena is the top level of our construct map. In order to define the lower levels of our construct map, the literature on student misconceptions with respect to ESS was reviewed by Briggs and his colleagues. Documented explanations of student misconceptions with respect to the day/night cycle, the phases of the Moon, and the seasons are displayed in Appendix A of the Briggs et al. article (2006).

The goal was to create a single continuum that could be used to describe typical students' understanding of three phenomena within the ESS domain. In contrast, much of the existing literature documents students' understandings about a particular ESS phenomena without connecting each understanding to their understandings about other related ESS phenomena. By examining student conceptions across the three phenomena and building on the progressions described by Vosniadou and Brewer (1994) and Baxter (1995), Briggs et al. initially established a general outline of the construct map for student understanding of ESS. This general description helped them impose at least a partial order on the variety of student ideas represented in the literature. However, the levels were not fully defined until typical student thinking at each level could be specified. This typical student understanding is represented in the ESS construct map shown in Figure 3 (a) by general descriptions of what the student understands, and (b) by limitations to that thinking in the form of misconceptions, labeled as "common errors." Common errors used to define level 1 include explanations for day/night and the phases of the Moon involving something covering the Sun or Moon, respectively.

In addition to defining student understanding at each level of the continuum, the notion of common errors helps to clarify the difference between levels. Misconceptions, represented as common errors in one level, are resolved in the next level of the construct map. For example, students at level 3 think that it gets dark at night because the Earth goes around the Sun once a day—a common error for level 3—while students at

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Level	Description
5 8th grade	Student is able to put the motions of the Earth and Moon into a complete description of motion in the Solar System which explains: • the day/night cycle • the phases of the Moon (including the illumination of the Moon by the Sun) • the seasons
4 5th grade	Student is able to coordinate apparent and actual motion of objects in the sky. Student knows that • the Earth is both orbiting the Sun and rotating on its axis • the Earth orbits the Sun once per year • the Earth rotates on its axis once per day, causing the day/night cycle and the appearance that the Sun moves across the sky • the Moon orbits the Earth once every 28 days, producing the phases of the Moon COMMON ERROR: Seasons are caused by the changing distance between the Earth and Sun. COMMON ERROR: The phases of the Moon are caused by a shadow of the planets, the Sun, or the Earth falling on the Moon.
3	Student knows that: • the Earth orbits the Sun • the Moon orbits the Earth • the Earth rotates on its axis However, student has not put this knowledge together with an understanding of apparent motion to form explanations and may not recognize that the Earth is both rotating and orbiting simultaneously. COMMON ERROR: It gets dark at night because the Earth goes around the Sun once a day.
2	Student recognizes that: • the Sun appears to move across the sky every day • the observable shape of the Moon changes every 28 days Student may believe that the Sun moves around the Earth. COMMON ERROR: All motion in the sky is due to the Earth spinning on its axis. COMMON ERROR: The Sun travels around the Earth. COMMON ERROR: It gets dark at night because the Sun goes around the Earth once a day. COMMON ERROR: The Earth is the center of the universe.
1	Student does not recognize the systematic nature of the appearance of objects in the sky. Students may not recognize that the Earth is spherical. COMMON ERROR: It gets dark at night because something (e.g., clouds, the atmosphere, “darkness”) covers the Sun. COMMON ERROR: The phases of the Moon are caused by clouds covering the Moon. COMMON ERROR: The Sun goes below the Earth at night.
0	No evidence or off-track

Figure 3. Construct map for student understanding of Earth in the solar system.

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level 4 no longer believe that the Earth orbits the Sun daily but rather understand that this occurs on an annual basis.

The top level of the ESS construct map represents the understanding expected of 8th graders in national standards documents. Because students' understanding of ESS develops throughout their schooling, it was important that the same continuum be used to describe the understandings of both 5th and 8th grade students. However, the top level is not expected of 5th graders; equally, we do not expect many 8th grade students to fall into the lowest levels of the continuum.

Principle 2: Match Between Instruction and Assessment

The main motivation for the progress variables so far developed is that they serve as a framework for the assessments and a method of making measurement possible. However, this second principle makes clear that the framework for the assessments and the framework for the curriculum and instruction must be one and the same.

Building Block 2: The Items Design. The items design governs the match between classroom instruction and the various types of assessment. The critical element to ensure this in the BAS is that each assessment task and typical student responses are matched to certain levels within at least one construct map.

Returning to the ESS example, the OMC items were written as a function of the underlying construct map, which is central to both the design and interpretation of the OMC items. Item prompts were determined by both the domain as defined in the construct map and canonical questions (i.e., those which are cited in standards documents and commonly used in research and assessment contexts). The ESS construct map focuses on students' understanding of the motion of objects in the Solar System and explanations for observable phenomena (e.g., the day/night cycle, the phases of the Moon, and the seasons) in terms of this motion. Therefore, the ESS OMC item prompts focused on students' understanding of the motion of objects in the Solar System and the associated observable phenomena. Distractors were written to represent (a) different levels of the construct map, based upon the description of both understandings and common errors expected of a student at a given level and (b) student responses that were observed from an open-ended version of the item. Two sample OMC items, showing the correspondence between response options and levels of the construct map, are shown in Figure 4. Each item response option is linked to a specific level of the construct map. Thus, instead of gathering information solely related to student understanding of the specific context described in the question, OMC items allow us to link student answers to the larger ESS domain represented in the construct map. Taken together, a student's responses to a set of OMC items permit an estimate of the student's level of understanding, as well as providing diagnostic information about that specific misconception.

Principle 3: Management by Teachers

For information from the assessment tasks and the BEAR analysis to be useful to instructors and students, it must be couched in terms that are directly related to the instructional goals behind the progress variables. Open-ended tasks, if used, must be quickly, readily, and reliably scorable.

Building Block 3: The Outcome Space. The outcome space is the set of categorical outcomes into which student performances are categorized for all the items associated with a particular progress variable. In practice, these are presented as scoring guides for student responses to assessment tasks. This is the primary means by which the essential element of teacher professional judgment is implemented in the BAS. These are supplemented by "exemplars": examples of student work at every scoring level for every task and variable combination, and "blueprints," which provide the teachers with a layout showing opportune times in the curriculum to assess the students on the different variables.

Principle 4: Evidence of High-Quality Assessment

Technical issues of reliability and validity, fairness, consistency, and bias can quickly sink any attempt to measure along a progress variable as described above, or even to develop a reasonable framework that can be supported by evidence. To ensure comparability of results across time and context, procedures are needed to

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Item appropriate for fifth graders:

It is most likely colder at night because

A. the Earth is at the furthest point in its orbit around the Sun.	Level 3
B. the Sun has traveled to the other side of the Earth.	Level 2
C. the Sun is below the Earth and the Moon does not emit as much heat as the Sun.	Level 1
D. the place where it is night on Earth is rotated away from the Sun.	Level 4

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Item appropriate for eight graders:

Which is the best explanation for why we experience different seasons (winter, summer, etc.) on Earth?

A. The Earth's orbit around the Sun makes us closer to the Sun in summer and farther away in winter.	Level 4
B. The Earth's orbit around the Sun makes us face the Sun in the summer and away from the Sun in the winter.	Level 3
C. The Earth's tilt causes the Sun to shine more directly in summer than in winter.	Level 5
D. The Earth's tilt makes us closer to the Sun in summer than in winter.	Level 4

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Figure 4. Sample OMC items based upon Earth in the solar system construct map.

(a) examine the coherence of information gathered using different formats, (b) map student performances onto the progress variables, (c) describe the structural elements of the accountability system—tasks and raters—in terms of the achievement variables, and (d) establish uniform levels of system functioning, in terms of quality control indices such as reliability.

Building Block 4: Wright Maps. Wright maps represent this principle of evidence of high quality. Wright maps are graphical and empirical representations of a construct map, showing how it unfolds or evolves in terms of increasingly sophisticated student performances.

Mapping Out a Learning Progression Using Construct Maps

The remainder of this article concentrates on just the first of the building blocks described above—the construct map—and its potential relationships with the idea of a learning progression, also described above.

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I have labeled this as the assessment structure. It might seem to have been a waste of time to describe all four of the building blocks when only the first is being used in the rest of the article, but the concern is that, unless the place of the construct map in the entire BAS approach is understood, its relevance and importance in the following discussion would be misunderstood. At relevant points in the discussion, issues concerning the items, the outcome space, and the measurement model will also be mentioned. But the main focus of this article is on the conceptual relationship between the construct map and a learning progression, hence these other matters, although they are of great importance for any actual realization of a construct map, will not be fully explored.

One straightforward way to see the relationship of construct map to learning progression is to see the learning progression as composed of a set of construct maps, each comprising a ‘‘dimension’’ of the learning progression, and where the levels of the construct maps relate (in some way) to the levels of the learning progression. I will call this a *within* assessment structure for a learning progression (i.e., because the levels of the progress variables are linked to the levels of the construct maps). Note that the psychometric view of these dimensions would likely be that they are positively correlated, and hence might be illustrated as dimensions in three-dimensional space originating from a common source, as is common in geometric interpretations of psychometric models. Here the angle between the arrows is an indicator of the correlation between the dimensions.

To illustrate this assessment structure, I use a much-reduced illustration of a construct map, which will be used as an icon in later figures to represent a specific (but generic) construct map. This icon is then used (several times) in Figure 5, superimposed on the earlier image of a learning progression, to illustrate the idea that the learning progression could be ‘‘mapped out’’ by a (small) set of construct maps. In this illustration, the levels of the construct maps all align, and that may indeed be the case, conceptually, but need not be required, as they might vary between construct maps. But the important point is that the *levels* of the learning progression relate to the *levels* of the construct maps.

One example of a learning progression that has being developed is on the topic of the Carbon Cycle, which is being led by Andy Anderson of Michigan State University (Mohan, Chen, & Anderson, 2008).

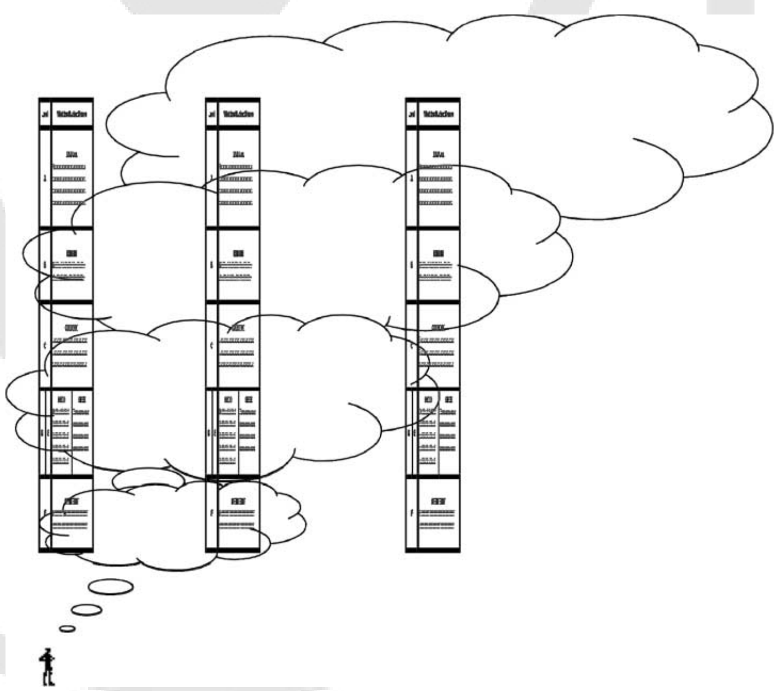

Figure 5. One possible relationship—the levels of the learning progression are levels of several construct maps.

Figure 6 shows a working document from this project illustrating two of the construct maps that are a part of the topic. In this example, the levels are clearly different in the two construct maps; however, the descriptions of the pairs of levels also exhibit a certain degree of consistency which was indeed an aspect of their development. As the levels move upwards, there is an analogy between the two construct maps in how the sophistication increases from level to level. One complexity that is not illustrated in this diagram is that the items are designed so that each item relates to a level of each of the two construct maps (so that the items may be laid out in a two-way grid according to the levels of each of the construct maps). This is an interesting and important aspect of the items design, and is crucial for item design and deployment, but should not affect the interpretation of the construct maps themselves.

The situation represented in Figure 5 may be too ‘‘schematic’’—it may be, for instance, that the consistency of the levels shown in Figure 5 is based on analogies in their structure and construction, but that these do not require that the levels actually be consistent across constructs in the timing of when students tend to get to them (or, equivalently in the items' difficulties). For example, it might be that some of the constructs are inherently more complex than others. This situation is illustrated in Figure 7, where the construct maps are ‘‘staggered.’’

It may be that the construct map is a ‘‘large’’ one, conceptually, or that the learning progression is a relatively compact one. In this case, it may be that a single construct map would serve to span (the measurement aspects of) the learning progression. This is illustrated in Figure 8, and was exemplified in Figure 3. Note that this example was not used as an initial one for a learning progression, as I wanted to avoid the suggestion that a learning progression might ‘‘normally’’ be represented by a single construct map.

Another possible relationship between construct maps and learning progression would be where the levels of the progress variable are each represented by one (or more) construct maps. This is illustrated in Figure 9. This sort of situation would perhaps arise where the learning progression was a rather lengthy one, and the assessments were needed to pinpoint student development within the levels (of the progression). I will call this a *between* construct map structure for the learning progression, as the levels of the learning progression amount to different construct maps.

Level	Hierarchy of Systems	Material Kind & Properties of Matter
7	Describes movements of matter through multiple processes at multiple scales	Correctly characterizes reactants and products of processes in terms of how they affect organic carbon compounds
6	Traces elements or atoms through single life process, relating multiple scales	Correctly identifies reactants and products of single life process
5	Describes movements of matters in simple chemical changes at atomic-molecular scale. (not just events)	Correctly identifies reactants and products in simple chemical changes.
4	Describe matter movement at macroscopic scale. (not just events).	Correctly identifies some reactants and products of simple chemical changes. Identifies solids, liquids, but not gases involved in chemical or physical changes.
3	Attention to hidden mechanism. Describes events as changes in materials.	Attention to hidden mechanism, but cannot identify any material kinds.
2	Describes changes as events (at macroscopic scale)	Identifies changes by using common sense of natural phenomena, but not as changes in materials
1	Egocentric/Naturalistic Reasoning: Respondents use human analogy to explain the changes in materials	Egocentric/Naturalistic Reasoning: Respondents use human analogy to explain the changes in materials

Figure 6. An example from the carbon cycle project.

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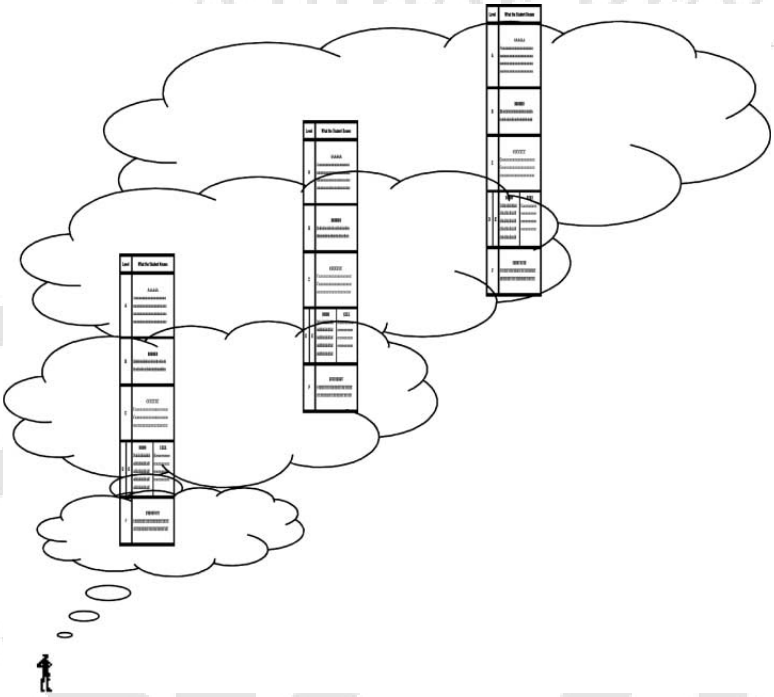

Figure 7. A somewhat different version of Figure 5—the levels are staggered.

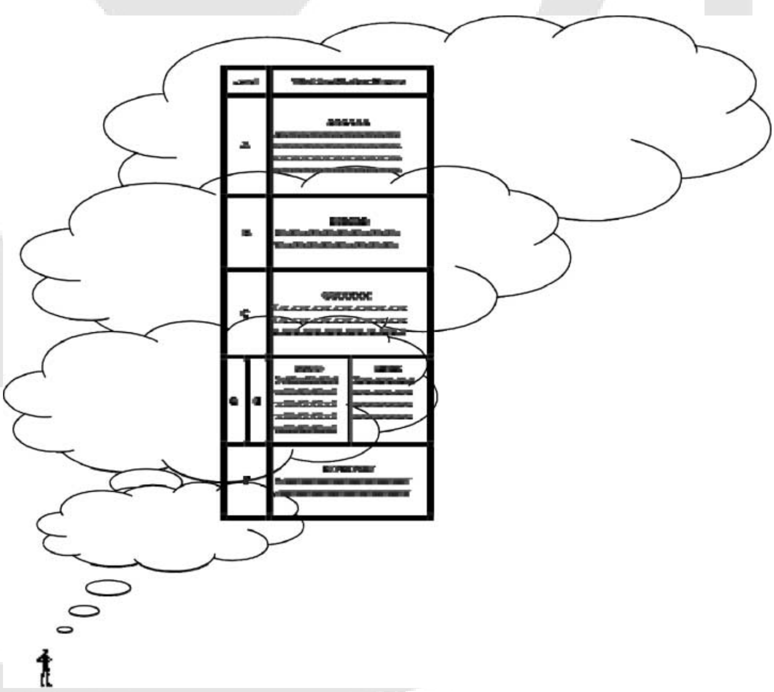

Figure 8. An extreme version of the situation in Figure 5: the levels of the learning progression are the levels of a single construct map.

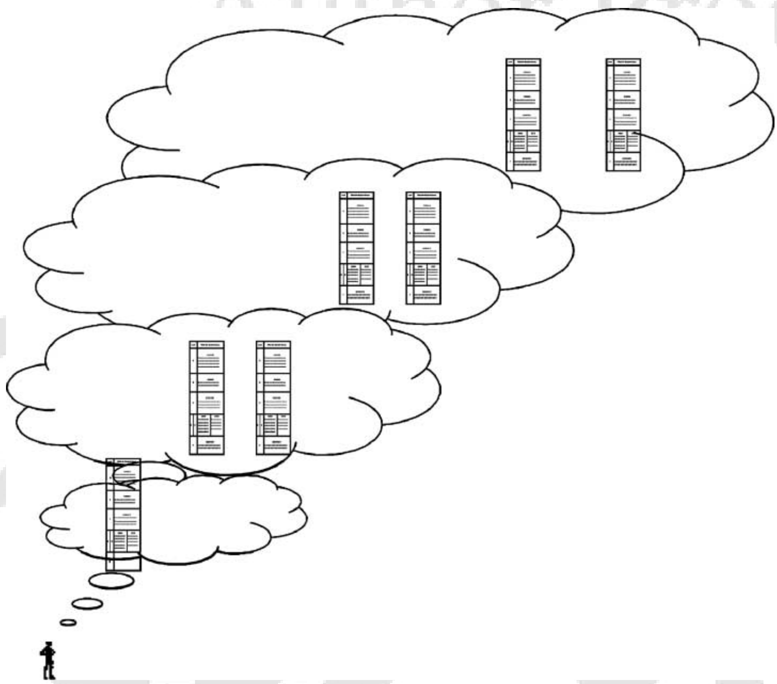

Figure 9. Another[Q5] possible relationship—between construct map structure—different construct maps inside each level of the learning progression.

As a further complexity, the relationship between the construct maps that is hypothesized may be more complex than that envisaged in Figure 9. For instance, there could be an assumption that certain of the constructs led to one construct rather than another. This could be illustrated as in Figure 10. Here, the attainment of levels of a construct would be seen as being dependent on the attainment of high levels of specific ''precursor'' constructs. An example of such thinking, this time in the case of the Molecular Theory of Matter for the middle school level under development with Paul Black of King's College, London, is shown in Figure 11 (Wilson & Black, 2007). In this example, each of the boxes can be thought of as a construct map, but the relationship between them is left unspecified in this diagram. In particular, the Density and Measurement and Data Handling constructs are seen as providing important resources to the main series of constructs, which is composed of the other four constructs, Properties of Objects, Properties of Atoms and Molecules, Conservation and Change, and Molecular Theory of Macro Properties.

A more complicated way of seeing such a possibility would be where there are links hypothesized that are between specific levels within a construct, and specific levels of other constructs (rather than the ''top to bottom'' relationships shown in Fig. 10). Specifically, the ''top to bottom'' arrows of Figure 10 would then inadequate to convey the subtleness of the content connections in the full vision of the learning progression. Of course, it would also be possible to have construct map structures that shared the features of both within and between patterns—these possibilities are structures more complex than I wish to pursue at this point.

The set of possibilities described above far from exhausts the possible field. For example, having made the distinction between within and between assessment structures, it is also clear that assessment structures could be built that were combinations of the two kinds, with some construct maps crossing over levels of the learning progression, and some remaining within a level of the learning progression—these might be called mixed assessments structures. One very large and important set of ideas that has not been mentioned above is the potential for using the model of a cycle as the core of a construct map, and hence for the structure of a learning progressions. Many educational ideas are expressed as cycles, and they open up a different and very

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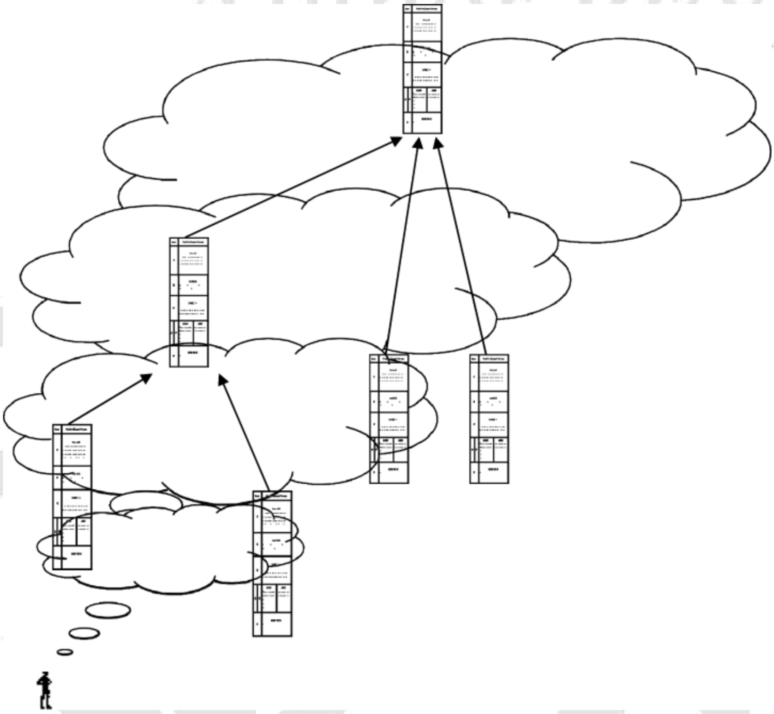

Figure 10. In this situation, there is a complicated dependency relationship between the construct maps in the learning progression.

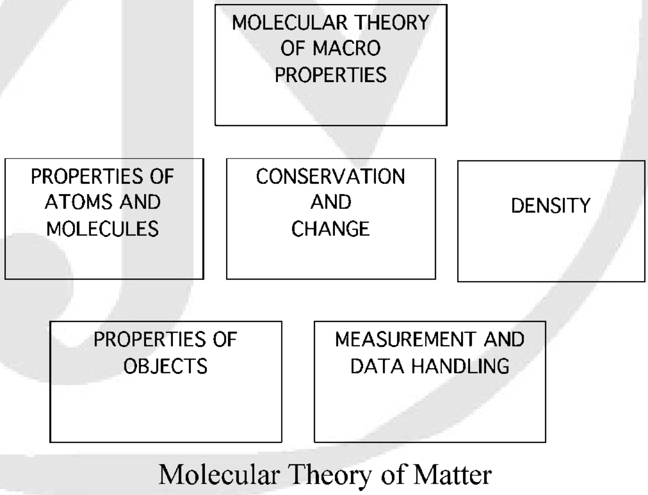

Figure 11. A set of constructs hypothesized to constitute a molecular theory of matter.

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interesting range of possible ways of thinking about a learning progression. This topic is worth investigating, and will be the subject of further work.

Discussion

Having laid out some basic possible structures for the way that construct maps could be seen as the ''skeleton'' of a learning progression, we now have some purchase from which to think about what would be a desirable way for that to occur. Thus, we can switch to asking the question ''How should we use a concept like the construct map to structure a learning progression?'' This question is best answered from within the perspective of a specific topic area, and with the learning goals in mind. But some general observations can be made. For instance, there are some who will be drawn to the simplicity of Figure 8—an approach like this could provide some recourse to a straightforward way of thinking about and assessing a learning progression. Some might be concerned by the lack of complexity inherent in this, however, and be attracted to Figure 5 instead, representing a more complex account of the learning progression. In fact, it could be the case that *both* of these could be applicable to a single learning progression. It might be, for example, that the situation in Figure 5 is a good one for expressing the appropriate level for in-classroom assessments, allowing for interesting instructional planning and sound diagnostic views of student progress. However, for summative purposes, it may not make sense to work at that level of detail, and hence, one might look to aggregating the three construct maps in Figure 5 into a summary construct map, as in Figure 8, and use that for end-of-course reporting, or for other summative purposes. Thus, the construct map models represented in these figures, although presented above as different choices, may well be logically and educationally compatible. But educationally, and assessment-wise, the point is that we may choose different ways to build up our learning progressions depending on the educational and assessment purposes we have in mind, and this satisfaction of different purposes need not require different assessment systems—the same system can be built to reflect these different purposes.

A different set of remarks can be made for the between construct map cases. Here the detailed version of the structures, such as those shown in Figure 10, may be amenable to assessment using a simpler structure such as that in Figure 9. Assessments could be designed to correspond to this simpler type of design (effectively the structures illustrated in Figure 10 without the links between the construct maps), and, separately, those assessments could be used to test out (statistically) the existence and strength of the links hypothesized in those figures.

The type of assessment structure chosen will have an important influence on the design of items. For example, in the within construct cases, items will often be constructed to range across the levels of the learning progression (although they may be linked to just one level too, of course). But, in the between construct map cases, it would seem to be more likely that the items would be situated mainly within a certain construct, and hence within a single level of a learning progression. It may be that some items consist of sets of sub-questions, and these could well have more complicated relationships to the learning progression.

The outcome space, being tied so closely to the construct map, will tend to have its features determined by each specific construct map. The situations where this might be modified are cases like that depicted in Figure 5, where there are possible commonalities across construct maps. This can lead to the possibility that items could be constructed, and scored, in similar ways for different construct maps. But it could also lead to possible confusions, where exactly the similarity just referred to can become a problem that obscures the genuine differences among the constructs and their respective levels. Balancing these issues is an important design task.

With respect to the measurement models that one would use to model the data arising from assessments based on one of the construct map structures described above, a great deal will depend on the nature of those structures. Statistically speaking, the approaches in Figures 5 and 9 are essentially both comprised correlated dimensions, so that a multidimensional item response model (Adams, Wilson, & Wang, 1997) would be suitable. However, the approach in Figure 10 would constitute a variant of structural equation models (SEM), although beginners may need to read previous chapters also)—that is, each of the construct maps would be a single SEM variable, and the arrows between would be the SEM paths. In contrast, the approach where the arrows point inside the boxes would constitute a more complicated form of SEM that I would call a

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"Structured Constructs Model" (SCM). In this instance, the "SEM paths" run not between the boxes (i.e., between the SEM variables), but from specific levels within those variables.

Conclusion

In this article, I have tried to outline some possible underlying assessment structures that one could build to undergird a learning progression. This has been done from very specific measurement perspective, that of the construct map that forms the heart of the BAS. I make no excuses about this focus, as the discussion above shows that, even taking such a particularistic view, there are a great many ways that the construct map concept could be deployed to give structure and form to the assessments to support a learning progression. Other measurement approaches could equally be used, but these would require separate development in separate papers. Laying out these possibilities is helpful to thinking about what the issues and limitations of such an approach might be.

One thing that emerges from the range of possible construct map structures that are shown is that there are a great many possible ways that the construct maps could be deployed to support a learning progression. This flexibility is important, as one would not want to have the potential usefulness of a learning progression to be constricted by the underlying assessment structure.

It is also clear that there are some important decisions that will need to be made when one is thinking about the assessment structure best suited for a given learning progression. Being aware of the range of possibilities described here, and possibilities beyond these, will help the developers of a learning progression in thinking about the form they want a learning progression to take, and how they will relate it to assessments. Considering such issues such as whether one would prefer a between or a within assessment structure, or something in-between, will be an important step in developing a new learning progression, or in modifying an existing one.

Equally clear, these choices will also have important ramifications for the other building blocks, the items design, the outcome space, and the measurement model. For this last, other important decisions will need to be made about the nature of the measurement model, whether it will be a traditional form of a uni- or multidimensional model, or whether it will include elements of structural equation modeling, or even more complex ones such as the SCM models mentioned above.

Looking to the topic of assessment structures *per se*, this article has really just scratched the surface of an important aspect of the application of measurement ideas in science education in particular, and, potentially, across the whole range of areas of educational achievement. Unidimensional and multidimensional item response models have been a mainstay of the measurement in educational achievement domains for the last few decades. Seeing how these can be extended into the complex areas allowed by SEM-like approaches, and the more subtle SCM approaches described above will be an interesting and challenging task in the future.

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