Chapter 52
Curriculum Coherence and Learning Progressions

David Fortus and Joseph Krajcik

In the 1999 TIMSS science achievement test for grade 8 students, the USA was ranked 18th place out of 38 countries (National Institute for Education Statistics 2001). Sofia Kesidou and Jo Ellen Roseman (2002) reported on an evaluation of the major American middle school science textbooks that were in use around the time of this test. This report revealed that almost all the textbooks dealt with a very broad range of topics and did not focus on coherent age-appropriate learning goals. They were piecemeal and lacked coordination and consistency across time, topics, and disciplines. The key concepts were often buried among unrelated ideas, surrounded by inappropriate details. The curricula did not take into account students' prior knowledge and did not build on them in a systematic way that Marcia Linn and Bat Sheva Eylon (2006) claimed would allow students to progress from superficial to integrated understanding. By integrated understanding we mean ideas that are connected to each other in such a manner that allows learners to be aware of and be able to use relationships between various ideas to solve problems and understand the world they live in. Such understanding allows learners to use this relational network of ideas to explain and predict phenomena as well as solve problems.

In parallel, in a study of student learning as measured by TIMSS, William Schmidt et al. (2005) found that curricular coherence was the most dominant predictive factor of student performance. Similar to Schmidt et al., we describe curriculum coherence as the alignment of the specified ideas, the depth at which the ideas are studied, and the sequencing of the topics within each grade and across the grades.

D. Fortus (✉)
Department of Science Teaching, Weizmann Institute of Science,
Rehovot 76100, Israel
e-mail: david.fortus@weizmann.ac.il

J. Krajcik
College of Education, Michigan State University, East Lansing,
MI 48824-1259, USA
e-mail: krajcik@msu.edu

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This analysis indicated that one of the likely reasons for the poor performance of the USA in the TIMSS exam was the incoherent nature of the textbooks used in American classrooms. It became clear that efforts to improve science education needed to consider how to design curricular material with a high degree of coherence.

Shortly afterwards, Mark Wilson and Meryl Berenthal (2006) raised the notion of learning progressions and Richard Duschl et al. (2007) reinforced it as a framework for designing curriculum and assessing student progress. Learning progressions are descriptions of successively more sophisticated ways of thinking about how learners develop key disciplinary concepts and practices within a grade level and across multiple grades. The underlying idea of learning progressions is that learning unfolds across time as students link previous ideas and experiences to new ideas and experiences. Learning progressions allow designers to bring coherence to their curriculum materials, coherence that is crucial in supporting student learning by providing alignment between standards, instructional tasks, and assessments across grades and grade bands.

As will become apparent in the following sections, there are actually different kinds of curricular coherence, some easier to obtain than others, but all are required outcomes of effective learning progressions. Attempts to develop coherent curriculum materials in the USA have been few and have typically focused on stand-alone units that do not provide the coherence between units, within and across years, that is one of the hallmarks of an effective learning progression that allows learners to develop integrated understandings. This chapter describes the different kinds of coherence, the difficulties involved in obtaining them, their relation with learning progressions, and the role that they all play in supporting student learning.

Different Kinds of Coherence

Content Standards Coherence

Schmidt et al. (2005) define content standards to be coherent if:

> … they are articulated over time as a sequence of topics and performances consistent with the logical and, if appropriate, hierarchical nature of the disciplinary content from which the subject-matter derives… They must evolve from particulars to deeper structures… This evolution should occur both over time within a particular grade level and as the student progresses across grades. (p. 528)

Hence, coherent content standards are likely to result in helping students to develop integrated knowledge that can be used to understanding phenomena.

The Atlas of Science Literacy of Project 2061 (AAAS 2007) presents an attempt to organize and sequence content standards to support the construction of deep and interconnected understanding of concepts. In many ways, the Atlas is like a huge, interconnected tapestry of Gagné-like knowledge hierarchies (Gagné 1966).

The Atlas is divided into many columns and four rows. Each column contains the concepts that are relevant to a particular strand of scientific thought or phenomena, for instance, mechanisms of biological inheritance, electric currents, or behavior at different scales. Each row contains concepts that are deemed appropriate to be learned in a specific grade band (K–2, 3–5, 6–8, and 9–12). Concepts that are logically or disciplinary dependent, are connected by arrows going from the basic one to the more advanced one. To promote the coherence of these maps, Jo Ellen Roseman and Mary Koppal (2008) report that Project 2061 attempted to include only those concepts that were considered central to their strands. While there is still a lack of evidence supporting many of the strands in the Atlas, this remains perhaps the most detailed and comprehensive example of content standard coherence.

Unfortunately, many states have not followed this example when crafting their own standards. State standards are often incoherent, too vague to be useful, and inaccurate (American Federation of Teachers 2003; Gross et al. 2005). This lack of content standard coherence and the large variability between the standards set by different states presents considerable challenges to curriculum developers and publishers and is undoubtedly one of the reasons for the poor state of US science textbooks (Roseman and Koppal 2008) and student achievement on tests of international comparison.

Learning Goals Coherence

One of the first decisions designers of instructional materials need to consider, whether they are developing a unit that deals with a single topic or materials that span several years of study and cover multiple topics and science domains, is what will be the learning goals of the curriculum. Creating a coherent set of learning goals is a crucial step in the design process. As Yael Shwartz et al. (2008) pointed out, learning goals should be the foundation of any curriculum; if they do not comprise a coherent set, anything built upon them will be shaky at the best.

Although learning goals are based on content standards, some important differences exist between them. The first difference is in their number – there are many content standards, so many that many researchers and curriculum designers think there are too many (Duschl et al. 2007). On the other hand, learning goals need to be limited in number to allow the designers and teachers to deal with them in satisfactory depth over the time allotted to the curriculum. We believe that just presenting ideas to students is not the same as engaging them in learning the ideas so that they build understanding. Too many learning goals lead to superficial coverage and little conceptual understanding in students. So once the focus of a unit is decided, the designers need to choose which content standards are age-appropriate and relevant to this topic. The relevant content standards will most likely be drawn from multiple strands in the Atlas (AAAS 2007) or another standards document. Often the number of standards that meet these requirements is still too large. What criteria should be used to pare down the number of content standards and how are these then linked to create a set that is coherent in the sense described by Jerome Bruner (1995, p. 334): "[giving the student] the experience of going from a primitive and weak grasp of some subject to a stage in which he has a more refined and powerful grasp of it"? Such a process will allow learners to develop a rich understanding of the concepts as the unit progresses.

This is where the relation between coherence and learning progressions first appears. As mentioned previously, learning progressions are research-based descriptions of successively more sophisticated ways of how learners develop key disciplinary concepts and scientific practices across time. Learning progressions can provide the framework to help designers decide which learning goals are critical to a topic, which are secondary and, which are not essential, and how these learning goals need to be sequenced to provide coherence. Of course, learning progressions need to be empirically tested using coherent curriculum. As such, the design of learning progressions and coherent curricula is an iterative process. The empirical work that results from validating learning progressions can provide evidence to support or indicate the need to revise the sequencing and organization of many of the strands in the Atlas.

A learning progression typically organizes concepts from particulars to deeper and more integrated structures. For example, the idea that objects appear to have different colors because they absorb and scatter different wavelengths of visible light is based on the idea that light scattered from an object needs to enter our eyes for the object to be seen. So it would be expected that a learning progression about the role of light in sight would place the idea that "light from an object needs to enter our eyes for the object to be seen" before the idea "different colored objects scatter different wavelengths of light" (AAAS 2007, p. 67).

However, since the study of learning progressions is a relatively young field of research and development, there are only a handful of existing learning progressions, and even fewer that have been fully articulated and tested (Catley et al. 2005; Directorate for Education and Human Resources 2005). So most likely, designers will not be able to use a learning progression as a ready-made artifact in supporting learning goal coherence. Instead, designers need to use a hypothetical learning progression, which describes a theoretical model for successively more sophisticated ways of thinking about the ideas for which they are designing curriculum but which have not been validated with empirical evidence, and use this as a first guess in selecting and organizing their unit's learning goals. Later on, data collected once the unit is completed and enacted in multiple sites, can serve as evidence confirming or disconfirming aspects of the learning progression (Smith et al. 2006). Thus, the process of using learning progressions to construct coherent learning goals that are the foundations for units is also the process by which the learning progressions are validated.

A second difference between learning goals and content standards is their specificity. As Joseph Krajcik et al. (2008) demonstrated, each content standard can involve multiple ideas that need to be separated, unpacked, and clarified as to how the designers intend to operationalize them. For example, this is how we unpacked a content standard:

> Content Standard: Light interacts with matter by transmission (including refraction), absorption, or scattering (including reflection). To see an object, light from that object – emitted or scattered from it – must enter the eye.
>
> Unpacked Content Standard: Students should recognize that these are the three basic ways in which light interacts with matter, and they should be able to distinguish between the three by classifying their observations of phenomena. Students should be able to relate the thickness, surface features, and opacity of an object to its ability to scatter, transmit, and absorb light. Students should be able to explain how the color of light transmitted or scattered by an object depends on the object's color (as perceived when illuminated by white light) and the color of the illuminating light, but they should not be expected to explain why certain colors/wavelengths are absorbed while others are scattered or transmitted.
>
> Students need not understand that scattered or transmitted light is actually the result of absorbed light that is re-emitted. We will deal with absorption, scattering, and transmission as three different phenomenological categories that provide a useful way of classifying certain phenomena.
>
> Students should understand that light that is not scattered or transmitted, must be absorbed. While we will not deal explicitly with the notion of conservation, we wish to plant a seed about conservation that will be returned to and reaped in the 7th grade energy unit.
>
> Reflection and refraction are phenomena that represent specific ways in which light can be scattered or transmitted by an object. They are specific because they describe how individual light rays are redirected when they come into contact with specific objects, rather than providing a general description of how the light interacts with matter. We will discuss the difference between scattering and reflection from planar mirrors, but will not investigate refraction. We will deal with the law of reflection.
>
> We will not explore how the redirection of light changes how an object appears to the eye. (Fortus et al. 2006, p. vi)

Note that this elaboration mentions not only what will be done, but also what will not. It also mentions how a particular idea will serve as the seed for a different idea in a different unit (see section on "Interunit coherence").

The final difference between content standards and learning goals is that learning goals specify not only what students should know; they also specify what students should be able to do with their knowledge. This is a variation on David Perkins' (1992) "understanding performances."

For example, the unpacked content standard about light described earlier and an unpacked standard about scientific modeling "models are used to illustrate, explain or predict phenomena" can be combined to make the following learning goal: "Ss use a model of light to explain why it is possible to see through some objects but not others" (Fortus et al. 2006, p. 172). Figures 52.1 and 52.2 illustrate this process. The same unpacked content standard can be combined with different practices at different places along a unit, as appropriate.

To summarize, a coherent set of learning goals is composed of a relatively small number of content standards, each unpacked to describe how it will be operationalized in the curriculum, organized to go from simpler to more complex levels of understanding, and specifying what students should be able to do with this knowledge.

Fig. 52.1 Learning goals

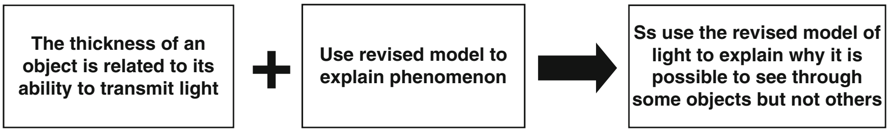

Fig. 52.2 A specific learning goal

Intra-unit Coherence

Intra-unit coherence results from the coordination between content learning goals, scientific practices, inquiry tasks, and assessments within a project-based framework. A coherent unit can be thought of as a four-dimensional entity, with a progression occurring along each dimension: content learning goals, scientific practices, inquiry tasks, and assessments. While designing the progression along any one of these dimensions is not a simple task, coordinating between all three progressions is very difficult and involves multiple design iterations. The former section described the characteristics of a coherent set of learning goals. The next three sections do the same for the other three dimensions and show how these dimensions can be intertwined.

Coherence of Scientific Practices

As elaborated by Helen Longino (1990), Nancy Nersessian (2005), Richard Lehrer, and Leona Schauble (2006), scientific practices represent the disciplinary norms of scientists as they construct, evaluate, communicate, and reason with scientific knowledge. As adapted to the classroom, scientific practices characterize how students use scientific understandings to make sense of and explain the world. Practices are important in science education for two complementary but distinct reasons: firstly, engaging in scientific practices is a means to engage learners in developing and using conceptual understanding; secondly, scientific practices define an important part of what it means to understand the discipline of science itself. As such, developing understanding of scientific practices can also be seen as a key learning goal.

There are many scientific practices, such as scientific modeling, constructing scientific explanations, designing experiments, and organizing and analyzing data that should be integrated into science education. However, just as with the content standards, there are too many elements to each practice to focus on them all together at the same time. Choosing which scientific practice to develop in a unit, on which elements of the practice to focus, and how to organize them in a coherent manner is as important a process as deciding how to obtain content learning goal coherence, and is done in much the same manner. Certain topics lend themselves to certain practices more than others. For example, the particle nature of matter is an excellent topic to engage in modeling because students can develop more sophisticated models of the nature of matter as they attempt to explain more phenomena. Evolution is not a good topic to engage in the design of experiments because of time constraints. Once the focal scientific practices for a unit are decided upon, the Atlas (AAAS 2007) or other coherent standards and a learning progression are used to identify the age-appropriate elements of the practices and organize them in a coherent manner. Due to the paucity of validated learning progressions, especially progressions of scientific practices (Directorate for Education and Human Resources 2005), there will be much uncertainty in how the scientific practice develops over time. Also, because of the interplay between content understanding and the understanding of scientific practices, it is unclear how understanding of practices in one area of understanding will influence understanding of the practices in other content areas. However, tentative work by Yael Bamberger and Elizabeth Davis (2011) and David Fortus et al. (2010) does indicate that the features of some practices may transfer from one content area to another.

Inquiry Sequence

What can a curriculum designer do to maintain student interest and engagement while inquiring into a topic that, off-hand, may not be not seem interesting to them at all, such as the interaction between light and matter or the particle nature of matter? Joseph Krajcik and Phyllis Blumenfeld (2006) indicate that many researchers have found that a driving question can serve to motivate students and maintain their interest over prolonged periods. Learners, however, need to be shown the value of driving question. One way this is done is by engaging students in anchoring phenomena. How is this done? Through attempts to explain the phenomena, students become engaged in formulating a scientifically accurate answer to the driving question. Since the driving question typically deals with a complex, nontrivial issue, the process of answering it will require several steps, some of which can be done in parallel because there is no concept dependency between them, while some depend on the results of other steps, using their outputs as inputs. This process can be seen as a progression toward the resolution of the driving question; each step adds detail and potentially combines different pieces of the answer into a larger, more complex entity, bringing us closer to full resolution of the question. It is important to realize that most learners will not see meaning in the driving question unless they experience the phenomena and see the relevance of the question to their lives (Krajcik and Blumenfeld 2006). For this reason, rather than phrase driving questions as topic-oriented questions, such as "What is the structure of matter?" they should be phrased as phenomenon-driven questions for which students can develop meaning, such as “How can I smell things from across the room?”

The steps to the answer of the driving question are mapped onto the learning goals of the unit. The organization of the learning goals, as dictated by a learning progression, will not always match the sequence of steps in answering the driving question. Not all the learning goals may be relevant to the answer to the driving question. Usually, the sequence of steps in answering the driving question can be reorganized to provide closer alignment with the coherent set of learning goals. At other times, the coherence requirement of the learning goals maybe so off that the driving question may need to be revised. Of course, as with any true scientific inquiry, one can make detours to ensure that prior knowledge is activated or to wander beyond the minimum requirements to respond to student interests. At the end of this process of choosing a driving question, analyzing its answer and mapping it onto the learning goals, the scope and sequence for the unit should be fully articulated: the unit will follow the path described by the answer to the driving question, with the various steps on the way aligned with different learning so that at the end of the unit, all the learning goals will have been covered. Shwartz et al. (2008) provide a few examples of how this was done in units dealing with the nature of light and the particle nature of matter.

Coherence of Assessments

Teachers and students need a feedback mechanism that will allow students to learn how they have progressed and where understanding impediments remain. Coherent assessments are embedded in a unit in a timely and ongoing manner, and they are aligned with the learning goals and the level of understanding that can be expected at different points in a unit; otherwise, the information they provide is dramatically less useful in supporting learning and teaching.

Coherent assessments should come in different forms – a discussion question, a homework task, the construction of a model, the analysis of data, a quiz. The assessments should be placed in strategic locations throughout the unit, places where the students have presumably already learned something about the learning goals addressed by the unit, but not too late so that there do not remain any other opportunities to rectify any difficulties that the assessment may uncover.

Each assessment opportunity should explicitly point out to the teachers why it is located where it is and what to do with possible student responses. For example, in a unit on light, after students have encountered the ray model of light, the different ways light interacts with matter, that light from an object needs to enter the eye for the object to be seen, and the relation between perceived brightness and the amount of light entering the eye, the following series of question could serve as an assessment of the understanding of these ideas. Note that the questions include information for the teacher regarding what to look for in students’ responses, why the questions are located where they are in the unit, and what to do if students are having difficulty responding to the questions (Fortus et al. 2006, p. 278):

> By this time Ss should be able to explain that some scattered light from an object needs to enter their eyes for the object to be seen. The next section builds off this learning goal, distinguishing between different colors of light. These are some questions will elicit students' understanding of this learning goal while setting the stage for the next activity, which involves mixing different colors of light on a screen.
>
> - Can you see the screen when the projector is off? Why or why not?
>   *Yes. Students should mention that light from outside is being scattered by the screen. Some of the scattered light is moving to their eyes.*
>   Turn on an overhead projector.
> - How does the screen look different now than it did before?
>   *The screen looks brighter.*
> - Why is the screen brighter?
>   *It is important that Ss be able to explain that more light is reaching the screen, since it is now illuminated by the projector AND by light from outside. Since more light is reaching it, more light is being scattered by it, so more light from the screen is reaching their eyes. When more light enters their eyes, they interpret whatever is being seen as being brighter.*
>   If Ss struggle to respond, you can place a transparency with the light model on the overhead projector and ask the following question.
> - If the screen is the object being seen in the model, what happens when more light is directed at the object?

There should be a progression in the assessments along the unit so that assessments that come later in a unit involve deeper understanding and target multiple, rather than single learning goals and practices.

Interunit Coherence

Interunit coherence is similar to intra-unit coherence, except that it relates to larger inquiry sequences, multiple scientific practices, and different content domains within and across years. Interunit coherence deals with the question of how to coordinate among units to support the development of content and practice learning goals across a year of instruction or across several years of instruction, so that learners build a deeper and integrated understanding of core ideas. While several units, mainly ones funded by NSF, have been crafted that attempted to achieve learning goal coherence and/or a coherent inquiry sequence, fewer have attempted to be coherent with respect to scientific practices. Almost none have attempted to achieve interunit coherence, for the simple reason that they were typically developed as stand-alone entities, not part of a coherent and comprehensive curriculum.

A coherent sequence of units is comprised of individual units, each one of which is independently coherent, but which are subjected to additional constraints and requirements, that allow them to build off one another, for ideas to flow from one to the others, and for the students to reach a higher degree of knowledge integration

(Roseman et al. 2008) than would have been possible than if the units were truly stand-alone entities, with no explicit connections between them.

Learning progressions are central to designing for interunit coherence, even more so than for intra-unit coherence. As stated earlier in this chapter, learning progressions are descriptions of successively more sophisticated ways of thinking about how learners develop key disciplinary ideas and practices across multiple grades. A single unit does not span multiple grades nor does a unit deal with multi-interdisciplinary ideas and practices. Thus, while the design of a coherent unit draws upon a learning progression to determine the sequencing of and connections between learning goals of the unit, this is only the beginning of what learning progressions have to offer. The real power of learning progressions is that they look at the development of ideas over prolonged periods of time, much beyond the scope of a single unit. Developing interunit coherence will require the integration of several learning progressions.

A single unit might draw upon two learning progressions – one for its content learning goals, the other for its central scientific practice. On the other hand, a curriculum that has interunit coherence must draw upon multiple learning progressions, one for each key disciplinary idea and one for each scientific practice. It is likely that these learning progressions were developed independently of each other, so the designers of coherent curricula face the task of figuring out how to conjoin these together.

To describe how this can be done, we use the example of a learning progression for the idea *matter and energy are transferred between organisms and their environment* and show how it was implemented in a curriculum developed by Joseph Krajcik et al. (2001, 2004) called IQWST (pronounced I-Quest) – Investigating and Questioning our World through Science and Technology – through grade levels and across disciplines, in multiple units, each of which provides a necessary element of this idea (Shwartz et al. 2008, p. 214). Table 52.1 identifies the various content standards from the Atlas (AAAS 2007) and their sequencing in the curriculum needed to support understanding of this key idea.

This progression of the ideas is not linear. It provides opportunities to revisit, enhance, build further, and apply knowledge in different disciplinary units and grades to construct integrated knowledge of the transformations of matter and energy in ecosystems and create a powerful view of explaining the world. The same key ideas are often addressed in different units, at different levels of sophistication, and highlighting different aspects. An important component of any learning progression is not just specifying the knowledge but also how the knowledge is used. For example, in the 6th-grade biology unit, students determine that food is made of carbohydrates, proteins, and fats, and provides energy and building materials for all living things. Students use these ideas to explain why they need to eat in order to grow and stay alive. The 8th-grade chemistry unit revisits this idea and investigates the molecular structure of these substances, concluding that they are complex molecules that explain ideas related to photosynthesis and respiration. Explicit links to ideas learned in other places are made throughout. Such interunit coherence ensures that the key ideas are not just dealt with for a short time: they stay in the curriculum

Table 52.1 Sequencing of standards across the curriculum to support a key idea

Key idea	Where it is addressed
All matter is made up of atoms	6th-grade chemistry
Food provides the fuel and the building material for all organisms. Plants use the energy in light to make sugars out of carbon dioxide and water	6th-grade biology – macroscopic perspective 8th-grade chemistry – molecular level
Atoms that make up the molecules of existing substances rearrange to form new molecules of new substances	7th-grade chemistry
Conservation of matter in a chemical reaction	7th-grade chemistry
Energy transformations and conservation in living things	7th-grade physics
Animals get energy from oxidizing their food, releasing some of its energy as heat	8th-grade chemistry – oxidation reactions
Food energy comes originally from sunlight	6th-grade biology 7th-grade physics – energy from the sun 8th-grade chemistry – photosynthesis
Matter and energy are transferred from one organism to another repeatedly and between organisms and their physical environment	6th-grade biology – food chains 8th-grade chemistry – cellular respiration and photosynthesis

and are revisited repeatedly from different points of view. This helps students make connections and gradually build an integrated knowledge of the key ideas.

At the same time, another learning progression involving the particle nature of matter is developing in these same units. The key idea that matter is made of particles is first introduced in the 6th-grade chemistry unit where students use these ideas to explain why objects can be smelled from across a room. The 6th-grade earth science unit uses the particle model to explain the water cycle. The 6th-grade biology unit uses this idea to discuss processes in living systems. The 7th-grade physics unit uses it in investigating and explaining thermal, chemical, and electrical energy. The 7th- and 8th-grade chemistry units use it in investigating the chemical reactions involved in photosynthesis and cellular respiration.

This approach is different than that found in traditional noncoherent curricula or in what has been called spiral curricula. It emphasizes that real-world phenomena are complex, the knowledge needed to make sense of them is not limited to a single discipline, and that understanding unfolds over time. In a traditional curriculum, photosynthesis will usually be presented as a topic in biology. The molecular aspects of the process, as well as understanding its importance in transforming light energy into chemical energy are not emphasized. Few middle school chemistry and physics curricula actually deal with the different aspects of photosynthesis (Schmidt et al. 2005). It is different from spiral curricula because ideas are dealt with in more sophisticated manners from multiple disciplinary perspectives to explain more complex phenomena.

A coherent curriculum should be more than just a tool that sequences tasks, learning goals, and scientific practices in a coherent manner. It should also be coherent with respect to the language it uses and the teacher support it provides.

Language Coherence

Every scientific concept and practice is accompanied by a multitude of disciplinary terms that are used by scientists when communicating with each other about these concepts. While students should not be expected to learn convoluted terms for the sake of knowing them, certain terms are central to scientific discourse on certain topics, and any omission of them will hinder the ability to freely communicate with these ideas. For instance, when learning about energy, the terms “conservation,” “transformation,” and “transfer” are key terms that students need to learn, because almost any scientific discourse on this topic will use them. Moreover, having fluency of these ideas allows learners to explain a host of phenomena that they experience in their lives.

On the other hand, often the same terms have very different meanings in the different science disciplines. For example, biologists often say that energy is used by an organism. For physicists, energy is never used; it is transformed or transferred. They would say that biologists are really talking about “free energy” or the “Gibbs function.” In another example, a system for biologists and earth scientists is a collection of components that together lead to complex phenomena. Chemists and physicists often speak of systems as anything within boundaries, real, or imaginary, that can be analyzed separately from their surroundings.

While the same terms often have different meaning, the opposite is often true too – different terms are often used as though they have the same meaning, leading to confusion as to why there needs to be multiple terms at all. For example, predict and hypothesize are often used interchangeably, even though there is a difference in their precise meaning. Information, data, and evidence are also very closely related, and are often used synonymously, even though they really do not mean the same thing.

Misunderstandings are guaranteed if the same word is used differently in different contexts or if different words are used as if they had the same meaning, especially with younger students. In coherent curricula it is important either to use terms in a consistent manner across all contexts or to explicitly clarify the different meanings the terms have in different places, why they are used in one place in one way and a different way in another place.

Coherent Teacher Support

Ever since Deborah Ball and David Cohen (1992) suggested the potential curriculum material could have in supporting not only student learning but teacher learning as well and Betsy Davis and Joseph Krajcik (2005) laid out design heuristics to realize this potential, educative features have become a standard characteristic of all high-quality curriculum materials. It is not enough for a coherent curriculum to include these features; these features themselves must be organized in a coherent manner, one that supports growth in teacher knowledge in a way that matches the other coherent features of the curriculum.

Most likely because of the education science teachers experienced and the manner in which most science textbooks are written, many teachers do not have a developmental perspective on how to help students learn ideas across time. As such, many teachers do not see the need to develop ideas across time. An educative curriculum that provides commentary, teaching ideas, and various supports is essential in helping teachers learn how to teach in a more developmental fashion. For instance, linking ideas within a unit and across units is a critical feature in teaching in a developmental manner, as it builds upon the prior knowledge of learners. In a coherent curriculum, the curriculum developers should frequently point out connections to related ideas developed in previous units and suggest how to relate these ideas back to students. Such a process allows students to develop integrated knowledge rather than isolated understandings.

Conclusions

As the world becomes ever flatter (Friedman 2007), with nations becoming more diversified, the challenge of how to provide quality science instruction is more amplified than ever. Today's children are growing up in a world where they will need to apply and communicate ideas, make sound decisions based on evidence, and collaborate with others to solve problems, activities that require a deep and interconnected understanding of the fundamental ideas underlying these problems. Yet, most of our schools do not have this focus and their teachers still use curriculum materials that lack any support for students to build ideas across time. Too many schools still try to cover too much content without focusing on developing deep, integrated understanding.

As described above, learning progressions are descriptions of successively more sophisticated ways of thinking about how learners develop key disciplinary concepts and practices within a grade level and across multiple grades. The underlying idea of learning progressions is that learning unfolds as students link previous ideas and experiences to new ideas and experiences. Learning progressions are essential in designing materials that have learning-goals, and intra-unit and interunit coherence – materials that can allow learners to develop integrated understandings of key scientific ideas and practices across time. However, much work needs to be done to design coherent curricula, validate learning progressions, and then redesign both the materials and the learning progressions.

At present, in the USA there is no curriculum built in this manner. Existing US curriculum has students experience ideas in a piecemeal fashion, leaving them with a superficial understanding of isolated ideas and not seeing how these ideas relate to one another. Curriculum materials that are based upon learning progressions need to be designed, implemented, and tested. Such empirical work will feedback into modifying the learning progressions. As mention earlier, each state has their own standards and often these standards are not coherent. It might be possible for each state to develop their own coherent materials, but such a process is too time- and resource-intensive for individual states (Roseman and Koppal 2008). The development of coherent curriculum materials calls for multiple cycles of design and development, testing and revising the materials, aligning materials, assessments, and teacher support with learning progressions. This requires substantial resources. Although the investment is substantial, the potential outcome of a generation of scientifically literate children is well worth the effort.

IQWST (Krajcik et al. 2001, 2004) is an example of a work in process that is attempting to rectify this situation by building coherence within and across units in a middle school science curriculum. These materials need to be tested to verify that this intense development work actually makes a difference and does lead to a more integrated understanding. But to do so requires that the materials be used by teachers as intended by the designers. This does not mean that the materials need to be scripted, but it will require intense professional development and educative features to help teachers use the materials as intended. The IQWST work is supporting and being supported by the development and validation of several learning progressions that will involve further iterations. Some of this work has started but more is still needed (Merritt et al. 2008; Schwarz et al. 2010).

Because of the overabundance of standards, teachers feel pressure to cover many topics, fearing that they will appear on high-stakes examinations. Yet, it is known that mere coverage of material does not lead to integrated understanding of ideas. Learners need to experience science in engaging contexts and apply ideas in order to learn. Yet with so many standards, teachers feel as if they must cover many topics. Many teachers did not learn science themselves in a developmental manner in which ideas built upon each other, where evidence was used to support claims and where science ideas were used to explain important problems and phenomena; as such, there is a need for educative resources and intense professional development that can support teachers in the use of coherent curriculum materials that can promote the constructing of an integrated knowledge of fundamental science ideas. Testing of coherent curriculum built on learning progressions could provide the evidence to show teachers and policy makers that learning ideas in depth actually supports science literacy more than just the covering of materials.

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