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Café Scientifique

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Cafés scientifiques (also known as science cafés, particularly in the USA) are informal, accessible, gatherings in which members of the public and scientists meet to talk about issues in science and technology that affect people's everyday lives.

Café scientifique has its roots in the *Café Philosophique* movement, begun in France by the philosopher Marc Sautet. Café scientifique began almost simultaneously in France (1997) and the UK (1998); the network has gradually spread until now 2012, there are cafés on every continent, although the distributed nature of the café network makes it difficult to be precise about exactly how many there are at any time.

Café scientifique is a philosophy, rather than an organization. The café scientifique website and other country-based sites offer support, guidance, and mentoring to café organizers, but all cafés are organized locally and autonomously, with no one person or group in overall control of the network. This means that the format of cafés varies from town to town and country to country; this entry focuses on the "classic," British café scientifique model.

The defining feature of a café scientifique is the venue. Cafés take place in bars, cafés, pubs, art galleries, village halls, bookshops, restaurants, and similar generic venues, not in universities or lecture theaters. This removal of the location from the academic milieu to the community context is important on two counts. First, the nature of the venue shapes the nature of the discourse. The atmosphere of cafés is relaxed, informal, and egalitarian; in a café, we expect to have a conversation. In a lecture hall, we expect to be lectured at. Therefore, in a café scientifique, the emphasis is on dialogue among equals, not on the one-way transmission and reception of information. Second, the seating of participants around tables ensures that they engage as much with each other as with the speaker, tipping the balance of power toward the audience, rather than the speaker.

Cafés are cheap, simple, and people-focused. Most operate without any kind of formal funding. This is made possible by the peer-to-peer, informal nature of the movement. Café organizers are normally volunteers; the venues are often free or very low cost, as cafés fill the venue on otherwise quiet nights. Entrance is likewise free, although many cafés ask participants to make a donation toward the speaker's expenses. Speakers are often drawn from local industry or universities, so expenses are kept fairly low. Most cafés eschew the use of technology such as presentation software or microphones, in line with the philosophy of keeping the interaction between audience and speaker as egalitarian and balanced as possible.

The classic format for a café scientifique is that the speaker gives a short introduction to

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the topic, usually about 15–20 minutes. This is followed by a break, of around 20 minutes, to allow glasses to be refilled and conversations to start. Then there is an open discussion in which comments, questions, thoughts, and opinions are exchanged, as often among the audience themselves as between the audience and the speaker. Cafés usually have a “host,” or facilitator, whose role is to keep the discussion moving. The length of the discussion time varies from café to café but is typically around 45 minutes to an hour. Most commonly, cafés meet once a month, sometimes with a break in the summer.

This simple model is highly adaptable to different cultures. For example in continental Europe, cafés often have two to four speakers; this is seen as a way to maintain a balanced argument. In Japan, discussion points are sometimes submitted by SMS, to avoid the disrespect of directly questioning an elder or superior. The model has, with varying success, also been used in schools in the UK, the USA, France, and Uganda (see www.juniorcafesci.org.uk).

The beginnings of café scientifique coincided with the cultural change from the promotion of “public understanding of science” to “public engagement with science.” Cafés scientifiques perfectly caught the mood for direct and open public dialogue, in which scientists recognized the importance not only of talking to people about their work but also of listening to people’s views. This change also found favor with governments, as they sought innovative ways to sustain public discussion about issues in current science and technology. This cultural acceptance has meant that what started out as an avant-garde, independent, and bottom-up movement has become a widely accepted model for public engagement with science, embraced by the science communication establishment: research funders, governments, researchers, policy-makers, learned societies, and more. While many of these groups operate very effective cafés, there is a danger that their needs and agendas may override the basic principles of conversation, democracy, equality, and accessibility espoused by café scientifique.

Cross-References

- ▶ Learning Science in Informal Contexts
- ▶ Public Communication of Science and Technology
- ▶ Public Engagement in Science

Capacity Beliefs

▶ Self-Efficacy in Learning Science

Careers and Gender

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Across science fields, women have been and continue to be underrepresented. Some disciplines are approaching parity, such as biology, while others, such as chemistry and physics, still lag behind. The issue of representation is a complex and multifaceted one and, even with years of research, is not something that can be easily fixed. Many issues are culturally embedded and very difficult to address, including implicit bias and gender roles. Other issues are a result of the historical progression of women into the sciences. For hundreds of years, women weren’t allowed to be scientists. By the early twentieth century, several exceptional female scientists were making contributions to various fields, but the norm was for women to stay out of science. In the United States, the passage of Title IX ushered in a new era for women’s educational attainment. These early generations of women scientists fought for opportunities and to be treated equally. The current generation of women entering science has more options available to them and as a result makes active and complex decisions, which often lead them out of academic scientific research.

At a national level in the United States, there has been a recognized need to promote gender equality in science careers. Starting in the 1980s, the National Science Foundation developed programs to help female faculty become more successful researchers. The current incarnation of these is the ADVANCE program, which funds research on female faculty, research on gender issues within institutions, and transformative programs to support female faculty at individual institutions.

The University of Wisconsin and the University of Michigan were in the first cohort of institutions to receive ADVANCE funding. Both institutions implemented workshops to train faculty and search committees on subconscious or implicit bias. Using empirical data, these workshops were effective in increasing the number of women interviewed and hired for STEM faculty positions. This highlighted one of the challenges facing women's progress in science – the bias they faced anytime they were evaluated on their work or qualifications.

The culture of scientific research was founded on the male scientist working long hours and being devoted to research, while his wife supported him and was a homemaker. Indeed, American pop culture has supported the male "breadwinner" and the female "homemaker" as the ideal family for quite some time. These images strongly conflict with a female scientist pursuing a career and cause considerable gender role tension for many women and dual-career couples. Females still feel pressure to be the primary caretaker for children and elderly parents, regardless of their employment status outside the home. There is a prevailing perception that scientists should be devoted to their research, putting in long hours and working constantly, in order to be successful. Managing these two roles, as female and as scientist, causes struggles for many women in science.

One solution to this conflict is to pursue a scientific career at the expense of family. While this was often the case for early generations of women scientists, current generations are not willing to make that sacrifice. Associated with lifestyle issues is the cost or stress that can be associated with pursuing a career in scientific research. Women perceive that there is a lot to give up when pursuing a scientific career, including family and personal time. Additionally, there is often a lot of pressure to publish and secure grant funding, leading to a competitive and high-stakes environment. These factors often mean choosing careers outside of academic research, which they believe will allow them to balance their personal lives and careers.

Another challenge is the perceived lack of value in certain disciplines of scientific research. Many women report wanting to make a difference in the world through their careers, also known as career altruism. For some research, particularly in the physical sciences, the outcomes of research are very far removed from daily life. It can be challenging for women to feel they are spending their time on something worthwhile if they cannot see the value of research. For this reason, teaching and industrial careers often seem more appealing because they are perceived to have more tangible and immediate impacts.

Women tend to have a lower expectation of success in science than men, which may be partly due to bias or socialization. Most people do not choose to pursue careers they expect to fail at, so expectation of success is a necessary component in someone's decision to pursue a scientific career. Having multiple successful experiences, a supportive network, and an enjoyment of the work lead to a greater expectation of success.

With few women in scientific careers, a lack of role models can be a problem for women and girls looking to enter science. Additionally, students report that women faculty often are negative role models, embodying examples of women they do not want to be. Challenging these negative role models requires women to enter scientific careers despite the lack of positive role models, which can seem risky.

When making career decisions, it is common to construct multiple possible selves that are associated with different career options. These possible selves are then compared to a person's ideal self or the life envisioned in a perfect world. The career chosen typically is the possible self that is most like the ideal self.

One challenge for students making career decisions is a lack of knowledge about available careers. There is often partial knowledge or misinformation that is used to make career decisions. With the information available, though, women go through a complex decision-making process when choosing a career. Often, this process leads them away from scientific research for any number of reasons discussed previously, which further serves to reproduce the culture of scientific research that they are resisting and trying to avoid.

Cross-References

- ▶ Attitudes, Gender-Related
- ▶ Gender
- ▶ Socio-Cultural Perspectives and Characteristics

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Case Writing

- ▶ Science Teaching and Learning Project (STaL)

Causal Induction

- ▶ Causal Reasoning

Causal Reasoning

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Causal induction; Understanding causality

Causal reasoning is a broad term used to refer to thinking that depends upon or aims to uncover a causal relationship between entities, events, or processes. It moves beyond the process of discerning patterns or covariation by looking for mechanisms that explain why two or more entities are related. Science often describes patterns – that something is connected, relates, or covaries with something else. It also seeks to define the reasons why particular patterns exist and this invites reasoning about mechanism – a key aspect of causal explanation. Human beings are sense-makers from an early age. Understanding the regularities in our world and knowing what accounts for them enable prediction and afford a sense of psychological control. An understanding of causality and its differences from correlation is therefore a central matter for science education.

When reference is made to causal reasoning, people often think about the ability to reason in particular ways. However, engaging in causal reasoning also involves perceiving or being sensitive to the occasion to engage in causal reasoning as well as being inclined to do so. This conception draws upon the triadic notion of thinking dispositions put forth by Perkins, Tishman, and colleagues. The research on what people do when cued to the existence of a causal pattern and asked to reason about it in contrast to how people engage in causal reasoning in everyday contexts is a key tension in research on causal reasoning as the paragraphs that follow elaborate.

Causal Mechanisms

Causal mechanisms refer to what makes the causal relationship happen. Mechanisms come in many forms. They may be physical as in mechanical devices, social as in intentions and goals, and biological as in germs and bacteria. Mechanisms can be described at different levels. For instance, one might explain why something happens by reference to a mechanical device or, at a finer level of grain, by reference to the forces involved. Consider causal explanations for what makes current in a simple circuit flow. One could respond at a number of levels, including flipping the light switch; opening a circuit and allowing current to flow; voltage that creates a push from the battery that moves electrons along a circuit; or a differential between electrons and protons at the poles of the battery that repels and attracts electrons so they move. Science often allows for more than one scientifically accepted mechanism. For instance, sinking and floating may be alternatively described with buoyancy or density explanations.

Causal Patterns

Causal patterns describe the covariation relationships and direction(s) of impact. When people think of cause and effect, they often think of a simple linear relationship involving a cause directly and immediately followed by an effect. However, causal relationships can be defined by a variety of patterns. For instance, there may be a bidirectional relationship between causes and effects as in mutual causality exemplified by symbiosis, commensalism, gravitational attraction, and so on. There may be a reentrant or cyclic causality involved as in relationships with inherent feedback loops, for instance, convection currents. Visualize the process involved in a home thermostat where convection currents trigger the thermostat to go on and off as the room cools and heats. When cyclic causal patterns have an amplifying feature, they can take on an escalating or spiraling pattern. Relational causal patterns involve a relationship between two variables, of equilibrium or of differential, that are responsible for an outcome. For instance, pressure differentials are responsible for air currents. Differentials in density account for the layers of our atmosphere – whether one layer sinks or floats on another.

Definitions of “pattern” and “mechanism” interact. For instance, if one believes that only the weight of an object is responsible for whether an object sinks or floats, they are likely to attribute a simple linear pattern. If one believes that a differential in density is responsible, then they are more likely to attribute a relational pattern.

Causal Features

Causal relationships are also characterized by features that can complexify the inherent causality. There can be time delays between causes and effects; causal action can be at a distance such that causes and effects are spatially separated. Causes can be obvious or nonobvious; for instance, carbon in the environment cannot be directly observed but its impact can, through adoption of specific causal reasoning based on extensive data. Other complicating features include tipping points or triggering features. These features result in departures from steady accumulation models and make it harder to detect when effects might occur. They tend to “hide” early accumulation because there is a certain amount of insurance in the causal system that accommodates early impacts. Therefore effects seem sudden and dramatic. Predicted climate change impacts are characterized in this way. Once a certain threshold is reached, a cascade of effects can dramatically occur. Reasoning about causality is impacted by these complexifying features because they affect the salience of the components in the causal equation and thus our ability to attend to them.

A significant body of research reveals that people operate via various default assumptions concerning the patterns, mechanisms, and features of causal interactions. A well-substantiated set includes a tendency toward assuming:

1. linear rather than nonlinear patterns
2. direct as compared to indirect impacts
3. unidirectional instead of bidirectional causal forces and impacts
4. sequentiality as opposed to simultaneity between causes and effects
5. that causes and effects will be obvious (until those possibilities have been exhausted) before considering nonobvious ones
6. that causes involve an actor and are intentional and active rather than non-intentional and passive
7. that causal investigation is warranted when a specific event occurs as opposed to recognizing that while events draw attention, they can be part of processes and steady states

playing out over time that are inherent to a broader causal system

8. explicit notions of causality that are deterministic with one-to-one correspondences between causes and effects even if in our everyday reasoning (as discussed below) we allow for causality based upon statistical regularities
9. that local causes and effects are local before considering distal ones
10. that the causal components are immediate to the outcome rather than time delayed or part of change over time
11. that causes are centralized with effects unfolding from that centralized cause in contrast to distributed or decentralized with emergent effects arising out of the many micro-interactions involved

These assumptions have a significant impact upon how we engage in causal reasoning. While these assumptions are driven largely from the modes of induction that we engage in (as discussed immediately below), attempts to make students aware of these patterns through higher-order reasoning and metacognition suggest some ability to moderate these expectations in situations that warrant it.

(Note: These default assumptions are elaborated and exemplified in Grotzer (2012).)

The cognitive science of how humans discern causal relationships

Three prevailing bodies of literature have made strong contributions to our understanding of how everyday causal reasoning works: Causal Bayes Nets (CBN) theories and the research on covariation that preceded it, specific generative transmission notions of mechanism, and the role of testimony from others (See Harris 2012).

CBN (Causal Bayes Nets) Approaches

CBN (Causal Bayes Nets) approaches are one of the prevailing model of how humans connect across statistical profitabilities to realize that a cause and effect are linked. Preceded by as rich research literature investigating how people attend to covariation between cause and effect, CBN theories argue that people sum across instances to discern causal patterns by association and that they also intervene upon and partition off certain variables to assess their impact. This, it is argued, allows people to detect causal structure by disambiguating causes. Intervention can refer to one's own actions, those of others, or those changes wrought by nature. A focus on covariation without attention to intervention or mechanism can lead to confusing correlative patterns for causal ones. Research by Alison Gopnik and her colleagues suggests that even young children follow Bayesian rules in summing across their experiences and that they are comfortable overriding imperfect correlation and using patterns of probability in contiguity to make causal inferences. Preschoolers were able to intervene to figure out the causal structure of problems with limited numbers of variables in deterministic and probabilistic contexts.

The existing studies on CBN reasoning were conducted in lab contexts without the attentional challenges and cognitive load of features that make "real-world" causality complex. Causal Bayes Net theories are effective in explaining how people meet with success in simple causal induction, but when causality becomes complex, issues arise. The CBN theory assumes acyclic patterns and the independence of the variables except for their direct and indirect effects (known as the Causal Markov Assumption). The real world is far more complex. One of the essential puzzles for CBN theories is to explain the ontological problem – how people get from a messy, complex world to a set of meaningful variables to reason about. Research on how initial, unconscious perception leads to attentional capture and then to focused perception shows that we miss a lot of information – especially when it does not fit with one's current expectations. So the question of how people know what to attend to from the wealth of stimulation coming their way poses challenges for applying a CBN model to a complex world.

For research purposes, CBN researchers often give the variables to the subjects. Further, intervening effectively in a complex world is a nearly impossible thing to do without sophisticated analysis. The unaided human mind in everyday contexts is unlikely to be able to effectively intervene and build effective causal models of such complexity. CBN accounts cannot fully enable complex causal reasoning. While much of the research on CBN reasoning is carried out in a lab in one attentional context, complex causal reasoning involves reasoning across spatial scales, extended time frames, instances where nonobvious variables compete for salience with more obvious ones, and complex patterns where effects may not become noticeable until substantive accumulation has occurred. If CBN reasoning is a predominant part of our causal repertoire, its shortfall may help to explain why people struggle so with causal complexity.

Reasoning About Mechanism

Reasoning about mechanism constitutes a second prevalent view in the cognitive science literature, represented by researchers such as Keil, Atran, and Leslie. It argues that people use their knowledge of mechanisms to reason about causality and that they amass considerable knowledge about types of causes, the causal force of particular mechanisms, and situation-specific details about where this information applies. For instance, consider how children learn about mechanisms such as remote controls, webcams, telephones, and so on, and then use this knowledge to reason about causality in particular instances. One strand of this research argues that what develops is a general notion of mechanism that children apply, but the other strand argues for domain-specific forces. Research supports the notion that children expect causal mechanisms and do not allow for causeless effects. Lacking knowledge of a causal mechanism, they may substitute magic as a mechanism – but they understand that explanation requires a mechanism. Further, even preschoolers reveal an understanding that mechanisms may not be obvious – as is the case with germs and contamination. Development appears to be in the direction of increasing knowledge of mechanisms and toward the realization that nonobvious mechanisms exist.

Testimony from Others

Testimony from others, a third body of research, focuses on how people learn from trusted others. Harris has argued that there are many concepts that children would never learn from firsthand experience alone and that the testimony of trusted others is an important source of learning about causal relationships. Complex causality offers many examples. For instance, the connection between automobile usage and changes to the polar bear habitats is unlikely to be discerned through covariation relationships and/or without deep and extensive knowledge of mechanisms that people would be unlikely to figure out on their own. Even the concept of sunburn – that a distant object in the sky can result in a painful burning sensation on one's skin but over time and not necessarily when one is still in the sun but hours later – is most likely to be learned from others. Harris argues that testimony is an important avenue to learning about mechanisms that cannot be seen – germs, oxygen, and so forth. Testimony also comes in the form of powerful narratives. A well-known body of research by Daniel Kahneman and colleagues demonstrates that people have a tendency to override statistical data, such as that discussed above under the CBN approach.

Instead, in a tendency referred to as the availability heuristic, people use narratives in the form of powerful available cases to reason from. For instance, consider reasoning about food safety. A certain food may have been safe 100 % of the times a person has eaten it and may be deemed safe to eat by the scientific community. However, one highly visible or emotionally laden case where a trusted food turned out to be dangerous can change people's consumption behaviors, at least for a period of time. This has happened in recent years with spinach, tomatoes, and cantaloupe, for instance. The cognitive load of summing across many cases may explain why we override this information with narratives motivated by affect; it may be adaptive to do so.

The research of Harris and colleagues demonstrates that even young children can be discerning about their informants and use subtle cues as to the reliability of the testimony that they hear. They attend to information about the informant: how much the informant is like them; how much consensus exists in the opinions of different informants; how familiar the informant is; and the perceived accuracy of the informant.

This suggests that variables in how causal information is communicated impacts how we incorporate and reason about that information.

In Conclusion

While these three modes of causal induction are often found in contrast to one another in the cognitive science literature, effective complex causal reasoning draws upon these forms of knowledge in ways that support and interact with one another. When cast in real-world contexts with messy, ill-structured problems, where sensitivity to causal instances, ability to reason in complex ways, and the inclination to do so are all in play, it makes sense that humans will bring their entire reasoning repertoire to bear on complex problems.

Cross-References

- ▶ Alternative Conceptions and P-Prims
- ▶ Argumentation
- ▶ Developmental Perspectives on Learning
- ▶ Epistemic Goals

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Chemistry

- ▶ Chemistry Teacher Education
- ▶ Chemistry, Philosophy of

Chemistry Teacher Education

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What Is Required of Chemistry Teacher Education

Certain key ideas appear to be necessary in any chemistry teacher education program. Gess-Newsome (1999), for example, highlights the need for integration of knowledge bases with informed decision making, exposure to examples of teaching excellence, and multiple supported experiences. These ideas are often in contradiction to preservice teachers' expectations as they expect to learn a "script" for chemistry teaching in line with their own successful learning experiences of chemistry in school. These ideas can also be in contradiction to chemistry teachers (and possibly the general public) who often believe that there is a received wisdom about learning to teach that can only be received by being in the classroom (an apprenticeship model).

How Is Chemistry Teacher Education Different from Studying Chemistry?

Studying chemistry is different from studying chemistry teacher education. Both chemistry and chemistry education are dependent on developing chemistry knowledge and their personal experiences, particularly in terms of how they know their chemistry knowledge. Chemistry teacher education also requires the development of knowledge in other domains such as pedagogical knowledge; subject-specific pedagogical knowledge (or pedagogical content knowledge (PCK) as defined by Shulman 1986); knowledge of educational contexts, purposes, and values (inclusive of curriculum, assessment, and evaluation); and knowledge of learners. It takes not only experience of teaching chemistry in schools if all of these knowledge bases are to be integrated, but also experience of other possibilities, feedback on different experiences, and time to make links between all of these factors.

Learning Progression: Big Ideas in Chemistry and How to Teach Them

One of the most cognitively demanding aspects of learning to teach chemistry is to identify the "big ideas" of chemistry which is followed by questions such as: what are age-appropriate views on these big ideas and if students do not hold the view, how does the teacher shift students' thinking in appropriate ways? For example, the idea of structure is one big idea, another would be chemical reactions. In looking at the idea of structure, the notion of particles is an early important idea, followed by progressively sophisticated ideas about what such particles might look like: a model for the particles (atoms). Understanding of the appropriateness of such a model rests in its ability to explain and predict most situations/phenomena, something that needs to be reached by the final years of secondary schooling. Understanding the progression of learning these ideas and that which is important and less important to learn also distinguishes chemistry education from chemistry and incorporates a small portion of the decision making that needs to occur when teaching chemistry.

Different Approaches

There are two dominant ways of viewing chemistry teacher education, with variations of each of these also apparent. These are chemistry teacher as learner and chemistry teacher as apprentice.

Chemistry Teacher as Learner

This approach concentrates on the development of pedagogical knowledge generally by paying attention to the learning experience (and its consequence then for teaching), with a clear focus on such understanding within a specific content area such as chemistry. Such an approach often requires the chemistry teacher educator and the preservice teachers to be co-learner and cocreators of knowledge (Corrigan 2009). Assessment tools need to focus on making judgments about the growth of the learners and identify what knowledge has been created in this approach. Reflection can often play an important role in assessment of this type with its ability to focus on a "problem" (a perplexing or curious situation) that can be framed and possibly reframed. In chemistry teacher as learner approaches, preservice teachers need to focus on their own "problems" rather than the problems of others.

Chemistry Teacher as Apprentice

This approach focuses on the development of pedagogical knowledge within the classroom, where continued experience promotes mastery of particular situations. However, if the apprenticeship occurs in a narrow range of situations, the ability to transfer what has been learnt to other settings is often hampered (Kennedy 1999). The integration of knowledge bases is often far less explicit, particularly if the range of experiences are limited. The focus remains on teaching rather than personal learning experiences, and so challenges to teaching styles can also be limited.

Chemistry Teacher as Clinical Expert

A variation on these models could be represented as *chemistry teacher as clinical expert* where there is a focus in the school component on developing particular expertise and competence in specified targeted areas. While this is more focused than the apprenticeship model, it is less reliant on reflection than the *teacher as learner* approach and therefore has differing consequences for understandings of being a teacher and doing teaching.

Cross-References

- ▶ Biology Teacher Education
- ▶ Curriculum in Teacher Education
- ▶ Pedagogical Content Knowledge in Teacher Education
- ▶ Pedagogy of Teacher Education
- ▶ Physics Teacher Education
- ▶ Science and Society in Teacher Education
- ▶ Science Teacher Education
- ▶ Secondary Science Teacher Education

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Chemistry, Philosophy of

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Keywords

Analysis; Chemical bond; Chemical element; Chemical equation; Classification; Disciplinarity; Inter-theoretic relations; Model; Periodic table; Reaction mechanism; Reduction; Representation; Substance; Synthesis

Philosophy of chemistry aims to provide robust analyses of the concepts, theories, and methods characteristic of chemistry and of the interrelations between them, including reflection on the ways in which they are related to, and potentially distinct from, the concepts, theories, and methods of other sciences. The following entry provides a brief survey of the main lines of investigation in contemporary philosophy of chemistry. More detailed treatments of these topics are found in Hendry et al. (2011), Van Brakel (2000), and Weisberg et al. (2011).

Core Concepts in Chemistry

Philosophy of chemistry, like the philosophical study of other particular sciences, devotes attention to the analysis of core concepts, including the concepts of chemical substance, chemical element, chemical bond, and reaction mechanism.

Chemical substances are the fundamental kinds of chemistry and are as important to understanding chemistry as the species concept is to understanding the biological sciences. There are three long-standing questions about substances: (i) What makes something a sample of the chemical substance that it is? (ii) What kinds of change can an exemplification of that substance survive? (iii) What is the difference between pure compound substances and mixtures? There are two general strategies for tackling these issues. One appeals to the molecular constituents of a substance and the other appeals to macroscopic criteria.

In either case, the theoretical building block for making sense of substances is the concept of the *chemical element*. Because it underwrites all chemical classification (discussed more below), an adequate analysis of the concept of element is necessary for an adequate account of substance. For individuating substances composed of a single element, the molecular strategy seems sufficient because the chemical properties of these substances are largely determined by the nuclear charge on the constituent atoms (i.e., the "atomic number" of the element). But compound substances are less amenable to a parallel treatment. Different substances may share the same elemental composition (in the case of isomers), elemental composition alone cannot distinguish between compounds and mixtures (e.g., hydrogen chloride gas and a mixture of hydrogen and chlorine gases in the corresponding proportions), and many compounds are simply not homogeneous at the molecular level. The most famous example is water: Pure liquid water consists of complex congeries of different species like H_3O^+, OH^-, and hydrogen-bonded oligomolecular structures, rather than collections of H_2O molecules, and this molecular heterogeneity is responsible for water's characteristic properties. If the relationship between molecules and substances is this complex, some have argued, the notion of "substance" may need to be understood independently of molecular constitution.

In fact, simple macroscopic criteria can clarify some of these cases. For example, a compound and a mixture of the same elements in the same molar proportions will exhibit radically different behavior under equivalent conditions of temperature and pressure. At room temperature and pressure, water is liquid but the mixture of hydrogen and oxygen is gas, and under conditions in which both are gaseous, the compound occupies two-thirds the volume of the same mass of the mixture. But the same thermodynamic grounding that captures our intuitions well in such cases would seem to view different isotopes of oxygen (^{16}O, ^{17}O, and ^{18}O) as different substances, because mixing samples of the different isotopes gives rise to measurable entropy changes. Yet chemical properties (i.e., dispositions to undergo chemical change), as mentioned earlier, are determined overwhelmingly by nuclear charge, which the different isotopes share, rather than atomic mass, with respect to which they differ.

Mixed substances pose a related set of problems concerning the persistence conditions of substance identity. When common salt (NaCl) dissolves in water, the ionic lattice breaks down, and the sodium and chloride ions form complexes with H_2O molecules. Is salt still present in brine? If not, what essential property of salt has been lost? On the other hand, if salt is said to be present, what should we say about a solution containing sodium hydroxide and potassium chloride? Is there salt here too? And how should we characterize the difference between pure and mixed substances in the first place? Potential answers drawing on either molecular or macroscopic criteria remain contentious, and the distinction between compounds and solutions itself comes under pressure with the recognition of nonstoichiometric compounds in the twentieth century.

After substance, perhaps the most central concept in modern chemistry is that of a *chemical bond*. The chemical bond serves to explain an extensive array of phenomena ranging from basic properties of bulk substances to whether particular reactions will occur under given circumstances, and what reaction pathways will be followed. In turn, the chemical bond is itself an object of explanation within the discipline. In contemporary practice the bond concept is a conceptual amalgam generated by the creative melding of classical and quantum notions following the incorporation of quantum mechanics into chemistry in the early twentieth century. At least two distinct conceptions of the chemical bond, the structural and the energetic, have been distinguished by philosophical analysis (Hendry et al. 2011). Each conception faces challenges with respect to internal consistency, coherence with physical theory, or explanatory completeness, and either would require significant development to provide an analysis both satisfying and sufficient. But can the chemical bond concept serve its explanatory role if it cannot be given a fully coherent interpretation within chemistry or if it is not fully consistent with more fundamental physical theory?

Another concept worthy of sustained attention is that of a *reaction mechanism*. To the extent that chemistry is the science of the transformation of substances, reaction mechanisms become a primary tool for explaining and predicting key facts about complex reactions: the nature of the various products, the quantities in which they are produced, and how these vary as the physical conditions change. William Goodwin has argued that organic chemistry actually employs two related mechanism concepts, the "thick" and the "thin" (Hendry et al. 2011). The thin conception is entrenched in practice, littering laboratory blackboards with diagrams and supporting the common reasoning patterns required to meet organic chemistry's particular predictive and explanatory aims. The thick conception, on the other hand, most readily connects mathematical models of chemical transformation to the experimental data measured in the laboratory. Further analysis of reaction mechanisms, especially as they relate to mechanism concepts in other sciences, remains a fruitful topic for future research.

Chemical Methods

In addition to conceptual analysis, many of the issues that demand philosophical attention concern the methods of chemistry, broadly construed.

Chemistry has an enduring concern with *classification* because of the multiplicity of distinct substances within its domain. Since the introduction of a compositional nomenclature in the 1780s, chemical classification has been erected principally upon a theory of constituents. The *periodic table* of elements is the most visible, and most fundamental, classificatory structure in chemistry. In its contemporary incarnation, the table serves to connect the realm of substances with the realm of atoms and molecules through the concept of *chemical element* (mentioned earlier). By highlighting the role of periodicity in chemical inference (roughly, analogical reasoning based on chemical similarity), the periodic table is a prime example of a representational tool that provides a framework for robust reasoning.

Indeed, the pragmatic significance of *representation* emerges as a general theme in recent philosophical work. The periodic table's two-dimensional matrix explicitly organizes elements in terms of horizontal and vertical relationships that facilitate identification of chemical similarity groups and trends. Similarly, because physical models effectively support reasoning involving spatial relations, such models flourished during the development of both nineteenth-century stereochemistry and twentieth-century macromolecular biology. Graphical formats support identification of potential energy surface maxima and minima that are crucial for determining reaction pathways. And the shift from largely intractable mathematical representations to diagrams was instrumental in allowing quantum-mechanical models of molecules to guide chemical reasoning regarding chemical bonding and reactivity. Perhaps most centrally, *chemical equations* function as an explicit bookkeeping device that relies on an inherent ambiguity regarding whether the equations represent facts at the level of substances or molecules. In each of these examples, the specific representational format is crucial for the efficacy of the inferential scaffolding.

More generally, investigations concerning the role, function, and significance of chemical *models* mirror those prominent throughout contemporary philosophy of science. As seen across the sciences, models in chemistry rely frequently on idealization and approximation for their power. We see this vividly in models ranging from the ideal gas law to mathematical models in quantum chemistry to ball and stick physical models in the classroom. Some models aim to provide explanation, others generate predictions, and still others facilitate and entrench common patterns of reasoning. Philosophical discussion of models as "mediators" between theory and phenomena is especially relevant to understanding this range of functionality.

Chemistry's laboratory practices are also distinctive, guided as they are by focus on the reliable manipulation and manufacture of substances. Control of this sort has been realized through the conjoined methods of *analysis*, by which chemists determine the constituents of a given substance, and *synthesis*, by which predetermined substances, or more minimally substances with desired properties, are produced. The basic questions are clear: How are synthesis projects conceptualized and organized? How are laboratory practices coordinated with theoretical representations? What are the characteristics of rational search for synthetic pathways? Innovations such as the development of automated search techniques raise interesting methodological questions, as does the heavy reliance on technological *instrumentation*, especially various forms of spectroscopy, for identification of chemical kinds. The epistemic challenges, as well as advantages, that accompany reliance on such instrumentation require systematic analysis.

At a more basic level, we might consider whether, and how, synthetic goals shape the very nature of chemistry as a science and ask how greater understanding of chemistry's orientation toward the controlled production of designed novelty clarifies or challenges traditional assumptions involving the relative disciplinary homogeneity of the physical sciences, the distinction between science and engineering or pure and applied science, and the role of values in science generally.

Relations Between Chemistry and Other Sciences

Intuitively, chemistry seems individuated by its characteristic concepts (substance, element, bond, etc.), but can these concepts be fully understood in terms of the concepts of physics? If not, can the chemical explanations that employ them be replaced by explanations that appeal only to physical concepts? Critically examining the assumption of reducibility is a theme that runs throughout contemporary philosophy of chemistry.

Any general framework should distinguish between *inter-theoretic* and *ontological reductions*. Traditionally, inter-theoretic reduction has been the central topic of debate. But even if chemical theories are irreducible to physical theories (inter-theoretic), the question remains whether the subject matter of chemistry is, in some sense, just that of physics (ontological). Recent arguments demonstrate that a robust conception of molecular structure cannot be recovered in a fully principled manner from the equations of nonrelativistic quantum mechanics (i.e., without making what is normally called the Born-Oppenheimer approximation). Molecular structure is effectively introduced ad hoc rather than explained. More generally, quantum chemistry appeals to concepts and traditions of representation from both physics and chemistry. This suggests a synthesis of chemistry and physics, rather than a reduction of one to the other. In a similar vein, the laws of thermodynamics provide constraints on chemical explanations without providing such explanations in full, again suggesting a non-reductionist model for the explanatory role of physical theories in chemistry.

Alongside these long-standing issues, *disciplinary differences* have emerged as a distinct philosophical concern and one that does not reduce to relations between theories. The historical development of molecular biology in relation to biochemistry reveals clear differences in the explanations offered within each subdiscipline, suggesting the disciplines may be meaningfully differentiated by their respective explanatory strategies. Meanwhile, consideration of prominent techniques for rational drug design, a landscape that places chemistry in close contact with pharmacy, suggests that we would do well to attend to the materiality and explicitly productive (medical, industrial, technological, and otherwise commercial) orientation of much chemical research. A broader issue concerns whether chemistry is currently fracturing from a unified discipline into a wide range of importantly distinct interdisciplinary enterprises such as molecular genetics, environmental science, and nanoscience. Examining interdisciplinary relations provides a different perspective on issues of reduction and autonomy, although they do not, by themselves, settle any traditional philosophical issues. More modestly, they highlight the social nature of theoretical, experimental, and technological achievements within chemistry.

Cross-References

- ▶ Biology, Philosophy of
- ▶ Epistemic Goals
- ▶ Mechanisms
- ▶ Models
- ▶ Representations in Science
- ▶ Scientific Visualizations
- ▶ Social Epistemology of Science
- ▶ Values in Science
- ▶ Visualization and the Learning of Science

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Child Psychology

► Piagetian Theory

China (PRC)

► Science Education in Mainland China
► Science Teacher Education in Mainland China

Citizen Science

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Citizen science is a term most often employed to describe projects for which volunteers collect data for use in organized scientific research. This usage of the term emerged from the Cornell Lab of Ornithology in 1994 when the lab desired a new name for its rapidly growing assemblage of data collection projects focused on birds. At that time, volunteer data collection efforts were relatively few in number, and most of the ones that did exist focused on monitoring the quality of lakes, streams, and rivers. Twenty years later, data-driven citizen science projects number in the thousands, and their participants number in the many hundreds of thousands. Projects cover a breadth of topics ranging from native bees to invasive species, from urban birds to arctic glaciers, and from pollen to stardust. Some projects engage a handful of participants in one small watershed, while others enroll many thousands of observers dispersed across several continents. Although projects vary in the degree of collaboration between volunteer participants and science researchers, in most projects volunteers receive some degree of guidance in project procedures to ensure consistency in data collection and accuracy in data analysis. The scientific impact of these projects, which yield knowledge by collecting and analyzing vast quantities of data at unprecedented scales, is easily measured by the rapidly growing number of publications based on volunteer-collected data (listings of projects and published papers are available at www.citizenscience.org).

While citizen science is sometimes considered a recent phenomenon, amateur scientists have been studying the world for much of recorded history, usually by noting observations of the environment around them. Also known as "volunteer monitoring" and "community science," citizen science efforts have yielded important datasets, specimen collections, and scientific insights since the seventeenth century and probably before. Much of our current information about the distributions of plants and animals, the timing of events in nature such as plant budding and bird nesting, the quality of water in streams and rivers, and the impacts of climate change on organisms around the world is derived from data collected by members of the public.

Although citizen science as a concept has a long history, the strategy of involving the public in scientific research as a method for increasing public science literacy is relatively recent. In the late 1980s, a group of educators pondering innovations in science education realized that by providing participants in volunteer monitoring projects with materials to support learning – for example, information about why a project was started, what scientific questions it was investigating, how a participant's data would be combined with data from others to answer those questions, and details about the organisms or phenomena being studied – the participants might learn scientific facts and concepts and also begin to understand how scientists conduct investigations that yield evidence-based results. For example, for The Birdhouse Network – which began in 1995 and is now part of Project NestWatch (www.nestwatch.org) – participants kept track of the birds nesting in birdhouses in their yards and communities. They noted the species, number of eggs laid, timing of hatching and fledging, and overall nesting success and then submitted their data to a centralized project database. The data were then analyzed by scientists to determine information such as the influence of latitude on nesting success. At the same time, through the process of learning about cavity-nesting birds and studying their breeding behavior – which was supported by instructional booklets, posters, and simple data forms – project participants increased their knowledge of a number of aspects of bird biology.

As the twentieth century got under way, the idea that public participation in organized research could yield “hands-on” science learning took hold rapidly, and the number of projects intended to achieve goals for increasing both science knowledge and public science literacy began to multiply. The expansion of complex citizen science projects was further fueled by the development of the Internet, which allowed project participants to submit data to online databases and, in some cases, to be able to access project data for their own interpretation. Also, some citizen science projects, such as the University of Minnesota’s Monarch Larva Monitoring Project, began to develop science curricula specifically designed for K-12 teachers who wished to incorporate citizen science into their classroom activities. Such curricula have been shown to help students learn many different aspects of science such as content knowledge and understanding of key features of scientific investigations and the nature of scientific research.

In response to the burgeoning field, the US National Science Foundation funded a workshop in 2007 that assembled 50 citizen science project leaders to discuss “best practices” for citizen science project design. The workshop yielded the “Citizen Science Toolkit,” which provided guidelines for developing, implementing, sustaining, and evaluating projects designed to achieve outcomes for both science and education. The NSF funded a second citizen science conference in 2011; this one focused on how citizen science projects could advance the field of biological conservation. The proceedings of these two conferences, both available at www.citizenscience.org, are a rich introduction into the field of citizen science and its outcomes for a wide range of project types. And in 2012, an open conference on citizen science held in Portland, Oregon, attracted nearly 300 professional scientists and educators who discussed a wide range of project models and who launched an International Association for Citizen Science (reports from this conference also are available at www.citizenscience.org).

In the early 2000s, a new form of data-driven citizen science began to emerge, born of developing technology and the concept of crowdsourcing. At the vanguard was a project called Galaxy Zoo, which employed the power of the Internet to enable members of the public to classify images of space captured by the Hubble Space Telescope. This form of citizen science became very popular as new projects were developed to explore the surface of the moon, model Earth’s climate using historic ship logs, and explore the ocean floor (www.zooniverse.org). Like the earlier monitoring projects, many of these data classification projects were intended not only to achieve scientific goals but also to help participants learn scientific information and develop positive attitudes toward science while participating in the scientific process. For example, participants in a project called “Citizen Sky” have demonstrated a positive change in scientific attitudes, apparently related to their engagement in the project’s social activities.

In 2009, a group of researchers working under the auspices of CAISE (Center for Advancement of Informal Science Education) produced a document that described different models of citizen science for which participants collect or classify data. These authors introduced the term “Public Participation in Scientific Research” (PPSR) as an umbrella concept to refer to a range of project types that engage participants in the scientific process to varying degrees. The authors found that different PPSR models yielded different types of learning outcomes and suggested that project developers be deliberate in their project designs, carefully matching design to desired outcomes.

An additional form of citizen science also exists as described by Alan Irwin in his 1995 book *Citizen Science: A Study of People, Expertise, and Sustainable Development*. In contrast to the definition of citizen science as the engagement of volunteers and professionals in collaborative research to generate new science-based knowledge, the concept of citizen science that Irwin champions aims to bring the public and science closer together, to consider possibilities for a more active "scientific citizenship," and to involve the public more deeply in issues related to risk and environmental threat. Some data-driven citizen science projects do have objectives for achieving better linkages between science and society and even "democratizing" science, such as work currently being conducted in Europe by the Extreme Citizen Science group (ExCiteS: http://www.ucl.ac.uk/silva/excites).

With its goal of transforming the world through the bottom-up creation of knowledge, the future of the citizen science field seems nearly boundless. The ultimate success of the field will be measured by the ability of citizen science to empower members of the public to invoke transformative change for themselves, society, and the environment, blending concepts and ideas from all forms of public participation into powerful societal change.

Cross-References

- ▶ Public Engagement in Science
- ▶ Technology for Informal and Out-of-School Learning of Science

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Claim

▶ Explaining as a Teaching Strategy

Classroom Learning Environments

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Keywords

Assessment; Environments; Learning

Students spend a huge amount of time at school – approximately 7,000 h by the end of elementary school, around 15,000 h by the completion of secondary school, and nearly 20,000 h by the completion of university. However, despite the obvious importance of what goes on in classrooms, most teachers and researchers rely heavily and sometimes exclusively on the assessment of academic achievement and other learning outcomes.

This entry is devoted to conceptualizing, assessing, and investigating what happens to students during their education by drawing on the field of classroom learning environments. Clearly, having positive classroom environments is a valuable goal of education. But, it should not be assumed that the equally important issue of student outcomes is ignored in this entry. Extensive past research provides consistent evidence that the classroom environment is so consistently associated with student outcomes that it should not be ignored by those wishing to improve the effectiveness of classrooms.

A milestone in the historical development of the field of learning environments occurred approximately 40 years ago when Herbert Walberg and Rudolf Moos began seminal independent programs of research that formed starting points of the work encompassed by this entry. Walberg developed the Learning Environment Inventory as part of the research and evaluation activities of Harvard Project Physics, whereas Moos developed social climate scales for various human environments, including the Classroom Environment Scale. Although learning environments research originated in the United States, it soon spread to other countries, especially Australia and the Netherlands. Furthermore, particularly in the last decade or so, Asian researchers have made comprehensive and distinctive contributions (Fraser 2012).

Assessing Learning Environments

Although classroom environment is a subtle concept, remarkable progress has been made in conceptualizing, assessing, and researching it. A considerable amount of work has been undertaken in many countries on developing methods for investigating how students and teachers perceive the environments in which they work. In particular, over the years, researchers have developed numerous questionnaires to assess students' perceptions of their classroom learning environments. For example, these questionnaires provide information about whether a class is dominated by the teacher or is student centered; whether students actively participate in class or sit and listen to the teacher; whether students cooperate and discuss with each other when they are learning, or whether they work alone; whether the teacher is supportive and approachable; whether the students have a say in the choice of teaching and assessment methods; and whether differences in students' interests and speeds of working are allowed for by the teacher. Some examples of popular classroom learning environment questionnaires, together with the dimensions that they assess, are given below:

- What Is Happening In this Class? (WIHIC) – student cohesiveness, teacher support, involvement, investigation, task orientation, cooperation, and equity
- Constructivist Learning Environment Survey (CLES) – personal relevance, uncertainty, critical voice, shared control, and student negotiation
- Science Laboratory Environment Inventory (SLEI) – student cohesiveness, open-endedness, integration, rule clarity, and material environment

These questionnaires have been used in different countries and at different grade levels. They have been translated into various languages, including Spanish, Arabic, Chinese, Korean, Indonesian, Thai, and the South African language of North Soto. They have been used by hundreds of researchers, thousands of teachers, and millions of students around the world. Most teachers and researchers find that it is easy and convenient to use these instruments to obtain information about learning environments from students.

Over the past four decades, learning environment researchers have attempted to answer many interesting questions. Does a classroom's environment affect student learning and attitudes? Can teachers conveniently assess the climates of their own classroom, and can they change these environments? Is there a difference between actual and preferred classroom environment, as perceived by students, and does this matter in terms of student outcomes? Do teachers and their students perceive the same classroom environments similarly? How does the classroom environment change when a new curriculum or teaching method is introduced? Do students of different abilities, sexes, or ethnic backgrounds perceive the same classroom differently? These questions represent the thrust of the work on classroom environment over the past 40 years (Fraser 2012).

Researchers have carried out many dozens of studies into the relationship between student outcomes and the quality of the classroom learning environment. These studies have been carried out in numerous countries and at various grade levels with tens of thousands of students. The consistent evidence from these studies is that the nature of the classroom environment is related to student outcomes (both cognitive and affective). Therefore, teachers should not feel that it is a waste of time for them to devote time and energy to improving their classroom environments because research shows that attention to the classroom environment is likely to pay off in terms of improving student outcomes.

Classroom environment instruments have been used as a valuable source of process criteria in the evaluation of educational innovations. For example, Martin-Dunlop and Fraser (2008) evaluated an innovative science course for prospective elementary teachers in a large urban university in California. When learning environment scales selected from the WIHIC and SLEI were administered to 525 females in 27 classes, very large differences were found on all scales (of over 1.5 standard deviations) between students' perceptions of the innovative course and their previous course.

Feedback information based on student perceptions has been employed in a five-step procedure as a basis for reflection upon, discussion of, and systematic attempts to improve classroom environments at various levels of education (Aldridge et al. 2012). First, students respond to the preferred form of a classroom environment instrument, with the actual form being administered in the same time slot about a week later (assessment). Second, the teacher is provided with feedback information derived from student responses in the form of profiles representing the class means of students' actual and preferred environment scores (feedback). These profiles permit identification of the changes in classroom environment needed to reduce major differences between the nature of the actual environment and that preferred by students. Third, the teacher engages in private reflection and informal discussion about the profiles in order to provide a basis for a decision about whether an attempt would be made to change the environment in terms of some of the dimensions (reflection and discussion). Fourth, the teacher introduces an intervention of approximately 2 months' duration in an attempt to change the classroom environment (intervention). Fifth, the students' actual form of the scales (i.e., the environment that the students perceive that they actually are experiencing) is readministered at the end of the intervention to see whether students are perceiving their classroom environments differently from before (reassessment). These studies usually reveal that there has been an improvement in classroom environment and that teachers value their involvement in this action research aimed at improving classroom environments (Fraser 2012).

Although this entry gives emphasis to assessing classroom environment questionnaires that tap students' perceptions, which has been the predominant method in past research, it is important to note that significant progress has been made in using quantitative and qualitative methods within the same study of classroom environments (Tobin and Fraser 1998). For example, in a multilevel study of the learning environment, qualitative methods involved visiting classes, using student diaries, and interviewing a teacher-researcher, students, school administrators, and parents. A video camera recorded activities, field notes were written during and soon after observation, and team meetings took place regularly. Based on this study, Tobin and Fraser (1998, p. 639) concluded: “We cannot envision why learning environment researchers would opt for either qualitative or quantitative data, and we advocate the use of both in an effort to obtain credible and authentic outcomes.”

Conclusion

Several implications emerge from this entry for improving science education. First, because measures of learning outcomes alone cannot provide a complete picture of the educational process, assessments of learning environment should also be used to provide information about subtle but important aspects of classroom life. Second, the evaluation of innovations and new curricula should include classroom environment instruments to provide economical, valid, and reliable process measures of effectiveness. Third, teachers should use assessments of their students' perceptions of actual and preferred classroom environment to monitor and guide attempts to improve classrooms. Fourth, when assessing and investigating classroom environment, a combination of qualitative and quantitative methods should be used instead of either method alone.

Cross-References

- ► Evaluation
- ► Learning Environment Instruments
- ► Program Evaluation
- ► School Environments

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Classroom Organization

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Keywords

Classroom management; Discipline; Effective teaching; Instructional repertoire; Learning environment; School culture

Since 1970, the journal Phi Delta Kappan has reported Gallup Poll results on US public perceptions of schools. Amongst other things, the poll identifies the biggest problems facing public schools; in 2010 and 2011, lack of funding for schools was number one with discipline and classroom control being second. Discipline and control has been number one or two for the last 42 years. Why is the issue of "discipline" so persistent? My guess is that we fail (collectively) to grasp the complexity of the teaching and learning process and the ways that more effective teachers encourage appropriate behavior and how they respond to students who behave inappropriately. The conundrum with effective teachers (science teachers included) is that they are often so smooth and seamless that we don't notice what they do unless we are actually looking for it.

Teaching is one of the most complex, demanding, and important of all occupations. Teachers (on average) interact with 20–30 students for 180–200 days a year, for 6–8 hours a day, encouraging students to focus on approximately 400 learning outcomes per year; during that time, very little is predictable. Each day students of different cultures, races, and genders enter science classrooms. Those students bring by-default factors over which the teacher has little control (e.g., fetal alcohol syndrome, dyslexia, autism, deafness, blindness, parents divorcing, living in poverty, being gifted, witnessing violence, being abused at home either physically, emotionally, mentally, etc.). To increase the complexity still further, those factors get nested into the literature on multiple intelligence and learning styles.

Striving to balance students working alone, competitively, and cooperatively in a laboratory-oriented science educational setting creates an intense context that can often result in conflict. Conflict (like change, stress, and competition) is not inherently good or bad. What makes conflict "good" or "bad" is the stance we take towards conflict combined with the skill sets we invoke to restore social order so that learning can continue.

So, for example, a student may say, "This is boring!" The less effective science teacher is more likely to take this personally and respond in a way that "pushes back" with the consequence of bonding the student against the teacher. The "expanded problem" is that if that student has friends, those friends also bond against the teacher. The effective teacher is unlikely to get "caught" and might say, "Boring for you? Listen, I had to plan it last night PLUS I have to teach it today. You should be feeling sorry for me right now," or "You're right, this is boring; tomorrow I'll do a better job" (the Tai Chi response), or "Thanks for being brave enough to let me know," or "Boring today? Well, enjoy today because it is downhill the rest of the year." They use humor, wit, truth, and humility – the Tai Chi's of classroom management: they merge the heart and mind.

The key idea here is that if the rest of the class has bonded with the teacher, the teacher's response works; if not, the response is less likely to work. Over the years, I have found that the issue is not the specific response, but rather the respect the students have for the teacher. No matter how well prepared teachers are, all students, at some time, are going to behave inappropriately and teachers have to deal with it.

In this brief entry, I explore the complexity of designing and enacting a science learning environment as it relates to how teachers encourage appropriate behavior and how they respond to students who choose to behave in a way that makes it difficult for teachers to teach and students to learn. The ideas being shared are the result of having worked with teachers for almost 40 years: having worked with teachers who ranged from those at risk of losing their teaching credentials to teachers identified as the most effective. I start with a few "prevention" ideas to consider before I develop an introduction to a repertoire of ways to interact with student off-task behavior.

The prevention side involves the intersection of numerous factors. I briefly discuss five factors. Whenever one of these five areas is not enacted effectively, the teacher increases the chances students will behave inappropriately and decreases the chances of resolving the issue: (1) teacher personality, (2) teacher's knowledge of curriculum, (3) teacher's ability to assess student learning, (4) teacher's instructional repertoire, and (5) the school culture.

Teacher Personality

When we ask science teachers to reflect on their great teachers, what comes up is sense of humor, enthusiasm, caring, challenge, and politeness. When we ask the same teachers to think of teachers they did not respect, the answers are the opposite, boring, didn't want to be there, embarrassed you publically, etc. You can see that teacher personality is a key piece. Interestingly, teachers can easily remember how the less effective teachers responded to students who were off task; however, they struggle to remember the specific responses of effective teachers. Why? Because they were smooth, seamless, kind, and kept it low-key emotionally.

Curriculum

Students also talk about being challenged, being involved in engaging, meaningful science lessons. They enjoy teachers "who really know their stuff," who make connections between science and other aspects of life, help students make a quilt of ideas. Students are less likely to be off task in those classrooms; and when they are off task, the teacher simply reminds them to focus by enacting a glance, a name, a pause, a gesture, a cough, a please, a "shift" of proximity, or some combination, but done respectfully so as not to provoke an escalation. These skills augment, rather than override careful planning, particularly where practical science activities are concerned; teachers need to plan and sequence physical enactment and intellectual engagement of students with each learning activity.

Assessment

Feedback has one of the highest effects on student learning; how we choose to assess student learning, how we encourage them to give us feedback, and how we give them feedback are critical. Hattie's (2012) research identifies feedback as one of the most powerful ways to impact student learning. Successful science students are less likely to be off task. Of course, when it comes to assessing student learning, if we as teachers fail to first assess our instructional repertoire and its effectiveness, then any decisions we make about student learning are going to be suspect.

Instructional Repertoire

Current research (Leithwood et al. 2009; Hattie 2012; Fullan 2011) reports that the teacher's instructional repertoire and their ability to differentiate their instruction are key predictors of student success. That said, teachers will struggle with 'differentiating instruction' in the absence of an extensive instructional repertoire. Instruction is one part of how teachers respond to the different intelligences, learning preferences/roadblocks, etc. Although most science teachers reserve the revered lab experiment as the means by which instructional practice is intentionally altered. However, teachers who structure groups effectively, frame questions effectively, listen and respond to student interest, etc., in varied and interesting ways are going to have less classroom conflict.

School Culture

If the school culture is balkanized, with no norms of collegiality or collaboration, then the school is unlikely to have a clearly articulated (enacted) school-wide set of procedures for effectively encouraging appropriate behavior. The reverse would be the case for a more collaborative school culture. The front "office" is of little value if school administrators have no idea why the student ended up in the office and what the teacher did to prevent the student ending up in the office in the first place. And just as problematic, the science teacher who sent the student has no idea what will happen at the office once the student ends up in the office.

When considering those five factors, one senses that prevention is more complex than it looks. In terms of school culture, all staff members must work together to create and enact a system that responds to student unacceptable behavior and to make sure they are not the reason the student(s) behaved inappropriately.

In the next section I situate how teachers respond to students once students get "off task." (See *Power Plays*, Bennett and Smilanich 2012). As science teachers, we must consider that students may be off task because the lesson is boring, meaningless, or of no interest or the classroom is not a safe place to learn. If that is the case, the teacher is part of the problem. Metaphorically speaking, if a restaurant gave us poor service, unpalatable food, and an ambience not conducive to eating, we would not return, and we would inform our friends so that they could avoid it too. We all assess before, during, and after eating. Students do the same thing: they assess before, during, and after learning, and they inform their friends of their conclusions. The "teaching" problem is that the science classroom is the only "restaurant" in town. How would you behave if the restaurant you had to eat in 200 days a year had poor food, poor service, and a poor eating environment?

Our students, albeit tacitly, have "scored" us. If our customer service rating averages out at 75 % or higher, things will go relatively smoothly; we can rely on a smaller set of skills to respond to the students because the students have bonded with us instead of against us. If our service rating is less than 50 %, we are going to struggle in the science classroom. Science teachers with higher ratings tend to believe that no matter how well planned, prepared, kind, and thoughtful they are, all students, at some time are going to misbehave and that they have to deal with it. They are less likely to be disappointed and are less likely to take it (show it) personally. As a result, the more effective science teachers have a more extensive enacted repertoire – they show greater flexibility (are more artful) in how, where, and when they respond to students: they are much less likely to judge. They are also more likely to spend more time working to understand how to work with students rather than how to control them.

When we ask grade two or grade 12 students to tell us what their teacher uses to get them to refocus, the students will say things like "they look at us," or "they say our name," or "they come over and sort of take it away," or "they just come close to us so we stop." Those are not secret skills, parents use them as well. We call these "invisible discipline skills." The problem is that having the skills is the science, enacting them is the art. I explain the "art" piece in the next paragraph.

When I work with at-risk science teachers to identify the skills, they employ to respond to students, and we compare their responses to highly effective teachers; we get no difference in that list. They identify the same "skills." The difference is that the effective teachers know when, how, where, etc., to employ those skills. They understand how to use the look inside of a "gradient of intensity" (i.e., the glance, the look, the stare, and the glare). They get the idea of a "light pink" look, a "medium pink" look, a "dark pink, look, a "light red look," etc. They don't use a "dark red" when the situation requires a "light pink" (and vice versa). Effective science teachers get the "art of enactment." That same idea of the "gradient of intensity" plays out with how they apply proximity, use a student's name, etc. That gradient of intensity plays out as the student or students' behavior escalates and the skills the teachers enact also become more sophisticated. That escalation is seen as "bumping it up"; as the student bumps up the situation, the teacher has to have a corresponding set of skills.

I don't have the space in this entry to describe the following nine "bumps," but they are simply logical responses to classroom situations. For example, Bump Three relates to effective choices with the follow through on the choice being Bump Four. Bump Five refers to power struggles. Bump Ten is when the student has made the decision to be expelled; the key with Bump Ten is that the student understands that he or she made that decision to be expelled, not the school staff. Classroom management is delightfully complex, our challenge is to make sure we become consciously competent (collectively), and not simply accidentally adequate (individually) in our thoughts and actions, to prevent and to respond to that complexity.

Cross-References

- ▶ Classroom Learning Environments
- ▶ Cooperative Learning
- ▶ Dilemmas of Science Teaching
- ▶ School Environments
- ▶ Teacher Craft Knowledge

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Code-Switching in the Teaching and Learning of Science

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Code-switching has been defined variously over time and in different contexts, since Haugen's (1956) definition of code-switching as the ability of a bilingual to introduce unassimilated words from another language into his or her speech. It has since been defined as the alternation between two (or more) languages; the ability to segregate competing languages and switch between them when contextually appropriate; the movement by a speaker from one language to another; the use of more than one language in order to contextualize communication; and the habit of switching from one language to another. According to Setati (1996), code-switching involves a word, a phrase, a sentence, or sentences and cannot happen between monolinguals, only bilinguals. It is a skill that requires competence in more than one language.

For a long time, code-switching was regarded as an inferior form of engagement. However, research findings in both language teaching and cognition continue to show that code-switching can serve important functions to facilitate and contextualize communication. Its importance in education has been investigated. For example, a few decades ago, some argued that code-switching might be linked to lower intelligence levels. However, subsequent research showed that there was no significant relationship between code-switching and intelligence. It is now believed that the ability to switch between codes may help with conceptual organization or thinking about things in a new way. In other research, code-switching has been identified as one of the strategies used in coping with the challenges of teaching and learning in a language that learners (and sometimes teachers too) are not competent in. However, in spite of these merits, code-switching has its constraints. If not mediated appropriately, it may interfere with meaning-making and may have a negative impact on the learning process. Also, learners may find it difficult to navigate the two languages, especially if they are not sufficiently competent in the second language as is usually the case where the language of instruction is not the learners' first language. Since the ability to switch between codes is indicated in conceptual organization, it could be inferred that failure to navigate between the codes may interfere with conceptual understanding. Code-switching in science teaching and learning is under-researched (e.g. Probyn 2004; Rollnick 2000; Setati et al. 2002).

Cross-References

- ▶ Language and Learning Science
- ▶ Scientific Language

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Cognition

- ▶ Alternative Conceptions/Frameworks/Misconceptions
- ▶ Cognitive Acceleration
- ▶ Conceptual Change in Learning

Cognitive Abilities

- ▶ Assessment: An Overview
- ▶ Cognitive Acceleration
- ▶ Cognitive Demand
- ▶ Metacognition and Science Learning

Cognitive Acceleration

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Keywords

Cognition; Creative thinking; Critical thinking; Higher-order thinking; Thinking

Introduction to Cognitive Acceleration

Cognitive acceleration is a term used to describe an approach to pedagogy and a research tradition in science education that is based on two broad principles: (1) that there is a general intellectual function in children which develops with age and (2) that the development of this general intellectual function is influenced both by the environment and by maturation (Shayer and Adey 2002). Cognitive acceleration pedagogy sought to stimulate and advance students' general intellectual functioning beyond what would happen as a result of maturation through the use of specially designed thinking lessons. The intention of these lessons is to improve students' intellectual capacity, thus leading to an improvement in their ability to participate in the school curriculum and an improvement in their school achievement.

This entry has five sections. The first very briefly outlines the Piagetian theory underpinning cognitive acceleration, the second describes the development of the cognitive acceleration interventions, the third outlines the findings from evaluations of cognitive acceleration interventions, the fourth describes the structure of the intervention, and the final section raises relevant issues of professional development.

Piagetian Theory and Cognitive Acceleration

The pedagogy of cognitive acceleration is largely based on Jean Piaget's theory of cognition and his constructivist theory of epistemology. This is the subject of an extended entry in this encyclopedia (Piagetian theory). Piaget regarded the development of cognition as an active process in which the brain constructs a reality based on the stimuli received through the senses, rather than as a passive process in which the brain assimilates representations of phenomena in the environment. He viewed this active process as a structural adaptation that enables the human organism to interact with and assimilate stimuli to construct an understanding of the environment.

Piaget and his associates concluded that as cognition or thinking develops, it changes in qualitatively different ways. Concrete operations consist of schema of student behavior such as the ability to order and classify in simple ways and to conserve number and volume. The more advanced schema of formal operations includes the ability to control variables and understand equilibrium, probability, and formal modeling.

An extensive study in the 1970s of Piaget's levels of cognition within a student population of 12,000 from a wide range of urban, rural, and high and low socioeconomically ranked schools in England and Wales indicated that, by the age of 16, only 10 % of these students had attained the level of late formal operational thinking and a further 20 % a level of early formal operational thinking. The remainder of the sample remained at or below concrete operational thinking. This level of cognition is well below that predicted by Piaget's estimates (Adey and Shayer 1994).

Development of the Cognitive Acceleration Intervention

In order to understand scientific concepts and methodology at any depth, students need to have reached the level of formal operational thinking. For example, the use of the particle model of matter as an explanatory model requires early formal operational thinking. Students who have not reached this level may be able to memorize information about the behavior of particles and recall it when tested, but they will be unable to use the model to explain observed phenomena or write scientific explanations that demonstrate an understanding of the implications of the model. The development of formal operational schema enables students to systematically use forms of higher-order thinking which include multivariate, abstract thinking, compound variables, ratios and proportions, probability and its implications, formal scientific models, equilibrium, and correlation.

Adey and Shayer were concerned that, as above, 30 % of 16-year-old students were able to think at the level of formal operations. These researchers believed that the stages of thinking exhibited by a class of students are not fixed and that it is possible to teach students how to think in new ways. In response to these concerns, Adey, Shayer, and colleague Carolyn Yates developed the Cognitive Acceleration through Science Education intervention (commonly referred to by the acronym CASE and commercially known and referred to by many teachers as Thinking Science) (Adey et al. 2001). CASE is a program of 30 lessons designed to demonstrate to teachers how to stimulate student cognitive development and improve students' ability to understand science. The lessons are part of a professional development program that supports teachers over a 2-year period as they learn the pedagogical skills required to fulfill the purpose of the lessons.

Evaluations of the Cognitive Acceleration Intervention

CASE developed into one of the most widely employed and highly lauded programs for developing high school students' thinking ability in the United Kingdom (UK) and internationally. Considerable evidence has been published on the effects of the CASE strategies on children's cognitive development and school achievement (Shayer and Adey 2002). Research with over 2,000 high school students in 11 UK schools showed that after 2 years of participation, the proportion of students using high-order thinking was significantly higher than the national average. The statistically significant gains made by the CASE students over the national average were large, 0.67–1.26 standard deviations. There also is evidence of long-term transfer effects of CASE on scholastic achievement, even beyond the area of science. Improved student achievement in subjects other than science has been attributed to CASE having an effect on general intellectual growth, as well as on science-related thinking skills. The achievement gains were found for the full ability range of pre-intervention students. Independent reviews have supported these findings. Some researchers have noted the lack of attention to the students' attitudes and motivations in the CASE research (e.g., Leo and Galloway 1996).

The general approach to cognitive acceleration has since been applied to other disciplines, including mathematics and technology, and programs have been developed for younger children in the early childhood and middle primary years (Shayer and Adey 2002). Cognitive acceleration programs also have been successfully adapted and trialed in many countries.

Structure of the Cognitive Acceleration Intervention

Thinking Science lessons are structured around six pillars:

1. Concrete preparation: The teacher spends a short time explaining the purpose of the lesson to students and advising them of necessary procedures such as matters of safety.
2. Data collection: Students participate in a scientific activity. The data collected forms the basis of the challenge they will discuss.
3. Cognitive conflict: Cognitive conflict is one aspect of a Thinking Science lesson that drives cognitive development. It involves a challenging or difficult situation; for example, when the data students collect are different to what they expected, they are stimulated to think in new and different ways to comprehend the data.
4. Social construction: The challenging problem is discussed by students in a group of three or four. It is important that students are explicitly taught how to discuss, listen actively, and work constructively in a group. Social construction, which is a challenging discussion, is the second pillar that stimulates cognitive development.
5. Metacognitive questioning: Metacognition involves students reflecting on their own thinking and articulating the approaches they took to problem solving. This gives other students insight into different ways of thinking and evaluating. During the lesson, the teacher and students use metacognitive questions to probe thinking during discussion, for example, "Why do you think that? How did you work that out? What made you feel confused?" Metacognition is the third pillar that stimulates cognitive development.
6. Bridging is the process of contextualizing the problem discussed in a particular lesson. It enables students to relate what they have discussed to their everyday life or to other experiences they have been exposed to in science classes.

The teaching of higher-order thinking, and/or critical and creative thinking, is an underlying assumption of almost all current secondary science curricula across the globe. Examples of such thinking include critically analyze, deduce, evaluate, explain, justify, and synthesize. However, rarely is a definition of these terms provided, and teachers often are unaware of how to teach in ways to ensure their students are able to develop these higher-order thinking skills. Thinking Science pedagogy leads to this development that is also the basis of critical and creative thinking.

Professional Development of Teachers

As with all new pedagogical approaches, effective professional development is an essential pathway to the high-quality pedagogy required for cognitive acceleration. Professional development is defined as effective when it changes teachers' pedagogical practice and improves student outcomes (Adey 2004). Widely recognized problems in the provision of effective professional development include a lack of executive support, history of innovations with little or no theoretical basis, lack of ownership of teacher learning, scant acknowledgement of teachers' current contributions in the classroom, failure to consider the whole school context and the teachers' work within that context, no direction about how to recognize and build effective collegiality, and lack of long-term support while new pedagogical approaches are explored and adopted.

Thinking Science professional development has followed well-documented principles for effective professional development and attempted to resolve these problems in the following ways. School administrative support is gained before the implementation of the program; teacher ownership of the program is developed by providing an understanding of its theoretical basis and involvement in the analysis of its effectiveness. Professional development is long term including central in-service days and an emphasis on in-class coaching to support teachers as they practice and acquire new approaches to pedagogy over the 2 years of the program. Furthermore, the development of collegiality is encouraged for mutual support and sustainability of the program. Thinking Science professional development focuses on the development of effective student-centered pedagogy and on the relationship between this and improved student outcomes.

Cross-References

- ▶ Alternative Conceptions and Intuitive Rules
- ▶ Developmental Perspectives on Learning
- ▶ Piagetian Theory

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Cognitive Apprenticeship

▶ Situated Learning

Cognitive Demand

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Keywords

Cognition; Information processing; Mental capacity; Mental demand (*M*-demand); Problem solving; Working memory; Working-memory capacity; Working-memory overload model

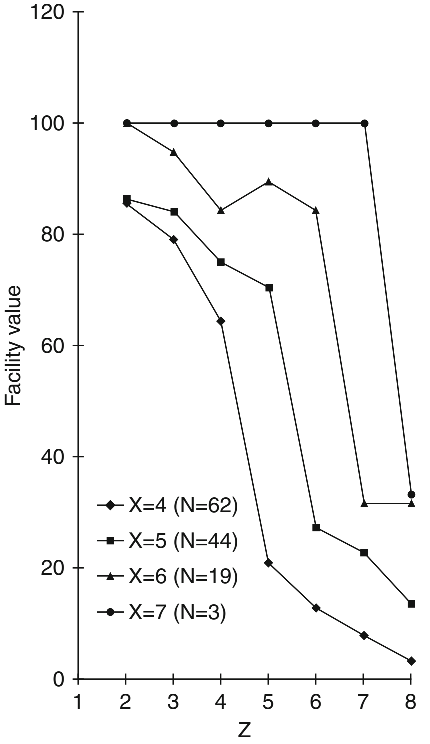
Cognitive demand or **mental demand** (*M*-demand) is a construct that is applied to the study of cognition and especially of problem solving. As such, it relates to science teaching, learning, and assessment of teaching and learning. In psychology and cognitive science, *cognition* relates to information processing, which in turn relates to a number of psychological or ► cognitive abilities or functions or variables (also called *psychometric variables*). Essentially, the cognitive demand of a mental task, such as a problem, is related to the complexity of the task/problem. In general, as a problem increases in complexity (in terms of what information has to be held and what process has to be performed), performance decreases. The complexity of a problem in science education is described by (a) the "*M*-demand" and (b) the "logical structure" of the problem. In this article, *M*-demand will be treated first.

The assignment of *M*-demand to a problem follows from the optional or minimum number of component steps required to accomplish the solution to the problem. This can be judged by comparison of the allocated *M*-demand by independent expert solvers of the problem. Another extended definition of *M*-demand is "the maximum number of thought steps and processes which have to be activated by the least able, but ultimately successful candidate in the light of what had been taught" (Johnstone and El-Banna 1986). The assigned *M*-demand of a problem can further be verified by a posteriori analysis of the students' solutions. This method is consistent with the four-step procedure for the evaluation of the *M*-demand known as *dimensional analysis* (Niaz and Logie 1993). In addition, the confirmation of the validity of the *working-memory overload model* can provide further support to the estimation of the *M*-demand of a problem (see below).

A central construct in information processing is that of *working memory*, of which a measure is provided by the *working-memory capacity* (Baddeley 1986). Alternatively, the construct of *mental space* is used, which is measured with the *mental capacity* (*M*-capacity) (Pascual-Leone 1970). Both the working-memory capacity and *M*-capacity variables are operationalized and measured by means of corresponding psychometric tests. Specifically, one way of assessing working-memory capacity is by means of the *Digit Backward Span Test*, which is part of the Wechsler Adult Intelligence Scale, while *M*-capacity is assessed by means of the Pascual-Leone's *Figural Intersection Test*.

A characteristic model involving working memory is the *working-memory overload model* (or hypothesis), which states that a subject is likely to be successful in solving a problem if the problem has an *M*-demand, which is less than or equal to the subject's working-memory capacity (W) ($M \leq W$), but fail for lack of information or recall, and unsuccessful if $M > W$, unless the student has strategies that enable him/her to reduce the value of M to become less than W (Johnstone and El-Banna 1986). Information processing relates then to a "holding/thinking space" (i.e., working memory), which has a finite limit, after which the decrease of achievement may be rapid. The rapid decrease in students' achievement has been connected to *working-memory overload* and has been usually demonstrated by an inverse *S*-shaped curve, which is the graph of the percentage of successful subjects as a function of the *M*-demand of a problem (see Fig. 1). For instance, from the graph for the working-memory capacity of 6, it follows that students with this capacity are, as a rule, successful in problems with *M*-demands of 2 up to 6, but fail when the *M*-demand assumes values of 7 and 8. The part of the curve with the largest slope is thought to correspond to the subjects' working-memory capacity overload.

Research has shown that the model was found not to apply to all kinds of empirical data, except for some specific cases. The following have been found to operate as limitations and necessary conditions for the model to be valid (Tsaparlis 1998): (a) the logical structure of the problem must be simple; (b) the problem has to be non-algorithmic; (c) the partial/component steps must be available in the long-term memory and accessible from it; (d) the students do not employ "chunking" devices (by means of which they



Cognitive Demand, Fig. 1 Facility value (%) in organic-synthesis problem solving versus *M*-demand (*Z*) versus various levels of working-memory capacity (*X*) for a sample of students ($N = 128$) without previous training in these problems (From Tsaparlis and Angelopoulos (2000), Reprinted with permission from Wiley)

chunk the problem into familiar chunks and thus are reducing the *M*-demand); and (e) no "noise" should be present in the problem statement; as "noise" is assumed the irrelevant and potentially misleading information that might be included in a problem.

In general, a sudden decrease in students' performance might occur not only because of the limitation of their working-memory capacity but also because of the interference of other variables; thus, it has been shown that psychometric variables, such as *disembedding ability* (degree of "field dependence/independence") and/or *logical thinking* (previously referred to as "developmental level" in the Piagetian sense), play an essential role in science problem solving. It is worth noting that in the working-memory model, field dependence is seen as a moderator variable: field-dependent subjects appear to possess lower working-memory capacity because they use part of their capacity to process irrelevant information. "Spatial ability," involving also disembedding of information, has also been found to affect student achievement in problem solving.

It was stated above that the complexity of a problem in science education is described by (a) the *M*-demand and (b) the logical structure of the problem. The *logical structure* is associated with the number of different *logical schemata*, which the solver has to retrieve from his long-term memory in order to solve the problem (Niaz and Logie 1993). According to Jean Piaget, a *schema* is an internal structure or representation (apparently in long-term memory), while the ways we manipulate schemata are called "operations." In ▶ Piagetian theory, schemata are continually growing and developing rather than remaining fixed. Describing thinking at various stages becomes thus an issue of trying to define the schema (or mental structure) and the operations (or internal actions) that a problem solver is using. In the case of chemistry, examples of logical schemata are chemical stoichiometry, gas laws, and the state of chemical equilibrium.

In a study about the validity of the overload hypothesis, organic chemical-synthesis problems were used, with a simple logical structure and varying *M*-demand from $M = 2$ to $M = 8$ (Tsaparlis and Angelopoulos 2000). In general, organic-synthesis problems are very difficult for the students, being very demanding in terms of information processing, because the number of pathways by which students could synthesize target substance "X" from starting substance "A" may be numerous. These problems are unique in that they can satisfy the necessary conditions that must be fulfilled for the validity of the tested problem-solving model (see above): they (i) exclude numerical or algebraic calculations, (ii) have a simple (one-schema) chemical logical structure, and (iii) cannot be answered by the application of an algorithmic procedure. The latter requirement is equivalent to them being real *problems* and not routine *exercises*. Two samples of students (ages 17–18) participated in the study: one sample had received some previous training in these problems, while the other sample had not. Although the predicted pattern was observed in both samples, it was found that the model was more useful in the case of the students without previous training (see Fig. 1). Finally, as expected, the model predicted better with the field-independent and the field-intermediate students than with the field-dependent ones.

The construct of *cognitive demand* or *mental demand* (*M*-demand) and its connection with *information processing* and other psychological functions have important implications for science teaching, learning, and assessment of teaching and learning. The findings of research can guide the construction of a series of problems in a science topic with the same reasoning pattern (the same logical structure) and varying *M*-demand. Student success, especially for novice learners, can be facilitated by the careful control of the *M*-demand, that is, by first introducing problems of low *M*-demand and by leaving problems of high *M*-demand for later use, when students have acquired experience and motivation. Teachers must feel their responsibility for this student transition: they must emphasize and consciously employ the relevant strategies throughout their teaching. Only when strategies have been learned should complexity be allowed to increase, so that students can learn to keep the value of *M*-demand (not the actual but their own modified by "chunking" *M*-demand) well within their working-memory capacity. In this way confidence, and hence motivation, can be maintained while complexity increases, leading novices toward the expert state.

Cross-References

- ▶ Information Processing and the Learning of Science
- ▶ Learning Demand
- ▶ Memory and Science Learning
- ▶ Piagetian Theory
- ▶ Problem Solving in Science Learning

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Cognitive Labs

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Keywords

Cognitive interviews; Protocol analysis; Talk-aloud protocols; Think-aloud interviews; Think-aloud protocols; Verbal analysis; Verbal protocol analysis; Verbal reports

Cognitive lab is a term frequently used to refer to a set of procedures and conditions (experimental situations) in which verbal reports are elicited and collected to study cognitive processes. Such verbal reports serve as a major source of data on the cognitive processes that subjects engage in when completing diverse tasks such as solving a problem, responding to a survey question, answering a test item, or reading different types of texts. Cognitive labs are used in diverse fields, but one in which it is frequently used is in the development and evaluation of assessments and questionnaires (or surveys).

Two issues are important to consider when discussing cognitive labs: (1) the necessity to focus on the actions intended to elicit and collect verbal reports and the information they provide about the inferred cognitive processes, rather than on the conditions in which they take place and (2) the liberal way in which certain words are used to refer to the methods to gather the verbal reports (e.g., think-aloud protocols, think-aloud interviews, talk-aloud protocols, verbal protocols, or cognitive interviews). Not all terms can be treated as equivalent and they impose their own characteristics to the experimental situation. The discussion of cognitive labs here is then centered on the issues related to verbal reports rather than the cognitive labs as a physical space or experimental situation.

Verbal reports have been considered by cognitive psychologists to be the available method that most closely "identifies the content of a person's mind…" (Leighton 2009, p. 2). A common feature to all the procedures used to obtain verbal reports is that subjects respond orally to an instruction or probe (Ericsson and Simon 1980, 1993). Two general procedures can be indentified for gathering verbal reports: protocol analysis and verbal analysis. *Protocol analysis* is often used to tap cognitive processes underlying the completion of a task; it helps to confirm cognitive models of task performance. *Verbal analysis* is used to tap knowledge structures; it helps to explore and generate cognitive models of task performance as well as beliefs and attitudes about the task at hand. Due to the space constraints, this entry focuses only on protocol analysis given the wide use of this procedure. For information about verbal analysis, see Chi (1997).

Protocol Analysis

Protocol analysis is guided by human information-processing models. It is used mainly for identifying, through verbalizations, cognitive processes involved in problem solving. These verbalizations constitute the verbal reports. Once they are transcribed, the verbal reports are referred to as the *protocols* (Ericsson and Simon 1993) that will be the subject of the *analysis*. Verbal protocols provide a source of evidence for tracing and documenting the representations and processes used by subjects to approach a task (e.g., generate a solution). These processes are compared to a hypothesized cognitive model of solution – a model of the possible logical sequences of cognitive steps needed to produce a correct response. In other words, protocol analysis helps to *confirm cognitive models* of task performance (Leighton 2009).

There are two types of verbal reports:

1. *Concurrent verbal reports*, in which subjects are instructed to verbalize their cognitive processes as they work through (or perform) a task. Talk aloud and think aloud are different forms of verbal reports that can be produced in concurrent verbalizations. Each represents different levels of information processing. In the talk aloud, the verbalization is direct; the subject verbalizes or reproduces the information as she or he is attending to the information. In the think aloud, the verbalization is mediated by another type of processing. The instructions to the subjects are also different: "Talk aloud as you multiply 24 times 36!" versus "What is the result of multiplying 24 times 36?"
2. *Retrospective verbal reports*, in which subjects are instructed to verbalize, retrospectively, the sequence of thoughts that occurred during the performance of a task. Ideally, retrospective reports should be done by the subject immediately after the task is completed since most of the information will still be stored in the short-term memory.

Conditions for Protocol Analysis

Experimental situation. Minimizing social interaction is critical to collecting verbal reports through protocol analysis. For example, the researcher or data collector should be seated behind and not visible to the participant. The rationale for this arrangement is that socially motivated verbalizations require additional cognitive processing to present the verbalizations in a coherent and understandable manner, which might affect the sequence and depth of thoughts (Ericsson and Simon 1993). Hence, when subjects are reminded to talk or think aloud, the preference is to instruct them to "keep talking" rather than saying, "please tell me what you are thinking" or "what are you thinking?"

Selection of tasks. Tasks used in protocol analysis should have a clear focus and avoid vagueness. This helps to ensure not only that subjects will be fully engaged while completing the tasks but also that the cognitive model of the task can be more easily developed. When subjects are fully engaged in the task, it is more likely that their verbalizations follow the same sequence of thoughts as occurring in a silent condition (Ericsson and Simon 1993).

Critical to protocol analysis is the identification of the cognitive model that is expected that subjects will use to approach the task at hand (the knowledge of the cognitive demands imposed by the task assigned to the subjects). This knowledge can be obtained through *task analysis* – the specification of the logically possible sequences of cognitive steps to produce a correct response (i.e., the solution path or the cognitive model of the task). Task analysis is usually conducted by experts.

When verbal reports are used in the context of assessment (mostly for validation purposes), another condition is required: tasks selected for verbal reports should be of *moderate difficulty* relative to the population of interest (Taylor and Dionne 2000). This moderate level of difficulty allows for more *controlled cognitive processing* – awareness of how the task is being approached. Easy tasks elicit rapid recall (automatic cognitive processing), leaving the subject unaware of how he or she approaches the task. On the other hand, difficult tasks may overload the working memory by exhausting all the mental resources in responding to the task, such as understanding the task, retrieving information from long-term memory, and selecting appropriate strategies to approach the task. With all the working memory occupied by these activities, few if any mental resources will be available for concurrently articulating verbally the cognitive processes involved in approaching the task.

Instructions. Critical to the generation of valid verbal reports is the nature of the instructions provided. Instructions need to be carefully worded because they can influence the nature of the verbal reports (Ericsson and Simon 1993; Tyler and Dionne 2000; see examples of instructions for talk aloud and think aloud in the concurrent verbalization section). The instructions for protocol analysis should emphasize general reporting of the participants' thoughts, and they should not include requests to report specific aspects related to the explanation or justification of responses (see conditions below). It is important to remember to use "keep talking" to remind the subject to talk rather than any other form that invites for social interaction.

Ericsson and Simon (1993) suggest the use of a couple of easy warm-up tasks which cognitive processes are well known but are not associated with the task at hand (e.g., "Talk aloud as you tie your shoelaces."). Warm-up tasks are intended to ensure that the instructions for generating appropriate verbal reports are understood. They are also intended to reduce anxiety and make subjects more comfortable in the experimental situation.

Analysis of Verbal Protocols

Steps for analyzing verbal protocols can be summarized as follows (Ericsson and Simon 1993; Taylor and Dionne 2000): (1) Transcribe the verbal report verbatim; transcriptions should capture as much detail as possible (e.g., pauses, emphases, tone). (2) Develop a valid coding system, based on the cognitive model of the task, to identify the processes and patterns of knowledge in the verbal data collected. The level of detail of the coding system will vary accordingly. It is important to remember that task analysis plays a critical role in the development of coding systems. This analysis along with the generation of the cognitive model of task performance constitutes a significant portion of the work required to segment and code the verbal protocols. (3) Segment the verbal protocols in units that will be the focus of the analysis, what will be coded. Ericsson and Simon (1993) suggest segmenting the protocol by statement. However, the segments can be aggregated to conduct other types of analysis (e.g., by episode or major process or steps in solving the problem). (4) Code each segment at the level suggested by the coding system. The complexity of the coding system will determine the number of codes applied to each segment. (5) Evaluate the reliability of the coding system. Clearly defined codes illustrated with prototype examples help to increase the consistency across coders. (6) Develop a complete model of the subject's cognitive procedures reported in the verbal reports that reflect the problem-solving process. Such models can be a description of the interconnection of the problem-solving stages or a pictorial model such as a decision tree graph (Ericsson and Simon 1993) or flowchart (Gierl et al. 2009). Graphical representations of the verbal protocols are used to match the path the subject took with the sequence of steps specified in task analysis and reflected in the cognitive model.

Limitations of Verbal Reports

The use of verbal reports raises three critical areas of concern (Wilson 1994): (1) *Completeness* refers to the difficulty of determining with certainty the completeness of a verbal report. Even in concurrent verbalizations, verbal reports can become incomplete if the cognitive processes cannot be easily verbalized, for example, when certain cognitive processes have become automatic. (2) *Reactivity* refers to the potential interference in the cognitive process when participants are asked to verbalize their thoughts – reactivity may change the cognition of interest, leading to a misinterpretation of the subject's cognitive processes. (3) *Non-veridicality* focuses on the issue that simply asking someone to verbalize their thoughts does not guarantee access to the cognition of interest, which may lead to misunderstanding their cognitive process. Still, a fourth concern can be mentioned inherent to protocol analysis; it is *costly* and *time consuming*.

To minimize the concerns raised above, three actions are recommended (Ericsson and Simon 1993; Taylor and Dionne 2000): (1) Use the two forms of verbal reports, concurrent and retrospective, as complementary methods to obtain a more complete picture of cognitive processes. The former helps to identify the knowledge and skills being used to approach the task; the latter helps to elaborate or clarify what was found in the concurrent reports. Retrospective reports also can be used to gather information about participants' metacognitive knowledge (Taylor and Dionne 2000). (2) Once the participants finished the task, do not wait too long to obtain retrospective verbal reports. What subjects remember, and how well, will generally depend critically on the interval between the moment the information is being processed and the moment of recall (Ericsson and Simon 1980). (3) For think-aloud verbal reports, do not allow subjects to rationalize or conjecture as they are engaged in the task.

A Final Note

It is important to acknowledge that cognitive labs are implemented in many different ways. The procedures used have become a big array of practices, and the names used to refer to these practices are now a complex combination of terms previously used for other purposes. This state of affairs is also due to the lack of effort from the research community to incorporate and clarify the use of terms in a more accurate way. An effort toward this end is needed not only to avoid confusion in the procedures used but also to have clarity about the inferences made based on the verbal reports. Inferences made about subjects' cognition depend on the type of procedures conducted and the type of verbal report collected.

Cross-References

- ▶ Alternative Conceptions/Frameworks/Misconceptions
- ▶ Laboratories, Teaching in
- ▶ Language and Learning Science

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Cognitive Partners

▶ Mindtools (Productivity and Learning)

Cognitive Preferences

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Keywords

Cognitive style; Conceptual understanding; Learning style

Cognitive Preference is a particular form of cognitive style that has at times in the last 50 years been a significant component of aspects of research on science learning. It was particularly prominent in research in the 1960s and 1970s because of strong logical links between the construct and the changes in emphasis to conceptual learning that characterized the dramatic developments of science curriculum and curriculum projects in the late 1950s and 1960s in the Anglophone world.

"Cognitive Style" (or, sometimes, "learning style") describes the notion that individuals have consistent patterns in the forms of information they seek and the ways they then gather and process this information. While there is continued debate about the extent to which any individual consistently behaves in this regard and as to the extent to which such consistency is a singular or multiple dimension of the individual's characteristics, cognitive style in a range of forms is a concept of significance in scholarship relating to human learning and behaviors (particularly in studies in the fields of education and management).

The curriculum projects of great influence in the late 1950s and 1960s began with PSSC Physics, closely followed by CHEM Study and BSCS Biology. These are often referred to as the First Generation projects or the "alphabet phase" of large-scale science curriculum development. These projects were all strongly characterized by a focus on conceptual content and developing student understanding of these concepts and a clear move away from descriptive, applied, and historical aspects of science. This focus on conceptual understanding as the most significant learning outcome to be sought went as far as attempting (sometimes implied, occasionally explicit) to more generally change the intellectual approaches of students towards a seeking of understanding in all contexts. This led quickly to Heath, a psychologist specializing in educational measurement, constructing in 1964 the notion of Cognitive Preference.

Cognitive Preferences were seen by Heath to be particular modes used by students in learning science (dealing with scientific information). He identified four of these modes:

1. Recall (R): Acceptance of information without consideration of implications, applications, or limitations.
2. Principles (P): Acceptance of information because it exemplifies or illuminates a fundamental scientific principle, concept, or relationship.
3. Questioning (Q): Critical questioning of information regarding its completeness, generalizability, or limitations.
4. Application (A): Emphasis on the usefulness and applicability of information in a general, social, or scientific context. Any student was seen to be consistently more inclined to use one of these modes above the other three.

Explorations of Cognitive Preference then quickly became very common in a range of approaches to researching the First Generation curriculum projects, from large-scale curriculum evaluation studies to studies of individual science learning that resulted from the use of the curricula. Assessment of an individual's cognitive preference has, I believe, always been done via pencil-and-paper testing. Questions on these tests always follow the same format:

– An introductory statement that relates to some aspect of the curriculum content that is the focus of the study is followed by four statements that extend or elaborate the introductory statement, with each of these four corresponding closely to one of the four modes of cognitive preference described by Heath.
– It is noted that all the four extension/elaboration alternatives are correct statements and the respondent is asked to either (i) select the statement they find most appealing or they would most like to learn more about, or (ii) rank all four statements (in terms of appeal or most like to learn more about), or (iii) choose both the most and the least appealing statements (or more/least like to learn more about).

The following is a typical Cognitive Preference test item:

> The pressure of a gas is directly proportional to its absolute temperature.
> (a) The statement as given above fails to consider effects of volume changes and changes of state.
> (b) Charles' or Gay Lussac's Law.
> (c) The statement implies a lower limit to temperature.
> (d) This principle is related to the fact that overheated automobile tyres may 'blow out' (Tamir 1985, p.2).

In this item option A corresponds to the mode Questioning (Q), option B to Recall (R), option C to Principles (P), and option D to Application (A).

Individual research studies using Cognitive Preference tests have consistently reported high reliabilities for these instruments. In his 1985 review and meta-analysis of then approximately 100 extant science education studies involving cognitive preferences, Tamir concluded "…the results reported here indicate that the cognitive preference construct demonstrates a reasonable level of validity, that Cognitive Preferences make significant contribution to learning, and that their inclusion in further educational research as well as their consideration in educational practice is to be encouraged" (p. 13). Despite this exhortation studies that include the construct, Cognitive Preference has been extremely rare since this time. It is almost certain that this is due to the moves that began in the early 1970s to expand the intentions of the science curriculum beyond the essentially singular focus on conceptual understanding that characterized the First Generation projects.

Cross-References

▶ Curriculum Movements in Science Education
▶ Inquiry, As a Curriculum Strand

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Cognitive Style

▶ Cognitive Preferences

Coherence

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Keywords

Assessment; Formative assessment; Learning progressions; Summative assessment

Assessment may serve different purposes in different contexts. In the context of classroom learning, teachers use assessment to collect information about students' competence in a particular domain (e.g., science) at the beginning of and throughout an instructional unit for planning and monitoring student learning. At the end of the unit, the school year or even a particular stage of education, teachers use assessment to collect information about student competence to evaluate the outcomes of student learning in scope of the unit or school year. In the school, district, state, or national level context, assessment is used for monitoring student learning across multiple school years. All these assessments may be considered to serve the eventual aim to improve student learning. However, only assessments that have an immediate effect on the assessed students' learning are considered formative assessment. Assessments used for certification purposes (e.g., grading) and monitoring purposes (e.g., comparing different curricula) are considered summative, as these assessments typically aim to comprehensively assess student competence in a domain without an immediate impact on student learning. Still, such assessments – better: the information obtained through these assessments – are utilized to send students to a school track that suits their level of competence the best. Or these assessments may be used to increase funding for those school districts whose students have been found to fall behind in mastering the required level of competence at a particular stage of their educational career. Sometimes the same assessment is used for different purposes. Teachers, for example, may use assessments carried out for certification purposes (e.g., an end-of-year test) and also for formative purposes (e.g., to plan student learning in the following school year).

However, while a single assessment can be meaningfully used for more than one purpose, that does not mean that one assessment can serve all purposes (National Research Council [NRC] 2001). Assessments need to be designed to first and foremost serve the purpose they are intended for. Formative assessment in the context of the classroom is typically designed around rich tasks that require the application of a combination of in-depth knowledge (e.g., an understanding of the core ideas of science) and complex skills (e.g., scientific practices). Summative assessments in large-scale contexts on the other hand typically build on multiple-choice items for more efficient scoring. And whereas information obtained through multiple-choice large-scale summative assessments can be used for formative purposes, for example, at the beginning of a unit, the information will not provide in-depth information of student thinking and as such is not suitable for monitoring student learning throughout a unit. In order to ensure that – despite their design to fit different purposes – the various assessments used within an education system all serve the eventual purpose of improving student learning, coherence needs to be established across the different assessments (NRC 2014).

Assessment should build on three foundational elements: a model of student competence development, a set of beliefs about typical tasks or situations students at each level of competence development can solve, and a set of (statistical) procedures to aggregate the information aimed for from the raw data. As the latter two elements are specific to the purpose the respective assessment serves, the first foundational element is the one by which to establish coherence. A comprehensive model of student learning about a domain (e.g., science) is needed that describes student learning at different grain sizes, across multiple-grade bands, within one grade band, from lesson to lesson, and even within one lesson. That is, multiple models of student learning about different aspects of the domain are required describing learning at the smallest meaningful grain size. These models then need to be integrated into a system which allows to describe student learning across time as a function of the content taught. So far, science education research has provided many assessments that can describe student learning on smaller timescales. What is missing is an empirical foundation for larger models of student learning that can align the structuring of content (i.e., curriculum) across several grade bands and serve as a framework for aligning assessments both horizontally and vertically (NRC 2006). This function is to be fulfilled by learning progressions (e.g., Wilson 2009, p. 727).

Cross-References

- ▶ Assessment: An Overview
- ▶ Formative Assessment
- ▶ Learning Progressions, Assessment of
- ▶ Summative Assessment

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Collaboration

▶ Problem Solving in Science, Assessment of the Ability to

Collaborative Learning in Science

▶ Cooperative Learning

Collaborative Work

▶ Internet Resources: Designing and Critiquing Materials for Scientific Inquiry

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Collective Inquiry

▶ Knowledge-Building Communities

Common Assessment

▶ Test

Communicating Science, Classroom Assessment of the Ability to

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Introduction

Scholars of science education have become increasingly interested in the classroom assessment of science communication ability. This interest is partially due to a growing realization that effective science instruction leads to improved communicative ability. In addition to mastering important science concepts, learners also develop a variety of communicative skills such as an improved ability to talk, write, argue, and reason scientifically. The following text introduces readers to scholarly work in which such communicative outcomes have become the object of classroom assessment efforts. Attention is given specifically to the different ways that classroom science communication is conceptualized and methodologically approached as part of science classroom assessment efforts. In some studies, science learners are viewed as developing the ability to express their thoughts in the language of science, and what is assessed is their ability to "talk science." In others, science classroom communication is viewed rhetorically, and what is assessed is students' competence in oral argumentation.

Talking Science

Classroom assessment of students' ability to talk science has been largely informal and formative, typically being conducted in the context of whole-class discussions at elementary grade levels. These oral assessment efforts are strongly influenced by the book *Talking Science* where Lemke (1990) identifies the stylistic norms to which speakers must abide in order to talk "proper science" in classroom settings: 1. Be as explicit and universal as possible. . . 2. Avoid colloquial forms of language. . . 3. Use technical terms. . . 4. Avoid personifications and. . . human attributes or qualities. . . 5. Avoid metaphoric and figurative language. . .6. Be serious. . .7. Avoid personalities and reference to individual human beings and their actions. . .8. Avoid reference to fiction or fantasy. . .9. Use causal forms of explanation and avoid narrative and dramatic accounts. (p. 133)

Lemke conceives of science as a school subject whose communication requires mastery over a specific register, that is, a specialized and context-specific variety of the English language. This characterization of "the language of science" has been used in recent studies as a basis to assess the effectiveness of elementary teachers' oral strategies in encouraging students to talk scientifically (i.e., make use of the scientific register). Pappas et al. (2003) describe how primary students tend to recount previous events and experiences in a generalized and impersonal manner when allowed to make spontaneous and unprompted contributions to the discussion during a loud reading of science trade books. Oliveira (2010) reports that referential questions (i.e., student-centered oral queries that require pupils to express their own conceptual understandings) prompt long, explicit, and precisely articulated student responses. Oliveira (2011) identifies provision of participant examples (oral descriptions of actual or hypothetical situations wherein the teacher presents himself/herself and/or students as characters to illustrate topics under discussion) with the generalized "you" as a strategy effective in encouraging students engaged in oral discussions to speak in a generalized manner consistent with the scientific register.

As a dynamic, continuous, qualitative, and formative endeavor, classroom assessment of students' ability to talk science informs subsequent teacher moves (reactive comments, follow-up question, and feedback provision). However, the feedback given to students is often too implicit and hence of limited informational value to pupils. Rather than explicitly commenting upon students' emergent ability to talk science, teachers tend to simply communicate their positive evaluation by indirect means such as pleased face expressions, affirmation (selective endorsement of student ideas), and topic uptake (selective follow-up on student ideas).

Arguing Scientifically

The literature on classroom assessment of students' ability to argue scientifically is considerably larger and more diverse. Focused on the rhetorical dimension of classroom science communication, a large number of studies have been conducted aimed specifically at assessing the quality (i.e., soundness and logical coherence) of students' science arguments by examining the extent to which they align with generic models such as Toulmin's Argument Pattern or TAP. This rhetorical type of assessment usually entails identification of argument components such as data, claim, warrant, backing, qualifier, and rebuttal.

Some studies focused specifically on the structure, justification, and content of arguments or student-generated products. Sampson and Clark (2008) used a variety of criteria (soundness, acceptability, coherence, correctness, and epistemic status) to assess an artifact written by a middle-school student to explain the thermal sensation of different objects (wooden, metallic, etc.). This study highlights how the same argument can be assessed as strong or weak and of high or low quality depending on whether the assessment is conducted from a perspective that is domain general, domain specific, content focused, or structure focused.

Others examined the process of argumentation or argumentation discourse, that is, the dialogic or interactional processes utilized by students to orally propose and justify arguments through whole-class or small-group discussions. In many of these studies, assessment was aimed at determining the quantity of scientific argumentation in science discourse. Erduran et al. (2004)

quantitatively assessed small-group argumentation by determining the relative frequencies of five different levels of argument. High-quality arguments were operationalized as being extended and composed of multiple rebuttals, whereas low-quality arguments were limited to claims and counterclaims.

In many studies, quantitative assessment was combined with the construction of visual representations of classroom oral argumentation designed to visually assess the soundness and rhetorical quality of student arguments. Maloney and Simon (2006) used "discussion maps" to assess the relative levels of rhetorical sophistication of small-group discussions among 10- and 11-year-old students in the UK. This visual assessment method led to the identification of different levels of argumentation, including sustained evidence-based argumentation (highest rhetorical quality), series of arguments, repetitive and dispersed argumentation, and discussions without arguments.

Conclusion

In sum, classroom assessment of science communication can take varied formats (qualitative, quantitative, verbal, visual, etc.) depending on whether emphasis is placed on communicative style (manner of talk) or interpersonal persuasion. This trend suggests that science classroom communication serves two distinct and often competing communicative goals: expressive and rhetorical. Therefore, care must be taken to ensure alignment between the particular communicative goal being pursued and the assessment strategies adopted to determine its achievement as a result of science instruction and learning.

Cross-References

- ▶ Assessment of Doing Science
- ▶ Communicating Science, Large-Scale Assessment of the Ability to
- ▶ Discourse in Science Learning
- ▶ Discussion and Science Learning

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Communicating Science, Large-Scale Assessment of the Ability to

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Introduction

At the international level, research on large-scale assessments of science education has focused on two distinct aspects of science communication. The first body of work is concerned with how science is communicated to test takers and the potentially adverse impacts that particular communicative patterns can have on international comparisons of student performance in science. The second area of research deals specifically with students' ability to communicate science content to assessors when writing in response to short open-ended test items.

Communicating Science to Test Takers

Research in this area has examined both verbal and visual aspects of science communication in international assessments. Ercikan (1998) examined the IES science test, a large-scale examination given by the International Association for the Evaluation of Educational Achievement to Canadian students. The IES test was developed in English and then translated into French. Differential Item Functioning (DIF), a statistical analysis that controlled for differences in student ability, indicated that 26 % of the 70 test items were linguistically biased, that is, favored speakers of a particular language due to poor translation (e.g., replacement of unfamiliar science terms with everyday expressions, word choices that hinted at the answer, varied degrees of sentence complexity, etc.). The specific ways that each language was used to communicate science to test takers differentially affected their performance, thus undermining the equivalence and comparability of test items across languages. Hatzinikita et al. (2008) reported that the way that scientific knowledge was communicated in PISA science test items and Greek school textbooks differed both verbally and visually. PISA science materials combined nonspecialized, everyday language with highly specialized forms of visual representation (abstract images designed according to scientific visual conventions, symbolism, and notation), whereas the exact opposite combination (specialized language and everyday/realistic imagery) was predominant in school science textbooks.

Writing Answers Scientifically

This body of work has given attention specifically to students' ability to provide scientific explanations in international assessments. Combining both structural and conceptual assessment criteria, Zuzovsky and Tamir (1999) examined written explanations provided by Israeli students (fourth and eighth grade) in response to short-answer science questions on the TIMSS examination. Their findings reveal that student communication of scientific explanations usually takes the form of poorly articulated verbal accounts that are often incomplete, highly fragmented, simplistic, and devoid of specialized scientific terminology. The authors emphasize that many students have difficulty in producing scientific explanations for the purpose of exhibiting and demonstrating their conceptual understanding in large-scale assessments. However, it remains somewhat unclear whether the issue is one of conceptualization (student inability to conceptualize according to scientific principles) or communication (student inability to communicate their ideas scientifically). In a more recent study, Frändberg et al. (in press) examine students' written responses to two constructed response items from the Swedish part of TIMSS 2007 and report that only 10 % (86 out of 954) of the answers explain physical and chemical changes in matter at the submicro level (contained explicit references to atoms, molecules, or particles). Evidence is provided that, without careful and explicit prompts from assessors, student written communication of scientific knowledge and ideas in large-scale assessment is predominantly limited to the macro level (i.e., focus exclusively on perceptible and tangible properties and aspects of natural phenomena rather than microscopic entities).

Conclusion

In sum, the above studies problematize the relationship between content and form (communicative format) in large-scale science assessments. The reported findings challenge the general assumption that what is being assessed and compared in international testing is scientific content knowledge and not science communication ability (students' ability to interpret and produce scientific texts). Student performance across languages and countries may reflect student (in)ability to engage with certain forms of science communication rather than mastery of science concepts, thus deserving more careful consideration and critical analysis on the part of international test developers.

Cross-References

- ▶ Assessment of Doing Science
- ▶ Communicating Science, Classroom Assessment of the Ability to
- ▶ Discourse in Science Learning
- ▶ Discussion and Science Learning

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Communication

► Problem Solving in Science, Assessment of the Ability to

Communities of Practice

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The idea of communities of practice (COP) emerged from sociocultural traditions of research in education, anthropology, and sociology and is a fundamental element of situated learning theory. Situated learning offers a perspective on learning that prioritizes the contexts in which thinking, doing, participating, and learning take place. This focus on context should not be simply construed as environments having superficial influence on activities, but rather that learning is fundamentally associated with engagement in social practice. Here, the idea of social practice denotes more than interactions among multiple individuals; it is a characterization of human activity such that practices are embedded within systems of social expectations, norms, and negotiated meanings. In other words, social systems give rise to and afford meanings to practice and learning. The social systems that emerge relative to particular tasks, problems, or activities are communities of practice. Therefore, all knowing and learning are situated, and communities of practice define, in large part, the situational realities that shape the knowing, learning, and activities that can transpire.

It is important to note that communities of practice do not just provide a referent to opportunities for group learning. COP offer a theoretical orientation to the basic nature of knowledge and learning. Jean Lave and Etienne Wenger first introduced the notion of situated learning and COP in an attempt to formulate a new theory of knowing, doing, and learning that accounted for their anthropological observations of communities and how individuals developed expertise in these communities. In their seminal work on the topic, they define a community of practice as

> A set of relations among persons, activity and the world, over time and in relation with other tangential and overlapping communities of practice. A community of practice is an intrinsic condition for the existence of knowledge, not least because it provides the interpretive support necessary for making sense of its heritage. Thus, participation in the cultural practice in which any knowledge exists is an epistemological principle of learning. (Lave and Wenger 1991, p. 98)

Defining Elements of Communities of Practice

Three basic elements comprise communities of practice: (1) a community, (2) a domain, and (3) practice. The community references a group of practitioners who come together through interactions. Such a community may interact physically, but interactions can also be facilitated through virtual tools. So, communities do not necessarily need to share physical proximity, but they do need to facilitate actual interactions among the practitioners. A single teacher accessing a static lesson plan through a website is not participating in a community with the author of that lesson plan if there are no ways for these teachers to share ideas, respond to one another, collaborate, etc. We could generate a near-infinite list of possible communities relative to the science education enterprise. To help illuminate some dimensions of communities of practice, I suggest three such hypothetical communities: a middle school science class, a group of science teachers working together within an online professional development program, and scientists conducting research in a particular subdiscipline of biology. In the case of the middle school science class, a group of students and their teacher are the primary members of the community, although there may be other community participants depending on the role school administrators and others such as teacher aides or class volunteers may play. This community likely comes together on a near-daily basis, and creation/dissolution of the group is mediated by the academic calendar. A community of science teachers participating in an online professional development program may never interact in a face-to-face format, but they have opportunities to interact dynamically through Web-based tools. A community of scientists contributing to the same research subdiscipline likely come together periodically through venues such as annual conferences, but they also interact through peer review processes, Web-based networking, and personal communications. Whereas the other examples of communities may have a naturally defined period of existence, the community of scientists may persist indefinitely or at least as long as the subdiscipline has interesting questions to pursue. The mechanisms for communication, size of the groups, and temporal dynamics of these communities may vary, but they share commonalities in terms of bringing people together with shared interests.

Communities of practice are more than just a group of individuals; a COP develops with respect a particular domain. The domain references the area of interest around which individuals come together. The idea is that COP do not emerge from random groupings, but rather are built by a network of people with shared interests and who are pursuing related goals. Each of the hypothetical community examples presented above is organized around particular domains. The middle school class comes together around the goal of learning science. This may be an idealistic representation of a middle school science class; critics may argue that this community is more interested in navigating the disciplinary and social expectations of the school and this may very well be the case for most middle school classes. In either case (and for other interpretations including those in which members of the community may have a combination of these and other intents), the community is organized around a domain. For the online teacher community, the domain relates to improving teaching practices, and the domain for the scientist community is defined by the focus and research questions driving their subdiscipline.

The third element is practice. Here, the focus is on the idea that individuals, who organize around a domain, engage in particular activities, access particular resources, use similar tools, etc. Communities of practice are not static assemblages of individuals who just happen to share a common interest, but rather are dynamic and necessarily involve participation. Referring back to the science education examples, the middle school class engages in shared practices such as routines related to things like taking notes and completing laboratory reports. Most classes have particular repertoires of acceptable (and unacceptable) activities that may involve use of classroom equipment, access to technology, and classroom discourse. Similarly, the teachers participating in online professional development will likely engage in community-specific practices such as the sharing of lesson plans and activities, sharing feedback with one another, interacting with new materials, etc. The scientific researchers employ various methods that have been negotiated through the community such that shared perspectives on standards for and the validity of evidence are evident (at least internally) and shared (although these shared perspectives may also be challenged).

Wenger, highlighted above as one of the scholars who introduced situated learning, continued to theorize about the conceptualization of communities of practice. He defines the COP construct in terms of three constitutive ideas that map to the three elements just presented: mutual engagement, joint enterprise, and shared repertoire (Wenger 1998). Mutual engagement highlights the social norms and expectations that define community structure. Joint enterprise represents the shared focus of group participation, that is, the domain of the community. Importantly, this joint enterprise is defined and continually refined by the community. The shared repertoire of a community consists of the resources, tools, protocols, and negotiated standards for practice. Here again, this repertoire is dynamic and can be continually renegotiated.

Communities of Practice and Learning

A community of practice perspective defines learning in terms of community-specific activity. A community member learns as she participates in the culturally mediated activities of the community. Lave and Wenger (1991) offered legitimate peripheral participation as a construct to account for social practice, which necessarily includes learning, within communities of practice. Legitimate peripheral participation provides a way to think about how community members with varying levels of experience (e.g., newcomers to the community versus more established old-timers) participate in the community. As newcomers develop understanding of community norms and expectations for participation as well as appropriate tools and processes for participation, they move toward "full participation" (Lave and Wenger 1991, p. 37). This trajectory of participation constitutes learning.

Whereas engagement in community-defined practices represents a fundamental aspect of learning, the identities that members create/assume within the context of their community determine the kinds of practices in which they can engage. There is a co-constitutive relationship between practice and identity, but importantly, practice and identity interact in dynamic ways such that an individuals' repertoire of practice and identity shift over time. A note on the use of identity is warranted: identity is a widely used construct across the social sciences and takes on various meanings depending on the framework used to define it. Sociocultural perspectives suggest that identity represents processes of positioning within a particular COP and this positioning is shaped by history and norms of the group. Therefore, this process and ultimately the identities that individuals assume (or create) are constructed together by the individuals and influential others within the community. As newcomers and their communities construct identities, the newcomers develop evolving views about competencies and potential relative to the community's domain making it possible for them to understand, use, and engage with disciplinary ideas and tools in new ways. From this perspective, identity construction is central to appropriating community practices and therefore is a fundamental aspect of learning.

COP as a Research Framework

Communities of practice offer a way of thinking about what it means to know, engage in activity, and learn, and this perspective has been used to frame science education research. In the final section of this entry, I introduce five recent studies, from major research journals in the field of science education. All five studies utilize COP as a construct to define and/or analyze problems related to the teaching and learning of science. This is not a comprehensive or even representative sampling of research framed in terms of COP. The presentation offers some examples of the diverse ways in which researchers have conceptualized and used COP. Table 1 presents citations for the five studies and abbreviated descriptions of each study's focus and main findings. In the table, I also describe the COP studied in terms of the three basic constitutive elements introduced above: community, domain, and practice.

The five articles showcase different kinds of communities of practice relevant to science teaching and learning. Feldman and colleagues (2013) study science research groups and explore how undergraduate and graduate students learn through apprenticeship in these groups. This research, which explores how newcomers to an established community appropriate community norms and practices, is highly

Communities of Practice, Table 1 Examples of science education studies that have utilized communities of practice to frame the research

Citation	Focus	Community	Domain	Practice	Key findings
Akerson et al. (2009)	Development of a COP for elementary teachers learning about nature of science (NOS) and how to teach NOS	17 elementary (K-6) teachers, a science education faculty member, and three graduate students	Teaching NOS ideas to elementary students	Engagement in a summer institute, monthly workshops, use of explicit NOS activities, formal reflection on classroom practices	Participation in the COP supported development of NOS ideas and improved NOS teaching. NOS modeling and explicit reflection were needed to achieve these gains
Feldman et al. (2013)	Build understanding of how graduate and undergraduate students learn to do scientific research while participating in science research groups	Graduate students, undergraduates, postdocs, and faculty members working on a particular scientific problem	The study documented three COP with unique domains: microbiology, geology, and hydrology	Weekly group meetings, journal club, various scientific procedures, field work	Advanced students provided much of the mentoring for newer students and hypothesized a progression of positions within a research COP: novice researchers, proficient technicians, and knowledge producers
Kisiel (2009)	Explore a partnership between a school and an informal science institution and how implementation of the collaboration impacts stakeholders and students	Two COP are investigated: (1) a new elementary school and (2) an aquarium education department	(1) Establishing a new school and supporting student learning	(1) Teach science 1 day per week (lessons are typically repeated in successive years)	Boundary objects (artifacts shared across the COP) and brokers (key individuals who mediated connections) facilitated the creation of an overlap between the two COP
			(2) Outreach and education programs for school groups and the public	(2) Teach the same lesson to many school groups	
Olitsky (2006)	Ethnographic exploration of teaching practices and classroom environmental factors that support positive “interaction rituals” such that solidarity, feelings of group membership, and interest in learning were achieved	33 grade eight students and their science teacher. The students were racially diverse and came together in an urban magnet school	Learning physical science concepts and developing interest in science	Engagement in class discussions, hands-on laboratory activities, group problem-solving, linking science ideas to areas of student interest (like sports)	Classroom conditions that supported positive interaction rituals: low-risk participation opportunities, activities with sufficient time and challenge, and positioning of students as knowledgeable and capable
Saka et al. (2013)	Exploration of a new science teachers’ participation in a school’s community and how this influences his induction into the profession	The teachers of a midsized, public high school with a racially and ethnically diverse student population	Supporting development and learning of the school’s students	A wide range of classroom- and school-oriented activities including faculty meetings, mandatory math “warm ups” in class, and informal conversations among teachers	Inconsistencies in individual teacher aspirations and school expectations shape the induction of a new teacher and lead to the teacher leaving the school

consistent with Lave and Wenger's studies of apprenticeship that served as the basis for conceptualizing situated learning and communities of practice. Olitsky (2007) explores how a class of middle school students and their teacher shape interaction rituals within their classroom-based COP. Saka and colleagues (2013) study the phenomenon of new teacher induction by conceptualizing a first year teacher's experiences in terms of his enculturation in the school's community. This article provides an interesting case in which the community newcomer has expectations and anticipated practices that contradict community norms. These tensions have important implications for the identity the new teacher constructs. Kisiel (2009) presents a study of interacting communities of practice. Potential connections between an elementary school and an informal science institution are easy to draw in theory, but Kisiel's study highlights ways in which the two communities, which share some of the same goals, maintain unique repertoires of practice that can present constraints to collaboration. The article also addresses ways in which these community boundaries were traversed. Finally, Akerson and colleagues (2009) explore professional development to improve elementary teachers' understandings of and abilities to teach nature of science. Whereas the other articles cited here study existing COP, Akerson and colleagues create a COP to support their professional development goals.

Summary

Communities of practice offer a theoretical orientation for what it means to know and learn. The construct emerged through studies of learning communities not associated with schools and classrooms, but the idea offers important implications for how learning is situated within community contexts relevant for efforts to support teaching and learning in any context. In science education, there are numerous communities of practice, many of which are overlapping and mutually influential. Science education researchers apply the idea of communities of practice in varied contexts to illuminate how people know, do, and learn science.

Cross-References

- ▶ Activity Theory and Science Learning
- ▶ Agency and Knowledge
- ▶ Cultural Influences on Science Education
- ▶ Didactical Contract and the Teaching and Learning of Science
- ▶ Language and Learning Science
- ▶ Situated Learning
- ▶ Socio-Cultural Perspectives and Characteristics
- ▶ Socio-Cultural Perspectives on Learning Science

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Companion Meanings

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In science education, a central aim is that students learn scientific facts, models, and theories. In many countries they are also expected to learn the skills associated with the work of scientists and about science as a practice and a field of knowledge. So, in general, we can say that in science education students are supposed to acquire scientific knowledge, scientific skills, and knowledge about science.

Even when knowledge about science is not one of the objectives of a specific teaching activity, it could be argued that we cannot teach scientific knowledge without at the same time teaching about science, i.e., about the kind of knowledge and the kind of activities that are regarded as valid. In the same vein, we could say that it is not possible to teach students scientific concepts without communicating something about nature, e.g., what nature is, how it works, and so on. It is also obvious that when learning science, students also learn about themselves in relation to school science activities and perhaps also to science. All these extras in teaching and learning are known as "companion meanings."

The term "hidden curriculum" has sometimes been used to capture these extras. However, it is important to note that companion meanings are communicated and learned while learning science, i.e., companion meanings accompany scientific meanings. As such, companion meanings have a pivotal role in the learning of a worldview in science education and are a crucial component in the socialization content of science education.

The idea of companion meaning is based on the reminders of pragmatic philosophers that it is not possible to act in the world without involving choices and values. These values are sometimes visible in our actions, while at other times we follow norms without reflecting on them. In the latter case, we are not mindful of the values that guide our choices; we just do what we usually do.

As teachers we develop certain teaching habits, and in executing these habits, the values by which we choose the teaching content may be invisible to us. But it becomes obvious that we need to make value judgments when we realize that we cannot teach all the facts of science within, for example, the framework of compulsory education. Our values come into play every time we plan a lesson since we must include certain facts and exclude others for the simple reason that it is not possible to accommodate all the scientific claims about, say, energy in a single lesson. Thus, we have to grapple with the question of which fact or facts about energy are more worthy than others. Here it is important to recognize that this is not necessarily a relativist standpoint, but simply a plain recognition that actions inevitably involve some kind of value judgment.

When Wertsch introduced the term "privileging," we could say that he brought this insight into the heart of learning. Learning is not a mystery; it happens all the time. What is puzzling, though, is how or why learning takes one direction rather than another. Privileging facilitates one of a number of possible directions of learning and results in a specific learning outcome. In certain practices, specific privileging processes prevail, and in order to become part of a scientific practice, we have to learn specific habits of privileging. Since the privileging process is about choice, values are naturally involved.

We can make a crude distinction between ethical and epistemic values, where the former are often described as dealing with what is a good and correct way of, for example, treating human beings and nature. Epistemic values concern the practical values that are crucial for a specific activity, and it is those we are concerned with here because they build up companion meanings.

One of the major systematic changes that occurred during the scientific revolution that began in the seventeenth century was the separation of humans from nature to the extent that scientists became the observers and manipulators of the object “nature.” Science required that nature be approached as an object, or thing, leading Thoreau and many others to criticize science for stripping nature of all its qualities. Regardless of whether or not we agree with that criticism, we have to learn to approach and talk about nature as a thing in order to learn and communicate science. For example, if we want to give the word “heat” scientific meaning, we cannot associate it with qualities that are connected to our bodily experience of feeling hot. Instead, we have to understand and use it in the context of a language game, where, for example, the word is given a meaning that is connected with the movement of things, i.e., atoms. The separation of nature from humans is one example of an intelligibility demand that we learn to practice as we learn science. Such demands are examples of companion meanings that we learn in the same time as we learn scientific concepts, models, theories, etc.

When we learn science, we also learn a new way of perceiving the world. Companion meanings play a crucial role in this learning because they help us to discern the things that really matter. When a biology teacher takes students to a forest, most of the students will see trees, while the teacher will also see connectedness. In order to perceive the forest in such a way, we need to master the practice of an intelligibility demand that is common in ecology, namely, that phenomena and events in nature are explained in relation to other phenomena and events.

Aesthetic expressions of likes and dislikes can also function as epistemic values and be crucial for the privileging process. Aesthetic values such as elegance are sometimes used in the privileging process in a laboratory: the fewer tests we use in order to reach the right results, the more elegant the experiment becomes. In this sense, learning science is akin to learning specific aesthetics. This becomes obvious if we look at the history of science. For example, biologists have long been dependent on artists’ representational aesthetics, i.e., making perfect representational drawings of animals and plants, for a valid science.

In science education, there is an almost constant production of companion meanings concerning what counts as valid or invalid knowledge and what counts as proper ways of proceeding in investigations in order to produce valid knowledge. These companion meanings concern what we sometimes call the view of science or the epistemological dimension of an activity. It is important to note that these companion meanings are learned, as the intelligibility demands, at the same time as we learn science. Companion meanings are sometimes reflected on by students, although more often than not students just learn to practice them. It is also important to note that the practice is learned in the context of school science and not in the context of science. Thus, the epistemology students learn is situated in the school science activities. Much of the learning revolves around learning how to discern between valid or invalid knowledge and ways of producing knowledge in school science. Many of the questions that students ask teachers, and a lot of teachers’ communications, relate to this discernment. For example, nodding or other encouraging actions often confirm that the activity that a student has staged is valid in order to, for example, generate a correct answer to a question (Lidar et al. 2006). This learning of a practical and situated epistemology can be an important part of the learning of a view of school science and of science.

The learning of companion meanings and the learning of a specific way of privileging in the meaning-making process occur in the same time. Thus, when we have learned a practical and situated epistemology, i.e., a practical epistemology (Wickman and Östman 2002), we have acquired a specific perception and a specific manner of producing meaning and knowledge.

When creating meaning and when learning, we cannot avoid creating a relation to the practice we are experiencing. Thus, the learning of science often involves an identification process. For example, we might learn that we are very successful or unsuccessful in relation to the ongoing learning process or that for one reason or another we are not cut out to be scientists. The identification process is often connected to the companion meanings that are communicated in science education, for example, the gender bias that accompanies a dominance of pictures of males in text books.

As companion meanings have a crucial role to play in the privileging process, paying attention to companion meanings can enhance educators' control of the learning process and thereby make the transition from everyday discourse to a scientific discourse as smooth as possible for the students.

Another benefit of paying attention to companion meanings is that it makes us better equipped to deal with crucial questions about worldviews, citizenship, identity, and scientific literacy in science education (Östman and Almqvist 2011). Worldviews do not only consist of things like conscious values and commitment, but also our way of practically perceiving and approaching nature, our fellow beings, truth, arguments, etc. Companion meanings are epistemic values that concern the latter. Moreover, there is plenty of historical evidence to show that epistemic values can be questioned and criticized from an ethical perspective. The criticism of Thoreau and others during the Romantic period is one example of this. Many biology teachers have also experienced that the practice of dissecting can no longer only be judged from an epistemic point of view, but must also include ethical values.

One way of furthering the benefits of companion meanings is to create typologies of the different types of content that make up science education. For example, the Curriculum emphases typology (Roberts 1998) highlights companion meanings about science, the Nature languages typology highlights the intelligibility demands regarding nature, and the Subject focus typology concerns companion meanings about the relationship between human beings and nature that is learned in conjunction with science (Östman 1998).

Cross-References

- ▶ Bildung
- ▶ Curriculum Emphasis
- ▶ Epistemic Goals
- ▶ Values
- ▶ Values and Western Science Knowledge

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Competence in Science

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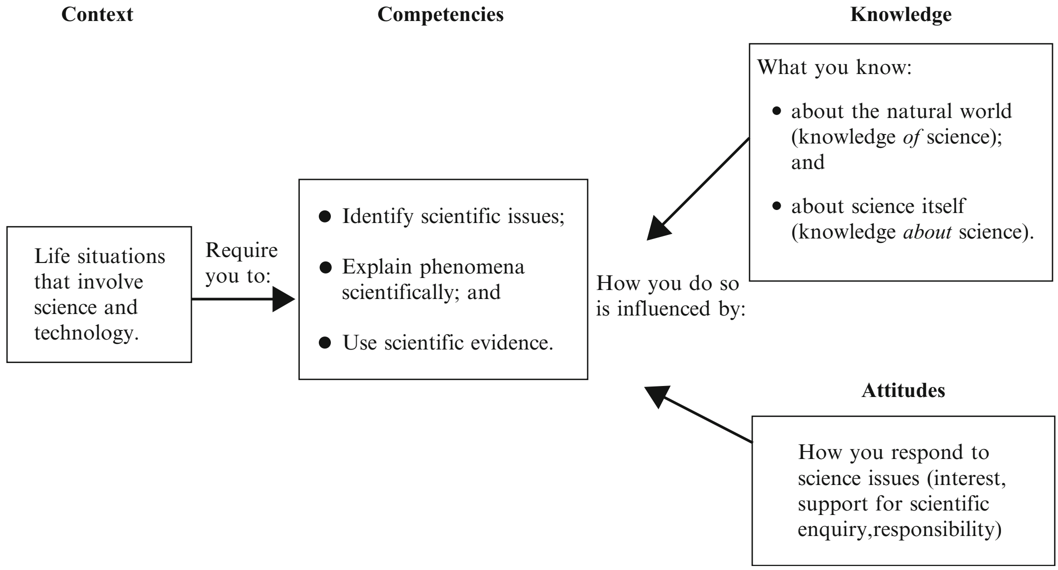
It is an international trend that national curricula and descriptions of expected learning outcomes from schooling are increasingly framed in competence terms, rather than in knowledge and skills to be learned. Competence in this usage refers to a certain "capacity" or "potential" for acting efficiently in a given context. The idea of competence has come into the educational sphere from the business community and society in general. Both business life and vocational training have for many years operated with job competence as something that reflects the expectations of workplace performance, the ability to accomplish a particular task. Also, in a globalized world, educational goals are increasingly being formulated across nations via global institutions such as the United Nations/UNESCO (e.g., "Education for all"), the OECD, and the European Union (e.g., "Lifelong learning") in order to capture some overall strategic aims. In this respect the introduction of competence into the



educational world reflects the role of schools as providing a general socialization and preparation for life, rather than only specific knowledge.

The reasons for the concept of competence having such a huge impact on education, despite its origins in the economic sphere, are manifold. Generally speaking, the impact of competence reflects the need for a concept to capture the complexity of demands placed on the individual person by modernity and post modernity in a time of diminishing social and cultural cohesion. This goes together with changing views on learning and teaching, from behavioristic approaches based on the transfer of canonical knowledge to constructivist ways of creating meaningful understanding through acting in authentic situations. This, in turn, is consistent with other factors influencing education such as the amount of factual knowledge growing in such an uncontrollably rapid fashion that education must shift focus to methods of knowledge acquisition and general practice within a subject, instead of selecting and transferring often quite randomized knowledge.

Due to its widespread and varying usage, competence is not an easy concept to capture. As Weinert (2001) expresses it: *There is no basis for a theoretically grounded definition or classification from the seemingly endless inventory of the ways the term competence is used. . . . There (is) . . . no single common conceptual framework.* Competence can be seen as an extension of the former goal category “qualification,” based on knowledge and skills, by adding to this the ability and willingness to use the knowledge and skills in complex situations. Fulfilling complex demands and tasks requires not only knowledge and skills but also involves strategies and routines needed to apply the knowledge and skills, as well as appropriate emotions and attitudes, and effective management of these components. Thus, the notion of competence encompasses cognitive but also motivational, ethical, social, and behavioral components. It combines proficiency and intentionality into a capability to solve tasks and problems of some complexity.

The most authoritative, international definition is probably from OECD’s DeSeCo project:

> A competence is defined as the ability to successfully meet complex demands in a particular context through the mobilization of psychosocial prerequisites (including both cognitive and non-cognitive aspects). This represents a demand-oriented or functional approach to defining competencies. The primary focus is on the results the individual achieves through an action, choice, or way of behaving, with respect to the demands, for instance, related to a particular professional position, social role, or personal project. (Rychen and Salganik 2003, p. 43)

The term competence is very often seen as interchangeable with competency, without any consistency in this interchangeability. Some will argue that "competence" is mainly referring to the concept as such (e.g., competence assessment problems), while "competency" is used referring to a specific ability (e.g., the competency to model in physics) but usage is inconsistent. The use of the plural "competencies" seems more widespread.

Competencies can be defined within the area of personal development (e.g., creative or innovative competence) and social behavior (e.g., teamwork competence) as well as within academic, subject-specific areas, like science. To become effective, science competencies require integration with personal and social competencies. For example, to design or to use models in science requires creativity and a certain level of affective involvement to enable one to overcome disappointments and criticism; further, working in groups and communicating the results requires social competencies.

Science competence can be attributed to a narrow part of science such as a part of a discipline or to a wider aspect of science performance, such as the ability to model. Used in the wider sense, science competence is closely linked to the concept of science literacy, where the construct of scientific literacy can be defined in terms of a set of competencies that a scientifically literate individual would be expected to display. This is for instance seen in the PISA 2006 Science Framework (OECD 2006), shown in the figure immediately below. In this framework scientific literacy is defined as the ability to use scientific knowledge and processes not only to understand the natural world but also to participate in decisions that affect the natural world; here the competencies are the specific processes that are seen as characteristic of science.

In other competence formulations of science, competence is seen as an integration of the processes and the knowledge and the attitudes in a practice – performed within relevant contexts. Many European countries have implemented competence models in science. For example, the Danish science competencies, used across all educational levels, are an attempt to capture what it is to do science, independent of the specific discipline or content. The Danish educational system operates with four core science competencies:

- An empirical, experimental competence (i.e., the ability to measure and to perform experiments and do fieldwork, to go into clinch with reality)
- A modeling competence (i.e., the ability to develop, use, and analyze models)
- A representational competence (i.e., the ability to describe and present knowledge using different modalities and formats and to transform between different representations of the same phenomenon)
- A putting-into-perspective competence (the ability to put science into cross-curricular, historical, philosophical, and personal perspectives, a "bildung" dimension).

These science competencies are described specifically in the different science domains/subjects together with general competencies like communication, argumentation, asking questions, etc. which are common for all subjects.

Teaching for competence is different to other science teaching. Conventionally a teacher will ask: "What must the pupils know?" – and will then plan what the students need to do in order to achieve this. In competence-directed teaching, the teacher will ask: "What must the students be able to do?" – and will then consider what they must know to be able to do this. The knowledge is subordinate to the actions and the situations the students are expected to control. The different elements necessary for performing the task are learned in coherence in a whole task approach in a realistic situation. It could typically be in a project-oriented sequence where the students learn actively and organize the learning processes themselves, with the support of the teacher.

Correspondingly, assessing science competence is different from assessing knowledge and skills. The more complex the learning goals, the more difficult they are to measure. The understanding of competences as the ability to cope with relatively complex challenges in an adequate way means that assessment methods necessarily have to be relatively advanced, flexible, and process oriented. And, at the very least, they have to be valid. Thus, artificial tasks such as multiple-choice test items that might test simple skills or knowledge recall can hardly measure competencies. For validity reasons competence assessment should be able to examine how students perform while going through the processes that constitute the competence to be assessed. Coincident with this, the assessment of a multifaceted concept like competence should be based on a competence model with multiple dimensions, and some clear criteria and some levels of performance should be described to establish a progression for scoring and for formative feedback reasons. The assessment also has to take place in real world or authentic situations to which the competence can be ascribed. For reliability reasons some kind of standardization should be applied to the expected activities. All these conditions are not easy to fulfill. At the one extreme students are observed in their everyday setting solving problems and tasks during a considerable time span, and the overall impression is judged. This is a costly method with high validity but often to the disregard of reliability and generalizability. At the other extreme students are placed in a room with paper and pencil to tick boxes and write short answers within a short time limit. With this relatively cheap method you can achieve high reliability, but this is clearly at the expense of validity. Irrespective of approach it is the nature of the test assignment (or the items) and the test situation that determines whether it is reasonable to consider the test a competence test. Especially for large-scale competence assessment, there is a risk that what is assessed is more isolated skills and detached knowledge than competence in the proper sense.

Cross-References

- ▶ Argumentation
- ▶ Assessment of Doing Science
- ▶ Bildung
- ▶ Companion Meanings
- ▶ Problem Solving in Science Learning

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Computer Simulation

▶ Authentic Assessment

Computer-Based Assessment

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Keywords

Computer based; Digital; Innovative; Next generation; Technology based; Testing

The next generation of assessments in science and other domains is taking advantage of technologies to transform what, how, when, where, and why testing occurs (Quellmalz and Pellegrino 2009). The capabilities of technologies are being harnessed to support assessment of the kinds of complex science understandings and practices advocated in the *Framework for K-12 Science Education* and the *Next Generation Science Standards*. These documents, along with other national and international science frameworks and standards, advocate teaching and testing of deeper learning about systems in natural and designed worlds integrated with application of the practices used by scientists and engineers to study and design these systems. Assessments of the *Next Generation Science Standards* will require dynamic, richer, and more extended and complex representations of science phenomena along with ways for students to actively investigate and modify the interactions among system components and emergent system behaviors. Forms of computer-based assessment are migrating from delivery on computers to other devices such as tablets, handheld devices, and tools not yet imagined. The increased mobility of assessment instruments permits greater flexibility for where and when evidence of learning can be gathered. Significantly, technology-enhanced assessments can blur the distinctions between assessments *of* and *for* learning.

Computer-Based Testing in Large-Scale Assessments

Initial forays into computer-based testing came from large-scale assessment programs administered by states, nations, and major testing companies. Economics and logistics were the primary factors that drove the search for efficiencies of assessment functions such as test development, delivery, adaptation, scoring, and reporting. Authoring shells and item banks aligned to content standards enable efficient development and assembly of items into comparable test forms. Online administration eliminates costs for shipping, tracking, and collecting print booklets yet simultaneously introduces other challenges related to computer access, server limitations, and security. Computer scoring provides rapid return of results and generation of reports tailored to multiple audiences. Flexible administration times and locales can shift annual, on-demand testing to interim, curriculum-embedded, and just-in-time challenges.

Large-scale computer-based testing now occurs in numerous international, national, and state assessment programs. In many of these programs, technologies are used not just to support testing logistics, but to also design innovative tasks and items that aim to measure understanding of dynamic science system interactions and the kinds of science inquiry practices not well measured by the traditional multiple-choice item format. In 2006, the Programme for International Student Assessment (PISA) began piloting computer-based science assessments and in 2015 will administer simulation-based science tasks. Similarly, the 2009 National Assessment of Educational Progress (NAEP) of science fielded interactive computer tasks to better assess science inquiry and will continue to administer these interactive investigations. The 2014 NAEP for Technology and Engineering Literacy will be delivered entirely online and include long and short scenario-based tasks to assess crosscutting practices for understanding technological principles, for developing solutions and achieving goals, and for communicating and collaborating. The state assessment consortia developing tests for common core math and literacy standards will be computer delivered and scored. One of the consortia will employ computer-based adaptive testing. It is likely that similar state consortia will be formed to develop new assessments for the *Next Generation Science Standards*. The next-generation assessments for science will be able to take advantage of advances in the use of simulations and games for promoting science learning to design innovative, interactive technology-enhanced science assessments (NRC 2011).

Technology Supports for Science Assessment

The rapidly advancing capabilities of digital and networking technologies are changing the ways that science assessments are developed, administered, and scored. These expanded logistical functions, in turn, will permit the design of richer, deeper, more interactive, and extended assessments that can measure coherent science knowledge and practices.

Technology-Based Assessment Infrastructures. Technologies support assessment functions related to authoring, delivering, collecting, and reporting measures of learning so that they are more efficient and economical. Technology can also assist the development and recording of alignments of the learning and assessment targets in state, district, and classroom science programs with the broader *Next Generation Science Standards*. Item banks and digital, multimedia collections of performance assessment tasks and products can be created and searched by the standards they test.

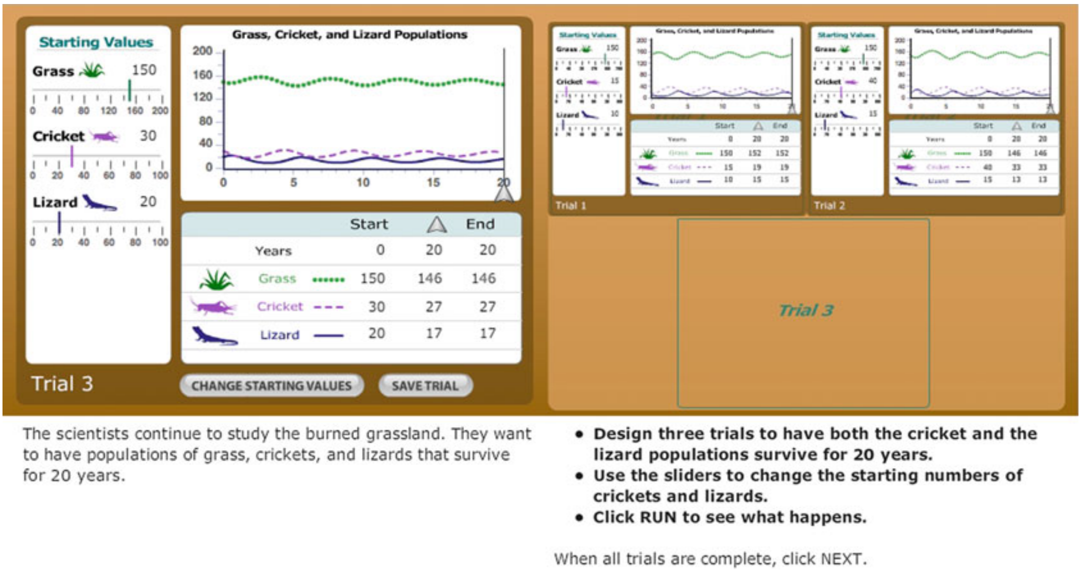
Technologies can expand the range of science and engineering design knowledge and strategies that can be tested. Not only can the core disciplinary ideas, crosscutting concepts, and science and engineering practices in the *Next Generation Science Standards* be assessed in real-world contexts and problems, but evidence of hard-to-test crosscutting practices such as scientific literacy, use of the "tools of the trade," collaboration, and communication can be collected. For example, Twenty-first-century skills for finding and using resources and for collaborative problem-solving can be more easily observed and recorded when the information searches, collaboration, and communications occur online. By permitting access to online resources and expertise, technologies can at the same time record those searches and assess them. Digital records of collaborations with virtual and real peers and experts can be tracked and evaluated. Summative tasks can be designed to provide specified science resources and virtual peers and experts. For performance assessments, planned assessment probes and tasks can be unobtrusively inserted by technology into activities and automatically scored or stored for rubric-based evaluations by teachers and students. Online training for reliable use of the rubrics by students and teachers can establish and document rater reliability. Electronic notebooks and portfolios can collect student work in multiple static and dynamic modalities, including samples of designs and work in progress as well as scans and video of final artifacts and performances. Customized reports of assessments and evaluations of interim work and artifacts and performances by individuals and teams can be analyzed, summarized, and reported to multiple audiences. For example, collections of engineered solutions and the records of their designs and iterative tryouts can support assessments of effective engineering design practices.

Innovative Technology-Enhanced Assessment Task Designs. Once the disciplinary core ideas, crosscutting concepts, and science and engineering practices to be tested have been specified, plans can be laid for collecting observations of learning to serve formative purposes during instruction and to serve summative interpretations of achievement. Technology-based formative assessments could be blended into hands-on and digital tasks during classroom-based science and engineering projects. Designs of assessments for summative judgments of learning would involve gathering evidence from final solutions and performances. Some of the component knowledge and practices involved in final performances or solutions could be responses to explicit tasks and questions that could be scored by the system automatically. Rubrics could guide evaluations of the complex performances.

A major technological advance is the capacity for representing dynamic natural and man-made systems "in action" and for making visible the invisible system interactions that are otherwise too fast, slow, big, small, or dangerous. Simulations can support student interactions with these dynamic displays to scaffold understanding and active investigations of how components interact to produce emergent system properties. Engineering projects can prepare alternative designs, tryout digital mockups and prototypes, run simulations to predict outcomes, and iteratively troubleshoot.

Technologies can support designs of innovative assessment tasks that will elicit observations of progressions of science learning (Quellmalz et al. 2012a). Technology-based interactive tasks can not only monitor learning, but also respond to student input with just-in-time feedback and coaching. These interactive, technology-based tasks can be designed using simulations, virtual immersive environments, and games.

Research on the benefits of system models and simulations for science teaching and assessment can offer guidelines for development of interactive science and engineering assessments (NRC 2011). Simulations can present models of natural and designed systems and their key components, interactions, and resulting system behavior. Simulation-based assessment tasks can be embedded within authentic, significant, recurring problems in the science and engineering domains. Computer-based modeling tools can allow students to see and iteratively test interactions among structural components of a system across time, scale, and levels. Student problem-



	Start	△	End
Years	0	20	20
Grass ••••••	150	146	146
Cricket - - -	30	27	27
Lizard ——	20	17	17

Trial 1: Grass 150, Cricket 15, Lizard 10

	Start	△	End
Years	0	20	20
Grass	150	152	152
Cricket	15	19	19
Lizard	10	15	15

Trial 2: Grass 150, Cricket 40, Lizard 15

	Start	△	End
Years	0	20	20
Grass	150	146	146
Cricket	40	33	33
Lizard	15	13	13

The scientists continue to study the burned grassland. They want to have populations of grass, crickets, and lizards that survive for 20 years.

- **Design three trials to have both the cricket and the lizard populations survive for 20 years.**
- **Use the sliders to change the starting numbers of crickets and lizards.**
- **Click RUN to see what happens.**

When all trials are complete, click NEXT.

Computer-Based Assessment, Fig. 1 Screenshot of SimScientists Ecosystem benchmark assessment to test use of simulations to investigate effects of changing population sizes

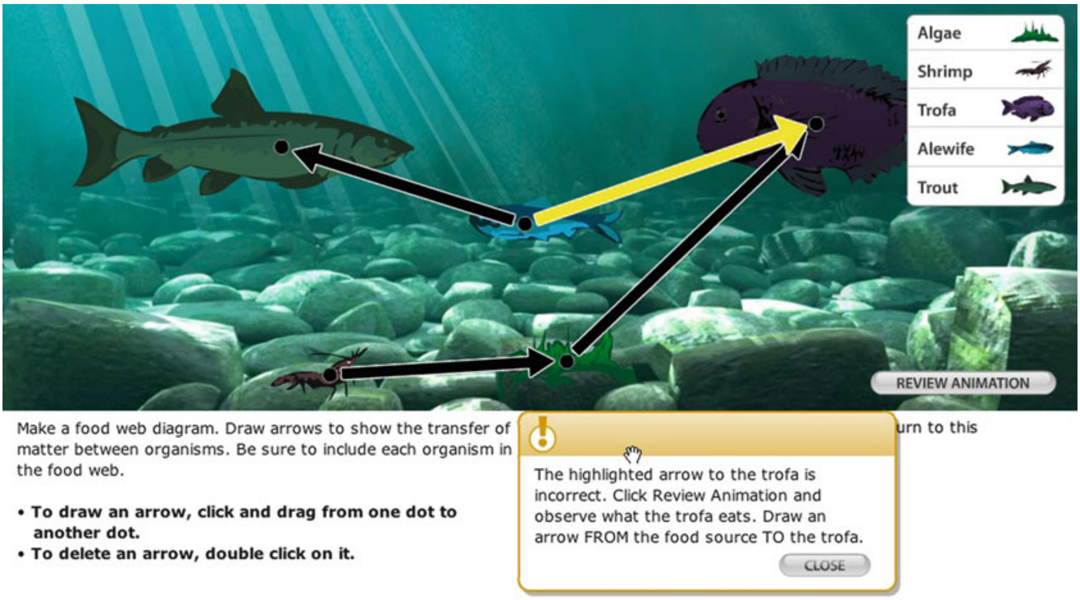
solving and inquiry processes can be logged and assessed.

For example, the SimScientists Assessment System is developing suites of simulation-based formative and summative assessments for middle school science units (Quellmalz et al. 2012a; http://simscientists.org). Figure 1 shows a screenshot of an excerpt from an end-of-unit benchmark assessment that tests students' inquiry skills. The screenshot is from an assessment scenario set in an Australian grassland. The overarching problem is that the ecosystem needs to be restored after a wild fire. In the first part of the scenario-based assessment, students observe the interactions of the organisms to create a food web representing the flow of energy and matter through the system. In the Fig. 1 screenshot, students' inquiry skills are assessed for using a simulation to conduct three investigations of what different numbers of organism populations would survive in a balanced ecosystem.

An important benefit of such technology-based interactive assessment tasks is that they can provide students with opportunities to use some scientific "tools of the trade." These might include manipulations of models and simulations for science and engineering tasks or use of computer design systems for an engineering task. Digital tools can allow students to find, organize, and analyze data and represent findings in multiple formats such as visualizations, graphs, tables, and models. Mobile devices can allow students to collect, store, and retrieve a range of observations and data in settings beyond the classroom. Presentation software can allow students to share designs, models of work in progress, and findings and solutions. Each of these tools of the trade can provide evidence of learning as they are being used.

Technology Supports for Classroom Science Assessment

Classroom-based science assessments can also take advantage of a range of technology affordances. One genre of computer-based classroom products mimics the item formats in state tests, thereby limiting the types of science knowledge and inquiry strategies that are and can be tested. Simulations, virtual immersive environments, and games are being developed to present

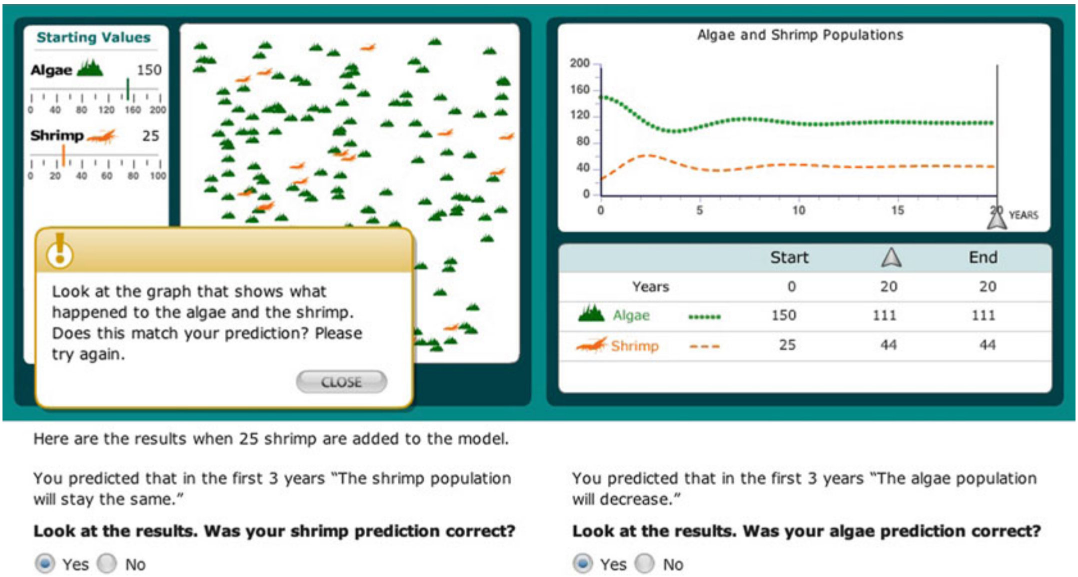


Make a food web diagram. Draw arrows to show the transfer of matter between organisms. Be sure to include each organism in the food web.

- **To draw an arrow, click and drag from one dot to another dot.**
- **To delete an arrow, double click on it.**

The highlighted arrow to the trofa is incorrect. Click Review Animation and observe what the trofa eats. Draw an arrow FROM the food source TO the trofa.

Computer-Based Assessment, Fig. 2 SimScientists screenshot of ecosystems formative assessment with feedback and mid-level coaching for drawing a food web



Look at the graph that shows what happened to the algae and the shrimp. Does this match your prediction? Please try again.

		Start	△	End
Years		0	20	20
Algae	••••••	150	111	111
Shrimp	- - -	25	44	44

Here are the results when 25 shrimp are added to the model.

You predicted that in the first 3 years "The shrimp population will stay the same."

Look at the results. Was your shrimp prediction correct?

● Yes ○ No

You predicted that in the first 3 years "The algae population will decrease."

Look at the results. Was your algae prediction correct?

● Yes ○ No

Computer-Based Assessment, Fig. 3 Screenshot of population dynamics inquiry task with coaching

dynamic, interactive representations of science systems and to integrate feedback and hints that can serve as formative assessments to benefit learning. For example, the SimScientists Assessment System is developing suites of simulation-based assessments to be embedded within middle school instructional units. The assessments are intended for formative purposes – to provide feedback and additional scaffolding to reinforce learning and to generate reports of learning progress. The simulation-based assessments are designed to measure assessment targets for understanding the components, interactions, and emergent behavior represented in models of science systems and also to assess inquiry practices for investigating the science systems. Figures 3 show ecosystems embedded assessments within the context of a remote mountain lake. When students are asked to draw a food web diagram in the embedded assessments, they are provided with graduated feedback and coaching that helps them complete the task before they can continue. Figure 2 shows the mid-level coaching students receive if they have not completed the task successfully on the second try. Students are coached to review the animation to observe the interactions between the organisms in order to correctly draw the arrow to depict the flow of energy from the energy source to the consumer.

Figure 3 shows a screenshot of a SimScientists Ecosystem curriculum-embedded assessment task for the science inquiry practice of using a simulation to predict, observe, and explain changes in the ecosystem. The embedded assessment is designed as a formative assessment that provides individualized feedback, graduated coaching, and a report of progress on the assessment targets.

When aligned with interactive summative assessments, curriculum-embedded simulation-based science assessments can become powerful components of a balanced state science assessment system (Quellmalz, et al. 2012b). Computer-based testing is rapidly evolving to support assessments of richer, deeper, interactive collaborative science learning. The capabilities of technologies will enable next-generation assessments to represent next-generation science learning.

Cross-References

- ▶ Computers as Learning Partners: Knowledge Integration
- ▶ Engineering and Technology: Assessing Understanding of Similarities and Differences Between Them

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Computers

▶ Computers as Learning Partners: Knowledge Integration

Computers as Learning Partners: Knowledge Integration

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Keywords

Argumentation; Assessment; Computers; Inquiry; Knowledge integration

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Introduction

The Computer as Learning Partner (CLP) project, funded by the National Science Foundation, has leveraged new technologies to strengthen inquiry activities and improve science learning in a research program involving a partnership of learning scientists, classroom teachers, discipline experts, technologists, and designers. CLP started by researching how Apple II computers with temperature-sensitive probes that generate dynamic, real-time graphs could serve as classroom *laboratory partners*. Later, taking advantage of the Internet, the partners designed the Web-based Inquiry Science Environment (WISE) as a *learning partner* to guide students as well as tools for teachers to monitor student progress, flag student work for class discussion, and provide feedback, making WISE a *teaching partner*. Recently, the partners have developed ways to analyze student work and provide adaptive guidance as students grapple with complex scientific ideas that allow the computer (via the WISE environment) to serve as an *inquiry partner*.

CLP classroom research involves longitudinal, comparison, and case studies that have been synthesized in the *knowledge integration framework*. The framework takes advantage of the multiple ideas students encounter and develop about each science topic. For example, when asked to predict the temperature of objects in their room, students make a wide variety of comments, like (a) metal objects are colder than wooden objects based on how they feel; (b) each object has its own temperature, like rabbits and humans; (c) objects come to the same temperature; (d) objects never come to the same temperature; (e) metal objects contain cold that can be used to keep people cool; and (f) objects get their temperature from the sun. CLP research revealed that a lecture on thermal equilibrium, telling students that all the objects (except those with their own heat source) are the same temperature, had little impact. Some students added this idea to their repertoire, but did not use it exclusively. Even when students used the temperature-sensitive probes to measure the temperature of the objects in the room, some asserted that the probes were "broken" because they showed that metal and wood objects were the same temperature! The CLP partnership designed instruction to help students build on their prior reasoning (e.g., that metals impart cold) to help them consider new evidence, construct better arguments, and articulate a coherent account of thermal equilibrium (Linn and Hsi 2000).

CLP research has focused on two main questions about knowledge integration. First, how can science instruction take advantage of visualizations and virtual experiments to design representations for new ideas that, when added to the repertoire of ideas, promote coherent accounts of science? Second, what forms of computer and teacher guidance encourage students to refine their reasoning strategies so that they can distinguish among their repertoire of ideas, increase the coherence of their ideas, and develop lifelong learning capabilities? For two decades, CLP has addressed these questions by experimenting with new technologies, refining curriculum materials, and identifying instructional principles and patterns that promote knowledge integration (Linn and Eylon 2011; Slotta and Linn 2009).

The curricular units developed by the CLP research program promote knowledge integration by engaging students in actively making sense of the evidence they encounter and iteratively improving the coherence of their arguments. Often, science instruction tells students accurate information and expects them to recall it in the future. But when new ideas are not integrated, students either forget them or conclude that they are appropriate for classroom activities but not everyday life. For example, one student remarked that objects in motion remain in motion in the classroom, but they come to rest on the playground!

Computer as Laboratory Partner

As a laboratory partner, CLP took advantage of temperature-sensitive probes that generated graphs as liquids cooled or were heated. These graphs helped to make ideas about thermodynamics visible to students. An unanticipated consequence was that watching data collection in real time also helped students understand the nature of graphs. When students used probes rather than recording data manually, they were more likely to accurately interpret a graph of a bicyclist going down a hill [speeding up] and then going up another hill [slowing down] rather than seeing the graph as an actual picture of a hill.

CLP recognized the importance of helping students to integrate their ideas. For thermodynamics, studies showed that students integrated more of their ideas when instruction featured an accessible “heat flow” model rather than a model based on molecular kinetic theory. A simulation, where students could conduct virtual experiments to determine the rate of heat flow in varied materials surprised many students, who initially thought that heat flowed at the same rate in all materials. This visualization also helped students interpret their sensory experiences, when touching metal and wood objects in hot and cold environments. They could develop the notion that they were detecting the rate of heat flow between their hand and the object, realizing that metals were better conductors than wood, and comparing the temperature of their hand relative to that of the object. The teacher, in the CLP classroom, asked his students to compare how metal and wood objects feel on a hot day at the beach and on a cold day in the mountains. CLP labeled ideas that promoted integrated understanding pivotal cases. Pivotal cases feature controlled experiments (such as comparing materials in hot and cold contexts), illustrate situations that are likely to reoccur in the lives of students, stimulate discussion among students by supporting narrative accounts of experiences, and connect multiple scientific principles (such as connecting insulation and conduction to thermal equilibrium).

CLP conducted a longitudinal study that led to four principles that guide the design of new curricular activities and materials (Linn and Hsi 2000):

Make science accessible – calls for encouraging students to connect new knowledge to preexisting knowledge and appreciate the relevance of science to their lives. In CLP, students connected their investigations of thermodynamics to personal experiences, like packing lunches so that food stays hot or cold.

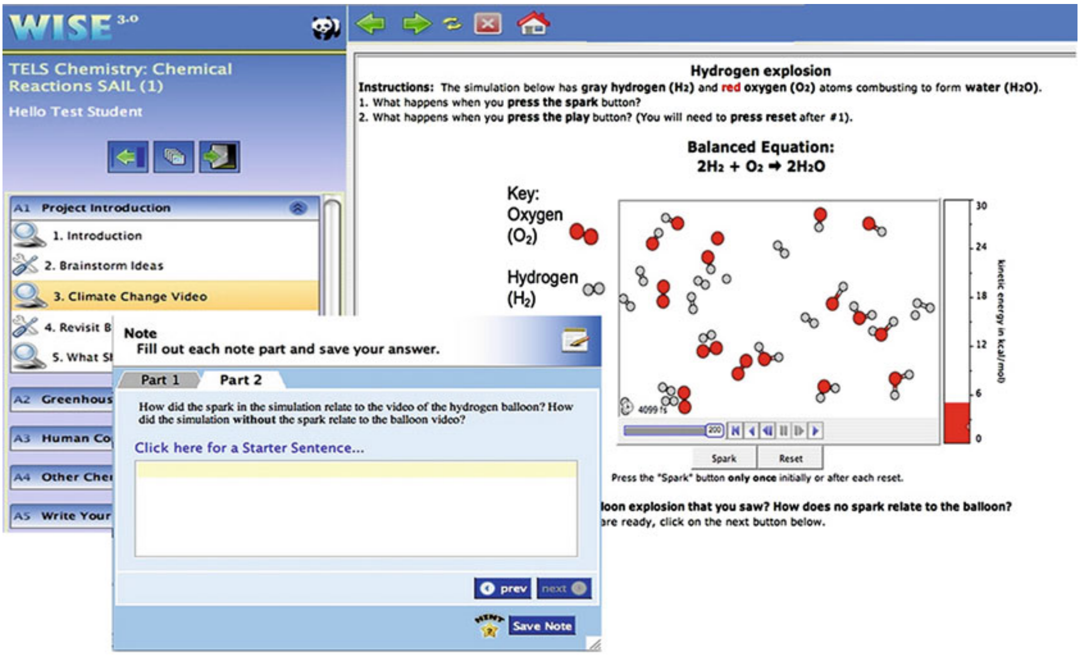
Make thinking visible – refers to both the process of modeling how ideas are connected and organized in normative understanding and the process of students articulating their own ideas to help teachers monitor progress. In CLP, our use of visualizations, pivotal cases, and real-time data collection with probes all served to make thinking visible.

Help students learn from others – calls for negotiating ideas with others, in order to jointly explain complex ideas. To achieve this in CLP, students worked in pairs to interpret their experiences. Often they appropriated ideas from their partner to advance their understanding.

Promote autonomy and lifelong learning – involves helping students monitor their progress and reflect on their ideas. To achieve this in CLP, students were guided by an inquiry cycle, reflected on their ideas in short essays, and explained their ideas to others in classroom debates. Thus, when students articulated their ideas, they benefitted in two ways. First, they reconsidered and often reorganized their ideas. Second, they made their ideas visible for others.

Computer as Learning Partner

Powerful classroom computers and Internet connectivity enabled the development of the Web-based Inquiry Science Environment (WISE) to further explore the computer as a learning partner. WISE logged in students and captured records of their inquiry activities, linking to embedded assessments and virtual experiments using an inquiry map (see Fig. 1). Using WISE, the research partnership could design comparison studies where students conducted different activities within the same classroom. Comparison studies revealed difficulties students had interpreting visualizations or



Hydrogen explosion

Instructions: The simulation below has **gray hydrogen (H_2)** and **red oxygen (O_2)** atoms combusting to form **water (H_2O)**.
1. What happens when you **press the spark** button?
2. What happens when you **press the play** button? (You will need to **press reset** after #1).

Balanced Equation:
$2H_2 + O_2 \rightarrow 2H_2O$

Press the "Spark" button **only once** initially or after each reset.

loon explosion that you saw? How does no spark relate to the balloon?
are ready, click on the next button below.

Note
Fill out each note part and save your answer.

How did the spark in the simulation relate to the video of the hydrogen balloon? How did the simulation without the spark relate to the balloon video?

Click here for a Starter Sentence...

Computers as Learning Partners: Knowledge Integration, Fig. 1 Screenshot of chemical reactions unit in WISE

conducting virtual experiments and supported our investigation of promising instructional sequences (Slotta and Linn 2009). A wide range of comparison studies included embedded and end-of-unit knowledge integration items that were scored using a rubric that emphasized the use of evidence to build an argument. Students generate short essays, concept maps, virtual experiments, and drawings, as well as annotations of scientific materials such as microscope slides to document their reasoning. These assessments contribute to learning by asking students to make sense of their ideas and explain them to others.

For example, in the *WISE Photosynthesis* unit, students explore how light energy is transformed into chemical energy and is stored as glucose, but have difficulty distinguishing among their views that energy from the sun is "used up," "disappears," and "gets stored in the chloroplast." Experiments comparing static and dynamic representations of photosynthesis and cellular respiration demonstrated that dynamic representations were better at promoting knowledge integration (Ryoo and Linn 2012).

In performing the *WISE Chemical Reactions* unit, students have multiple ideas about what happens between one side of the equation and the other. They often believe that "there are no intermediate states," that "all the molecules break into atoms and recombine," and that "extra atoms disappear." When students make drawings of the initial, final, and intermediate states of the reaction (i.e., to articulate their predictions) and interpret the visualization (Fig. 1), they gained a more integrated understanding than those who just conducted additional virtual experiments (Linn and Eylon 2011).

WISE researchers synthesized a knowledge integration instructional pattern, combining the comparisons studies and related research (Linn and Eylon 2011). The pattern has four processes:

Making predictions. When students make predictions before encountering new ideas, they articulate their repertoire of ideas. Asking for predictions acknowledges the individual backgrounds and experiences that students have and enables designers and teachers to appreciate the diverse ideas students bring to science class. By testing their predictions, students are guided to interpret the results of their investigations in light of their own ideas.

Adding ideas. The knowledge integration pattern calls for adding pivotal cases that students find accessible. It incorporates research showing that dynamic, interactive visualizations only succeed when combined with other knowledge integration processes including making predictions and distinguishing ideas.

Distinguishing ideas. WISE researchers found that students need to distinguish new ideas from existing ideas within their repertoire to fully integrate their understandings. For example, when students were asked to fill in four boxes to draw how a chemical reaction progresses, they tended to revisit the visualization to test their conjectures and add more normative ideas. Those who only conducted more experiments also watched the visualization additional times but did not pay attention to elements, such as lone atoms, that eventually were combined into molecules.

Reflecting. When prompted to reflect after encountering new ideas, students explain their reasoning and construct knowledge – both well-documented strategies for increasing learning outcomes. When combined with activities that support students' distinguishing among ideas, prompts for reflection and explanation ensure that students reconsider nonnormative ideas.

WISE investigations led to a set of design principles to help teachers and curriculum designers take advantage of the knowledge integration processes (Kali et al. 2008). For example, one principle calls for encouraging students to critique flawed experiments that require them to distinguish among ideas in their repertoire.

Computer as Teaching Partner

Embedded assessments can provide formative evaluation of student learning that also helps teachers refine their practice. In a busy classroom using computer-based materials, it is hard for a teacher to distinguish between a student who is learning intently by exploring a model or experiment and one who is just going through the motions or is confused. As materials become more sophisticated, it is increasingly difficult for teachers to play an active role in planning their delivery or enacting instruction within the classroom. WISE developed tools for teachers such as "flag student work" so they could monitor classroom activities and review student work to plan their next lesson.

The knowledge integration framework is also valuable for designing professional development programs to improve use of technology-enhanced materials. When teachers used the knowledge integration framework and evidence from student work to revise their instruction during a summer workshop, they were able to improve student outcomes the following year. A review revealed that, in general, when programs engaged teachers in the knowledge integration processes of making predictions about the effectiveness of instruction, introducing new ideas as pivotal cases, reviewing student work to distinguish among alternative teaching practices, and reflecting on their plans to implement the unit in the following year, they were more successful than programs lacking these elements (Gerard et al. 2011).

Computer as Inquiry Partner

WISE is taking advantage of new technologies such as natural language processing to explore how automated guidance, when added to proven online inquiry units, can augment teacher effectiveness and encourage students to integrate their ideas. By diagnosing the student's knowledge integration level within a reflection or other assessment, encouraging the student to revisit relevant visualizations or conduct a new activity, and asking the student to regenerate their argument, automated guidance can help students distinguish among their ideas. Comparison studies suggest that knowledge integration guidance is more effective than either specific guidance (identifying inaccurate ideas) or general encouragement (e.g., to add more evidence) for helping students build coherent understanding.

The CLP and WISE research programs have identified promising ways to ensure that all learners can succeed at science inquiry. Designing powerful pivotal cases that take advantage of visualizations and guiding students with the knowledge integration patterns have the potential to prepare scientifically literate citizens. The knowledge integration framework offers designers principles and patterns that can improve assessment, curriculum materials, instruction, and professional development.

Cross-References

- ▶ Argumentation
- ▶ Inquiry, as a Curriculum Strand
- ▶ Inquiry, Learning Through

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Concept Mapping

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Keywords

Graphic organizer; Knowledge map; Knowledge visualization

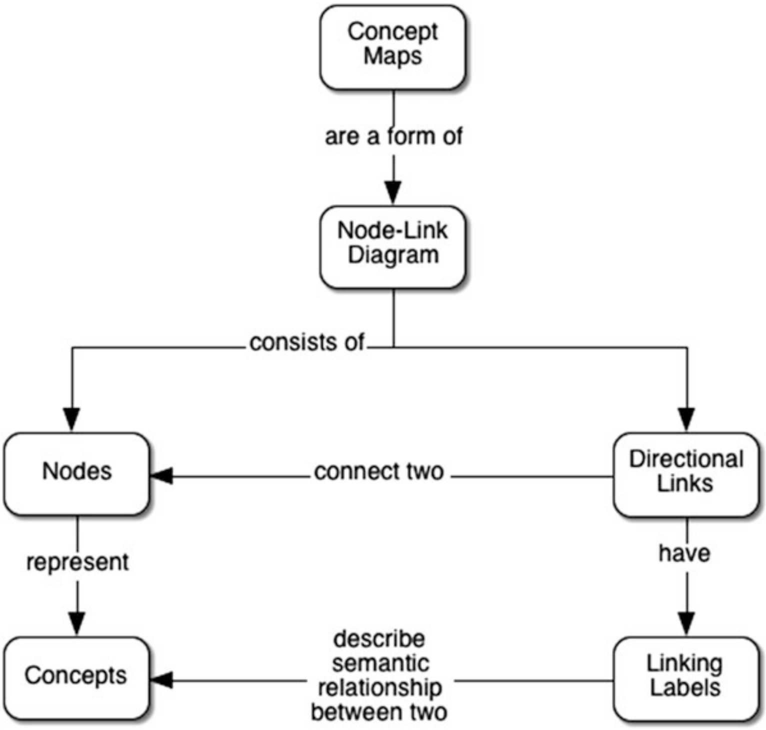
Definition

From the perspective adopted in this entry, a concept map is a node-link diagram showing the semantic relationships among concepts, where the process of constructing concept maps is known as "concept mapping." A concept map consists of nodes (concepts), arrows as directional links, and usually captions for each link that describe the relationship between nodes [see Fig. 1]. Concepts can be described as perceived regularities or patterns of events or objects, or records of events or objects. Two concepts connected with a labeled arrow can be described as a proposition. Concept maps are versatile graphic organizers that can represent many different forms of relationships between concepts. The relationship between concepts can be articulated in the link captions, for example "leads to" (causal), "consists of" (part-whole), "follows" (temporal), "is inside of" (spatial), "increases" (quantified), or "is different than" (comparison). Nodes (usually nouns) and linking phrases (usually verbs) can be interpreted as a semantic network of propositions.

Difference to Other Forms of Node-Link Diagrams

Various forms of node-link diagrams have been developed for educational purposes. Some of the earliest examples of node-link diagrams were developed by the Greek philosopher Porphyry of Tyros in the third century AD to graphically visualize the concept categories of Aristotle. Commonly used examples of node-link diagrams are mind maps, flowcharts, and concept maps. Mind maps, in which connections are unspecified associations represented by nondirectional lines without linking phrases, are often arranged in a radial hierarchy around a single central concept. Flow charts, first presented by engineer Frank Gilbreth in 1921, show the intermediate steps between input (e.g., problem) and output (e.g., solution) of a system. Flow chart connections are usually ontologically of the same kind, such as information, energy, time, or material. In

Concept Mapping, Fig. 1 Concept map about concepts maps (By Beat A. Schwendimann)



contrast, linking phrases in concept maps can represent any form of relationship (e.g., temporal, procedural, functional, subset, superset, causal, etc.) and topological arrangement (e.g., hierarchical, hub, decentralized network, circular, etc.).

Background

One theoretical perspective that influenced concept mapping is that of David Ausubel's assimilation theory [see "▶ Ausubelian Theory of Learning," "▶ Meaningful Learning"], which stresses the importance of individuals' existing cognitive structures in being able to learn new concepts. Inspired by this perspective, Joseph D. Novak and his research team at Cornell University developed concept mapping as a means to graphically representing concepts, based on their research on understanding changes in children's science knowledge (1984). With its emphasis on actively engaging learners in eliciting and connecting existing and new concepts, concept mapping is considered as being consistent with a constructivist epistemology, as it aims to support the elicitation of existing and missing concepts and to promote the construction of connections.

Construction of Concept Maps

Concept map setups can vary from open-ended to very constrained forms. Concept mapping tasks with few constraints can provide learners with a focus question while giving them free choice to select their own concepts and links. A "focus question," such as a how or why question, can help students to understand the purpose of the concept map activity and guide their concept map generation. A somewhat more constrained form of activity would provide learners with premade lists of concepts or link captions but give free choice of which concepts to connect. Highly constrained applications of concept mapping would perhaps provide learners with a skeletal network structure and premade lists of concepts or link captions, with which the learner fills in blanks within the structure. Concept maps can be constructed by hand using paper and pencil, flash cards, and post-its or by using computer software, of which there are many educational offerings, including Inspiration and CMap. Research indicates that concept mapping can facilitate the development and revision of concepts with software supports for hyperlinks (e.g., to Web pages or other concepts) and multimedia (Canas 2003). Concept mapping requires initial training to familiarize learners with the concept mapping principles and criteria for concept map evaluation.

Concept Maps and Learning

Concept maps have been applied as learning tools in many science disciplines, including chemistry, biology, earth science, ecology, astronomy, and medicine. They have been used with all ages from children to adults, using individual or collaborative activities, in asynchronous or synchronous formats. Meta-analyses have shown that concept mapping produces generally positive effects on student achievement and large positive effects on student attitudes (Horton et al. 1993; Canas 2003; Nesbit and Adesope 2006).

Concept mapping, especially in its more constrained forms, has also been found to be a reliable and valid form of assessment for changes in students' understanding of science concepts. Research comparing concept maps to multiple-choice tests indicates that concept maps assess different forms of knowledge (e.g., propositional or hierarchical). Concept maps can reveal students' knowledge organization by showing connections, clusters of concepts, hierarchical levels, and cross-links between concepts from different levels. Cross-links are of special interest, as they can indicate creative leaps on the part of the learner (Novak and Gowin 1984).

Concept maps can be analyzed either qualitatively or quantitatively. Quantitative analysis can include concepts, hierarchy levels, cross-connections, propositions, or network structure. The number of links and concepts, while easily countable, provides limited insight into a student's understanding. Propositions are more informative elements of a concept map and can be used to track changes in students' understanding. Proposition analysis can include all links or only a selection and can value all propositions equally or attribute weights differently. Research suggests that scoring only selected propositions can be more sensitive to measuring conceptual change because it focuses only on key concepts of the concept map (Schwendimann 2014). Concept map analysis often compares student-generated maps to an expert-generated map. This approach can provide instant and authoritative feedback but has limits in terms of capturing the wide range of alternative expressions of student understanding. Network analysis methods often focus on elements like network density or the connectedness of selected concepts. Qualitative analysis of concept maps can include changes in types of link captions or topographical analysis methods to describe the overall geometric structure of the concept map.

Applications of Concept Maps

Concept maps can be used in many ways in science education, for example, as tools for lesson planning, as advanced organizers, as learning tools for students, as online navigation interfaces, as knowledge management interfaces, or as assessment tools. Different explanations have been proposed to explain the observed benefits of using concept maps. Concept mapping can support eliciting existing concepts and connections and serve as a memory aid by off-loading them as external node-link diagrams. Concept maps can support learning science by identifying central concepts from different contexts. The explicitness and compactness of concept maps can help learners to maintain a "big picture" view. The "gestalt effect" of concept maps allows for the viewing of many concepts at once, increasing the probability of identifying gaps and making new connections. In a concept map, each concept is represented by only one node, and all connections related to that concept are presented in one location. Concepts derive their meaning in part from their connections to surrounding concepts. Visual chunking of related concepts or the arrangement of concepts in hierarchies can reveal epistemological structures. Compared to written linear summaries, clustering-related concepts into meaningful patterns can foster quick information retrieval, in part because concept maps use a simple syntax for propositions (node-link-node) and limited amounts of text to represent concepts. Concept mapping can be seen as a first step in ontology building and can also be used flexibly to represent formal arguments. Fast information retrieval from concept maps can be beneficial for collaborative activities. Viewing or generating concept maps may also promote the integration of concepts in both verbal and visuospatial memory. According to Paivio's dual coding theory, the verbal information and the visuospatial information of concepts reside in separate but potentially interlinked memories. Integrating verbal and visuospatial information of concepts can be simultaneously processed and provide alternative ways to retrieve concepts. Finally, the process of translating concepts from texts and images to a node-link format may foster deeper reflections about concepts and their connections and prevent rote memorization.

Limitations of Concept Maps

Similar to geographical maps, concept maps do not aim to include all possible concepts but rather only a selection of meaningful ones. Concept maps usually constrain connections between two concepts to a single relationship, which requires distinguishing and selecting between multiple possible relationships. Concept map construction requires an initial training phase to learn how to generate, interpret, and revise concept maps. Generating, revising, and evaluating concept maps can be time-consuming. More constrained forms of concept mapping can be faster and more reliably evaluated, but they offer limited freedom to express one's understanding. Also, the same concept or linking phrase could take on different meanings for different learners or contexts. Concept mapping activities can be beneficial to improve conceptual understanding but may have limited effects on basic recall.

Implications for Science Education

As a learning tool, concept maps can support eliciting scientific concepts and connections and can make students' organization of concepts visible to themselves and their peers and teachers. Graphic organizers, such as concept maps, can support the integration of students' isolated concepts toward a more organized, interconnected network of concepts. Research indicates that the implementation of concepts maps can shift the epistemological authority from the teacher to the student, reduce emphasis on right and wrong answers, and create visual entry points for learners of varying abilities. Findings suggest that concept mapping may be particularly beneficial for lower performing students by providing scaffolds (e.g., a selection of important concepts) and by modeling active inquiry. When introducing concept mapping, the teacher should make the possible benefits for the learner explicit: that they will help students to reflect, to communicate what would otherwise be incommunicable, and to retain a trace of what otherwise would disappear. Concept maps are cognitive artifacts that help elicit students' concepts and support self-explanations; but they can also be seen as social artifacts through which students communicate or make their ideas accessible to others. When concept maps are generated collaboratively, they become shared social artifacts that elicit existing and missing connections and spur discussion among students and teachers. The constraint to only one link between two concepts requires collaborators to negotiate, creating a genuine need to support arguments with scientific evidence.

Cross-References

- ▶ Alternative Conceptions and P-Prims
- ▶ Assessment: An Overview
- ▶ Concept Maps: An Ausubelian Perspective
- ▶ Conceptual Change in Learning
- ▶ Constructivism

- ▶ Meaningful Learning
- ▶ Mindtools (Productivity and Learning)
- ▶ Prior Knowledge
- ▶ Technology for Science Education: History
- ▶ Technology for Science Education: Research

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Concept Maps: An Ausubelian Perspective

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Keywords

Knowledge Map; Knowledge Visualization

Origin

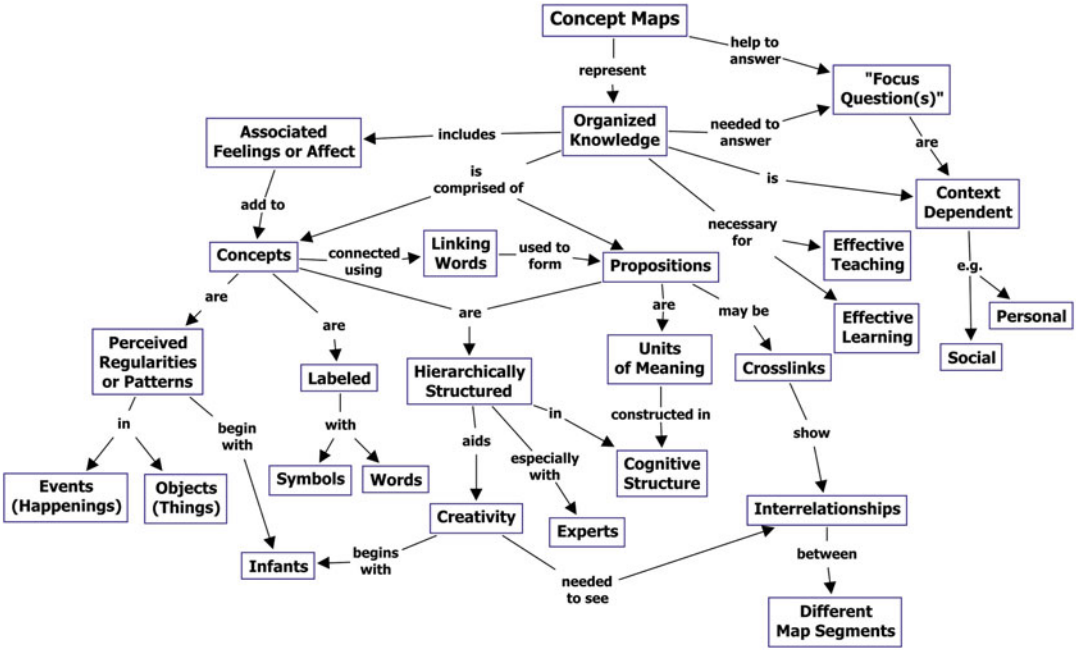
Concept maps were invented at Cornell University in the early 1970s in response to a need to explore growth in conceptual understanding of children in a 12-year longitudinal study of children's learning of science concepts (Novak and Musonda 1991). Audio-tutorial science lessons were provided to children in grades one and two (ages 6–8), and they were subsequently interviewed to assess their understanding of the concepts presented. Similar interviews were done with the same children as they progressed through school through grade 12. Building on Ausubel's assimilation theory of learning and constructivist epistemology, Novak's research group found they could summarize the interviews on a concept map and show specific changes in children's concept and propositional knowledge of basic science concepts over the 12-year span of the study. Figure 1 shows an example of a concept map and describes the nature of concept maps. Figure 2a, b show concept maps drawn from an interview with a child at the end of grade 2 (a) and for the same child at the end of grade 12 (b). The figures show clearly the child's growth in understanding of basic concepts dealing with the nature of matter and energy and also the good organization of this knowledge. These figures illustrate the Ausubelian principles of meaningful learning including subsumption of new concepts and propositions under more general concepts, acquisition of new superordinate concepts, and progressive differentiation of knowledge in this domain.

Application of Concept Maps to Learning How to Learn

Graduate students working on the 12-year study noted above found the use of concept maps helped them learn in the work they were doing. This led Novak to develop systematic approaches to learning how to learn and eventually to a book with this title (Novak and Gowin 1984). The book has subsequently been translated into Arabic, Chinese, Finnish, Italian, Japanese, Portuguese, Spanish, and Thai. Concept mapping and Ausubel's ideas about learning began to be used worldwide.

Development of CmapTools Software

In our early work at Cornell, we made concept maps mostly with pen and paper. While this

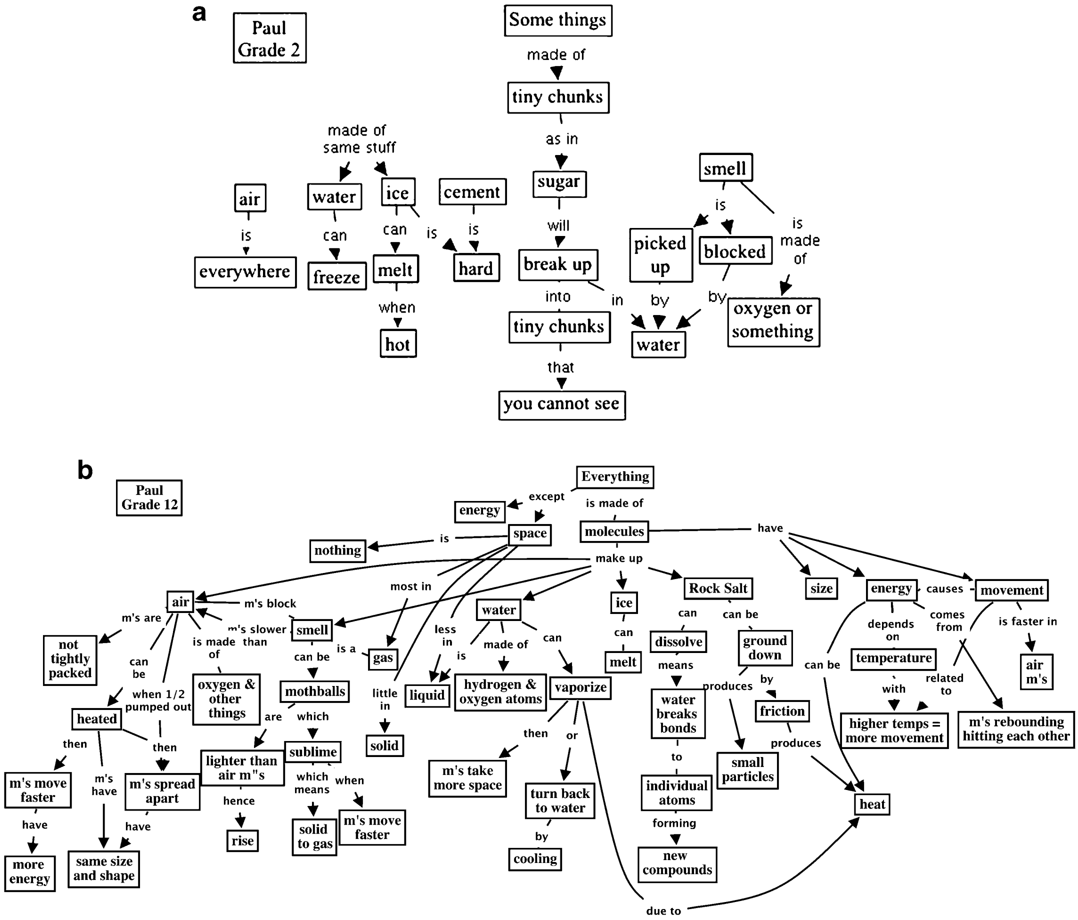


Concept Maps: An Ausubelian Perspective, Fig. 1 An example of a concept map

works well with small concept maps, it becomes very awkward with maps containing 50 or more concepts, especially as one chooses to make alterations to these maps. We used Post-itsTM notes in some of our work, and while these provide for easy team work and easy movement of concepts, changing linking lines and linking words often required completely redoing the whole concept map. As appropriate computer software became available in the early 1980s, we began to use this for preparing maps for publication, but at that time essentially all students lacked computers and/or the software to do concept maps.

In 1987, while on sabbatical leave at the University of West Florida, Novak began working with Kenneth Ford and Alberto Cañas, who later became Director and Associate Director, respectively, of the Florida Institute for Human and Machine Cognition (IHMC). Ford pointed out that the primary problem in the field of artificial intelligence, his specialty, was to find a way to represent knowledge and to extract knowledge from experts in a precise and reliable way. He saw concept maps as a solution to this problem and so began a collaboration that continues today. NASA, the Department of Navy, the National Security Agency, and other US federal and private organizations found the use of concept maps an excellent tool for capturing and archiving expert knowledge and for facilitation of team problem solving. With grants from these organizations, IHMC, under Cañas's leadership, developed excellent software for creating concept maps of the form shown above, CmapTools. This tool makes it easy to show individual concepts in nodes connected by linking lines with appropriate linking words attached and arranged hierarchically. Figures 1 and 2 were drawn using CmapTools, based on the original paper and pencil maps. The software is available at no cost at http://cmap.ihmc.us, a site that also provides access to numerous research studies and other documents that give additional information on concept mapping.

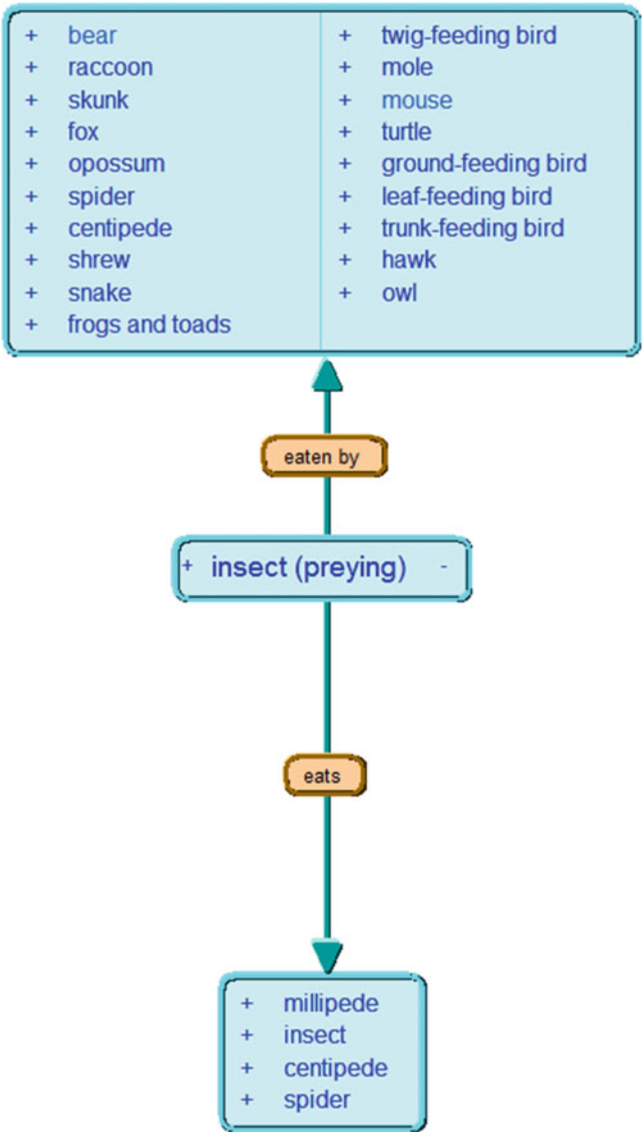
Fisher and her colleagues saw concept maps as a useful tool for identifying and changing student misconceptions/alternative conceptions (Fisher et al. 2000), and Fisher and Faletti created



Concept Maps: An Ausubelian Perspective, Fig. 2 (**a**) Concept map drawn from an interview transcript, grade 2 (age 7) student. (**b**) Concept map drawn from an interview transcript, same student as (**a**), now grade 12 (age 17) (Note how superordinate learning and extensive subsumption and integration of new concepts and propositions have occurred)

SemNetTM software in 1986 (also available at no cost at: http://www.biologylessons.sdsu.edu/license.html). Figure 3 illustrates some of the factual details identified by Fisher and her colleagues that need to be properly assimilated by biology students to overcome some misconceptions and build a valid knowledge structure.

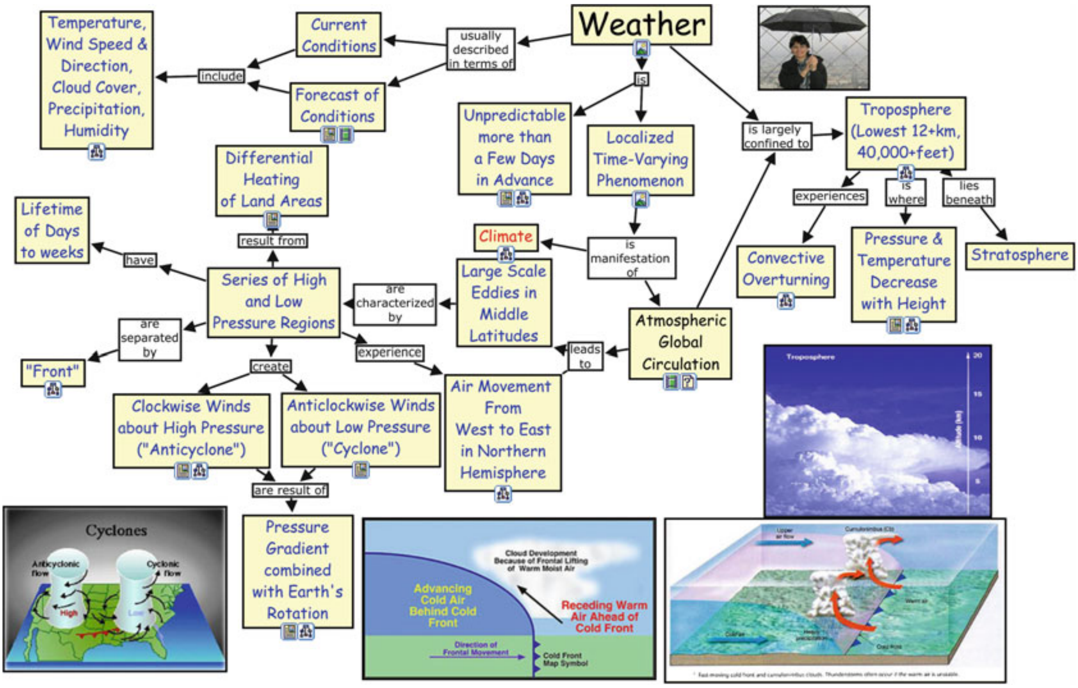
CmapTools has the unique, patented feature that allows a person to attach any digital resource to any concept on a map by simply dragging the icon for this resource to a target concept and dropping it on the concept. This resource becomes part of a "knowledge model" that is stored with the concept map. The resource can be opened by simply clicking on the icon for the resource type and selecting the desired resource. In this way, one can do more than just create a concept map; one can create essentially a digital knowledge portfolio with a broad range of digital resources linked into the map. Figure 4 shows an example of a concept map with resources attached, and inserts show some of the resources that can be accessed via icons at the bottom of concepts. The complete file of concept map and all resources is referred to as a "knowledge model." There are many such "knowledge models"; these can be accessed at http://cmex.ihmc.us.



Concept Maps: An Ausubelian Perspective, Fig. 3 A sample of concepts needed to assimilate properly to understand some biological relationships

Further Developments with Concept Maps: Focus Questions and Parking Lots

As our work with concept maps progressed, we found the clear identification of a focus question the concept map sought to answer was critically important, especially when working with individuals or groups that were seeking to solve some problem. A parking lot is a list of concepts suggested by an individual or group that they deem as important to answering the focus question. This step is usually relatively easy for individuals or groups and in some ways resembles what is done in mind mapping. After identifying pertinent concepts (say 15–20), these are ordered from the most inclusive, most general concept to the least inclusive, most specific concept. Then these concepts are used to begin building the concept map. If computer software is used, this is mechanically quite easy, since concepts from the list can be simply moved into the developing concept map, and then appropriate



Concept Maps: An Ausubelian Perspective, Fig. 4 A sample concept map on weather showing some of the resources that can be accessed via icons attached to concepts (From Briggs, with permission)

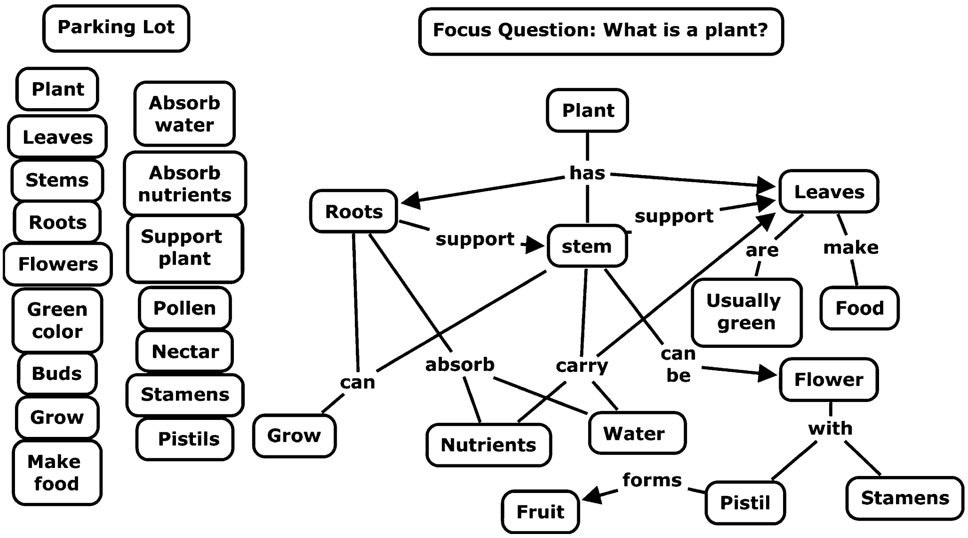
linking words can be added. Figure 5 shows an example of a concept map so created. This map can be elaborated by adding pictures, video clips, etc. Because of the importance seen in the development of a good focus question for good concept mapping, the CmapTools software has this built into its protocol.

Often, with older groups in particular, as they began to build a concept map, they see the original focus question is not actually the central question they are trying to answer. It is then common for a group to modify or even completely change their focus question as they began to map concepts and propositions pertinent to the question.

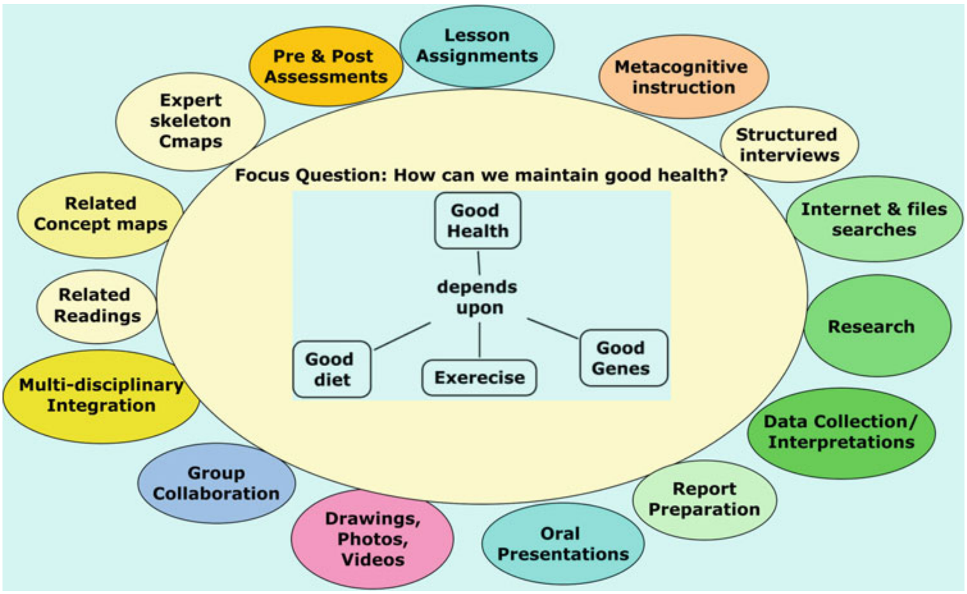
Focus questions may deal primarily with the structure of an object or an event of interest or they may deal with the process of creating an object or event. Sometimes when mapping a sequence of events dealing with some process, maps can be more cyclic or flow chart in form. Depending on the kind of question to be answered or the purpose of the concept map, the structure of a good concept map can vary (Derbentseva et al. 2006). However, we have found hierarchical structures to often be the most useful.

Concept Maps as Metacognitive and Metaknowledge Tools

Constructing a concept map requires a learner to identify key concepts in the material and to show meaningful relationships between concepts as explicit propositions. Moreover, to arrange these concepts into an appropriate structure takes further thought and action. To do this well, the learner must engage in relatively high levels of meaningful learning, and concept maps have been shown to be powerful aids for achieving high levels of meaningful learning in virtually every discipline and from preschool to adult research teams. The more learners engage in concept mapping, the more keenly they become aware of the central role that concepts play in meaningful learning and in understanding any



Concept Maps: An Ausubelian Perspective, Fig. 5 A concept map about plants, showing the focus question used to begin and a parking lot



Concept Maps: An Ausubelian Perspective, Fig. 6 Schematic showing how to employ a new model for education using CmapTools, via an expert skeleton concept map on health, WWW, and other resources (identified in smaller ovals) integrated together into one digital file

domain of knowledge. In short, they become better learners.

We often hear science defined as an organized body of knowledge, but seldom are we shown exactly what this means. As learners become skilled in concept mapping, they become acutely aware of the organized concept and propositional nature of science. If they also engage in science project work, they see sharply how concept and propositional knowledge guides the creation of new knowledge in any discipline. In short, they become aware of the nature of and construction of new knowledge. This consequence is part of the reason for concept maps being valuable as "metacognitive and metaknowledge tools." More generally, since tools that facilitate learning can also be seen and used as metacognitive tools, concept maps are important tools for developing metacognition. This is demonstrated by both the *Learning How to Learn* book (Novak and Gowin 1984) and by the value of concept maps as one significant strategy in the classroom-based approaches to enhancing student metacognition in the Project for Enhancing Effective Learning.

CmapTools Make Possible a New Model for Learning

As noted above, from 1987 and continuing today, IHMC worked to refine and add functionality to what evolved into CmapTools. Also during this period, there were exponential increases in computer power in personal computers and materials available on the World Wide Web. Among the features developed in CmapTools were means for easy collaboration between learners and mapmakers permitting easy collaborative learning and virtually unlimited information on any topic. In 2004, Novak and Novak and Cañas proposed a new model for education that employs the power of collaborative learning utilizing CmapTools, a wide range of learning activities, the relatively unlimited WWW resources, and expert skeleton concept maps to scaffold early learning.

The idea behind expert skeleton concept maps is to provide some initial conceptual guidance to a team of 2–4 learners who subsequently engage in a variety of learning activities, as depicted in Fig. 6. Prepared by experts, the expert skeleton concept maps serve to define an important domain of knowledge to be studied and also provide cognitive scaffolding to make it easy for an accurate starting point for organizing knowledge in this domain. Learners who have used expert skeleton concept maps in this way have reported considerable merit in this use, particularly in impact on learning of concepts. They value expert skeleton concept maps; their value in reducing the problem of prior misconceptions still needs to be researched. The teacher's role is primarily to serve as a guide and coach and also to model her/his own learning as the student's progress on their projects. As students do WWW searches, their own interviewing of experts, experimentation, reading, etc., they record their progress using CmapTools to create a comprehensive knowledge model. Figure 6 illustrates how, using CmapTools and building on an expert skeleton concept map, materials from all other forms of learning can be combined into a digital knowledge portfolio. These can be stored for future reference or used to further elaborate understanding in this domain of knowledge. Such portfolios have powerful potential, including if used from an early age and then throughout schooling.

Cross-References

- ▶ Ausubelian Theory of Learning
- ▶ Concept Mapping
- ▶ Conceptual Change in Learning
- ▶ Constructivism
- ▶ Cooperative Learning
- ▶ Meaningful Learning
- ▶ Metacognition and Science Learning
- ▶ Mindtools (Productivity and Learning)
- ▶ Multimodal Representations and Science Learning
- ▶ Project for Enhancing Effective Learning (PEEL)

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Conceptual Change

▶ Alternative Conceptions and Intuitive Rules
▶ Alternative Conceptions and P-Prims
▶ Alternative Conceptions/Frameworks/Misconceptions
▶ Conceptual Change in Learning
▶ Learning Progressions

Conceptual Change in Learning

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Keywords

Cognition; Conceptual Change; Conceptual Understanding

Introduction

With his idea that the most important factor influencing learning is what a learner already knows, Ausubel could in some ways be argued to have started a new and still ongoing research area at the end of the 1960s: conceptual change. Since then, a very large volume of research has addressed students' understanding of a given topic and how it changes with different ages or as a result of instruction. The notions of "concept" or "conception" are used to describe a certain piece of knowledge which has to be learned by a student (concept) or refer to the understanding a student holds at a particular point in time (conception, alternative conception, or misconception). "Conceptual change" describes and assesses how naïve, nonscientific, or "wrong" conceptions develop to become improved, scientific or "correct" concepts. Predominantly, research on conceptual change is based on a constructivist epistemology assuming that concepts are a result of personal or social constructions.

During the last 40 years, strong evidence has been gathered that students entering a science classroom typically hold conceptions which are very different to those of scientists. In order to adapt instruction to students' prior ideas, research has aimed to assess students' conceptions in various science topics. The body of literature describing content-specific conceptions involves studies that number, literally, in the thousands and is still noticeably increasing. Issues addressed are not only subject-matter concepts but also students' ideas about nature of science (NOS) or scientific inquiry (SI) and their concepts about learning.

Even though conceptual change has a relatively long research tradition and some basic assumptions are shared, there are also noticeably differences between frameworks used to describe conceptual change (e.g., Duit and Treagust 2003; Scott et al. 2007). Coming to terms with conceptual change research is not only difficult because theoretical frameworks differ, but also because the focus on concepts and conceptual change can be very different. Concepts and conceptual change can be addressed from a social or an individual perspective. Whereas the first perspective aims to describe how communities (e.g., scientists, engineers, or classmates) create, develop, and share concepts which are new for the community (Thagard, pp. 374–387 in Vosniadou 2008), the latter describes how concepts are developed by individuals (e.g., scientists or students). Furthermore, conceptual change research can address expert learning (scientists, engineers) or novice learning (students). In science education research, the vast majority of work in conceptual change aims to describe and explain students' difficulties in establishing fundamental scientific concepts by adapting an individual perspective. In addition, the transition from a naïve to a more scientific

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This entry is dedicated to Phil Scott.

understanding is investigated, and how this process can be best promoted. In this line of research, it is stressed that conceptual change should not be confused with the notion of learning: Conceptual change is part of learning but not all learning is conceptual change (e.g., Vosniadou, p. 1 in Vosniadou 2013).

Even though science education researchers can share the observation that students hold particular misconceptions in various topics, the assumed reasons why these misconceptions exist and why learners are resistant to change cannot be observed directly. As a consequence, theoretical frameworks have taken different routes depending on the assumptions as to what are the main barriers for conceptual change. Among the different approaches which can be identified, four frameworks are frequently mentioned: the "classical conceptual change approach" which was introduced during the 1980s and developed further by Strike and Posner (1992), Vosniadou's "framework theory approach" (Vosniadou et al., pp. 3–34 in Vosniadou 2008), Chi's "categorization approach" (Chi, pp. 61–82 in Vosniadou 2008), and diSessa's "knowledge in pieces approach" (diSessa, pp. 29–60 in Limón and Mason 2002). Even though these four frameworks frequently appear in association with conceptual change, other frameworks can be identified which also seem to describe issues of conceptual change, for instance, Marton's "phenomenographic approach" (Marton and Pang, pp. 533–559 in Vosniadou 2008), Stavy's "intuitive rules approach" (Stavy et al., pp. 217–231 in Limón and Mason 2002), or von Aufschnaiter's "level approach" (von Aufschnaiter and Rogge 2010). Even though the frameworks differ, they all have a primary focus on the same three broad questions:

- What are concepts? Is there any other knowledge or understanding which is "more" than a concept or "less"?
- What are the mechanisms by which conceptual change takes place? Why is particular conceptual understanding difficult for students to achieve?
- How can conceptual change be promoted?

Within the following sections, issues addressed with these three questions are discussed with reference to the frameworks offered by Chi, diSessa, Strike and Posner, and Vosniadou, as well as, where it applies, Marton, Stavy, and von Aufschnaiter.

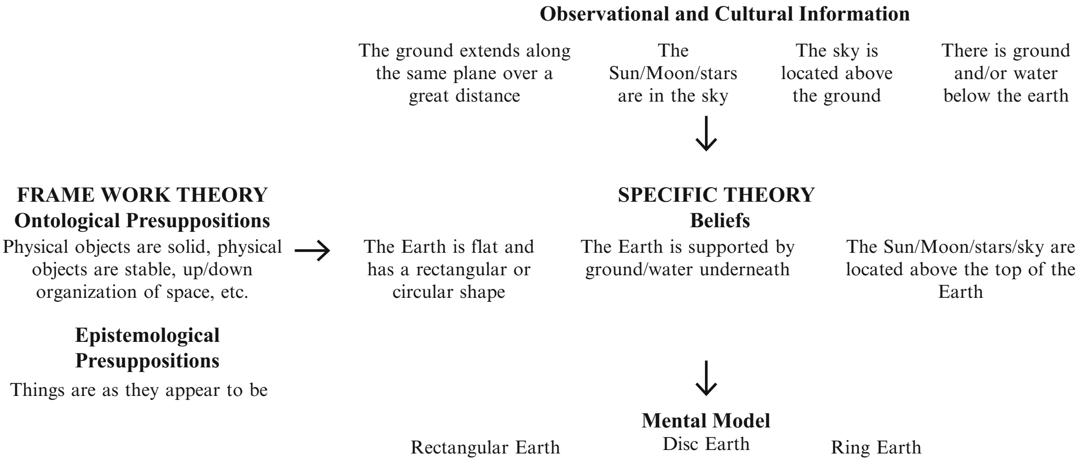
Concepts

Within the different frameworks, different notions for concepts are used (for instance, belief or coordination class), and also understanding of the same terms (such as mental model) can vary. Thus, frameworks cannot be compared easily. However, common to most frameworks is the (usually implicit) idea that concepts are specific mental elements and refer to an understanding of certain principles (e.g., von Aufschnaiter and Rogge 2010). Moreover, most frameworks assume that human cognitive structure is composed of more than one type of mental element. The notion of grain size is often used to express that "smaller" and "larger" mental elements are considered (see Table 1). Grain size can differ in two ways: Typically, mental elements of smaller grain size form an interrelated set to establish mental elements at greater grain size which have the character of networks. Grain size can also refer to the context specificity of mental elements. Here, elements at smaller grain size refer to a particular context whereas mental elements at larger grain size are assumed to encompass varying contexts. Common to the majority of the frameworks is the idea that the cognitive structure described is central in organizing individual thought and learning (Strike and Posner 1992, p. 148).

In Strike and Posner's framework, the cognitive structure is composed by a conceptual ecology which comprises learners' knowledge and of which concepts are constituent parts. Different sorts of concepts are integrated into the conceptual ecology, such as organizing concepts, analogues concepts, metaphors, or epistemological beliefs. Vosniadou describes a more elaborated idea of the cognitive structure (Fig. 1) in which

Conceptual Change in Learning, Table 1 Grain size of mental elements described in different frameworks

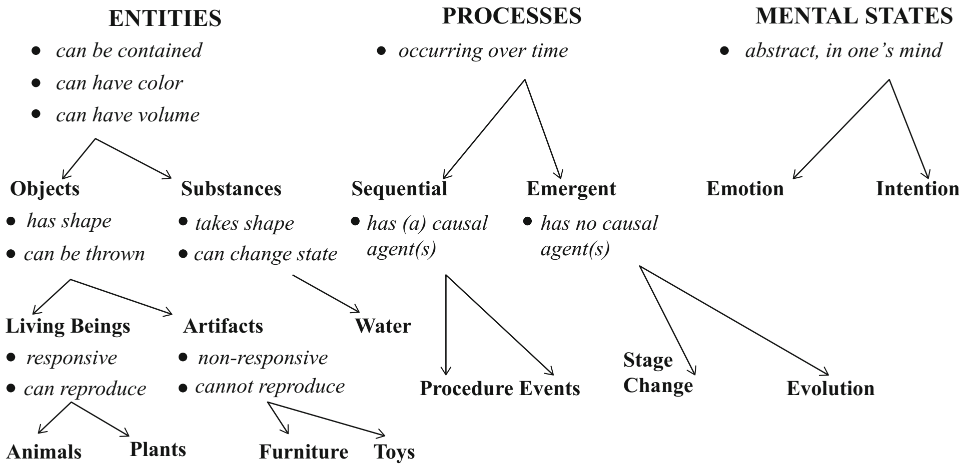
Approach	Grain Size Small	⟶			Grain Size Broad	Grain size increases with
Chi	belief	—			mental model	interrelationship between elements; classification can also differ (ontological categories or "lower" categories, see Figure 2)
diSessa	p-prim	—	readout strategy, causal net	—	coordination class	interrelationship between elements (only coordination classes have the status of concepts)
Strike & Posner	concept	—			conceptual ecology	interrelationship between elements
Vosniadou	mental model	—	belief (part of specific theory)	—	presupposition (part of framework theory)	reducing context specificity (only beliefs and presuppositions have the status of concepts)



Conceptual Change in Learning, Fig. 1 Conceptual structure described by Vosniadou (similar to Vosniadou et al., p. 8 in Vosniadou 2008)

unspecific framework theories have an impact on specific theories in which beliefs have the status of concepts. From these theories, mental models are formed while individuals make sense of the current situation (such as a task, a problem, or a question).

In diSessa's approach, the cognitive structure is composed of coordination classes which have the status of concepts. These coordination classes are an integration over causal nets as a knowledge base and readout strategies as ways in which current situations are observed. As very basic



Conceptual Change in Learning, Fig. 2 Ontological trees with hierarchical and lateral categories described by Chi (similar to Chi, p. 58 in Vosniadou 2013; see also Chi, p. 64 in Vosniadou 2008)

mental elements, unrelated phenomenological primitives (p-prims) are described which are applied to everyday situations. An example of a p-prim is "force as a mover." In similar ways, Stavy assumes that activities of learners are often established from underlying intuitive rules. In contrast to diSessa, Stavy argues that only a limited number of intuitive rules can be identified, whereas diSessa assumes that a very large number (several hundreds) of p-prims exist.

In Chi's framework, a mental model is an organized collection of beliefs and has either the status of a concept or a system of concepts. In addition to distinguishing between mental models and beliefs, Chi argues that mental elements refer to ontological categories which classify as to whether the mental model and its beliefs are about entities, processes, mental states, or another category not yet identified (Fig. 2). Different ontological categories do not belong to the same tree (capitalized terms in Fig. 2) whereas lateral properties do. Categories of different trees or different branches do not share properties, for instance, a tennis match can last 200 min (processes) but cannot be green (entities). Thus, the network character in Chi's approach has a more hierarchical layout than typically described in other frameworks. As a consequence, ascribing a grain size to ontological categories (see Table 1) does not make much sense as these are used to classify mental models and beliefs which themselves have different grain sizes.

Research Debates About These Frameworks

(a) *Coherency of cognitive structures*

Among different ideas as to what limits students' understanding of science concepts, two distinct reasons are frequently discussed. For many researchers, an individual cognitive structure is composed of a coherent set of mental elements which have been established via repeated everyday experiences and are therefore stable and resistant to change (e.g., Chi, Strike and Posner, Vosniadou). On the other hand, some researchers argue that students' conceptual understanding is limited because the underlying conceptual structure is not very coherent. Even though there is an ongoing debate about the issue of coherency (e.g., diSessa, pp. 31–48 in Vosniadou 2013), there is not as yet any resolution between these two clearly contrasting positions. It has to be stressed that empirical evidence aiming to clarify the issue as to whether a learner's knowledge base is coherent is difficult to gather as the underpinning assumptions about conceptual structures heavily influence how evidence is gathered and interpreted.

(b) *Mental elements versus situated constructions*

The large majority of conceptual change frameworks describe specific mental elements which are assumed to determine individual activity (e.g., Chi, diSessa, Posner and Strike, Vosniadou; see Table 1). In contrast, some researchers argue that concepts are constructed from moment to moment and refer to ways in which a particular situation is experienced (e.g., Marton, von Aufschnaiter). Thus, these latter researchers do not claim any specific layout of a cognitive structure; rather, they investigate variability and stability of a learner's ongoing activity. They also stress that research needs to take care that a learner's utterance is not interpreted from the researchers' point of view (first-order perspective) but needs to be investigated from the learner's point of view (second-order perspective).

(c) *Usefulness of prior conceptions*

Conceptual change research typically focuses on those conceptions which are "wrong" (misconceptions) and have to be developed to more scientific ("correct") concepts. Thus, research is oriented towards learners' mistakes rather than towards the potential of their initial ideas (Halldén et al., pp. 509–532 in Vosniadou 2008). With their focus on areas in which students typically hold misconceptions, the frameworks are also limited in their power to explain why sometimes correct conceptions are established and what exactly differentiates situations with successful concept formation from those in which misconceptions are established. In order to have a more productive approach towards students' conceptions, those aspects of existing conceptions which can be used successfully to develop a student's conception further should be understood and taken into account.

Conceptual Change

The notion of conceptual change covers the description and analysis of how a learner or a group of learners (including expert learners) progress from prior conceptions to disciplinary or new scientific knowledge. In science education research, typically students' conceptual change is investigated by interpreting their written answers or statements, utterances, and/or drawings. Overall, two fundamentally different approaches can be identified. Those researchers who model a cognitive structure infer specific mental elements from students' products. Afterwards, these elements are classified, partly by using content-specific categories (e.g., diSessa, Vosniadou; see Fig. 1) or by more general categories (e.g., Chi; see Fig. 2). Researchers, who do not aim to describe cognitive structures which determine individual activity, classify students' products and utterances directly. Again, classification can either be content specific (e.g., Marton) or using more general categories (e.g., von Aufschnaiter).

In order to distinguish conceptual change that is more likely to occur or is less demanding for a learner from change which requires larger revisions, some authors introduce the distinction between "weak" and "strong" restructuring. Similar to the idea of grain size, "weak" revisions (also labeled as "assimilation" or "conceptual capture") are considered to be smaller and/or less demanding, whereas "strong" revisions ("accommodation" or "conceptual exchange"; see Duit and Treagust 2003) are considered to heavily affect the knowledge base and should therefore be harder to achieve. The distinction between weak and strong can be used to provide an overview about conceptual change dynamics described in different frameworks (see Table 2). Table 2 also contains some information about the conditions seen to be needed for conceptual change which are described in the different frameworks. It should be stressed that the overview in Table 2 is meant to give a brief introduction and serve as an orientation. As such, it cannot communicate all details of the different frameworks.

Concepts and conceptual change are typically assessed by interviews or tests. A widely known example of the latter is the "Force Concept Inventory" which was initially developed by Hestenes,

Conceptual Change in Learning, Table 2 Brief overview of conceptual change described in different frameworks

	Weak restructuring	Strong restructuring	Remarks
Chi	*Revision and transformation*: False beliefs and flawed mental models (“inaccurate misconceptions”) are revised and transformed	*Schema creation and categorical shift*: Not yet established (ontological) categories are created and/or “incommensurate misconceptions” assigned to another category	If information is only added to belief/mental model, this is not considered as conceptual change Missing categories and tree swapping between ontological categories are demanding
	Conditions of conceptual change: Weak restructuring can be based on refutation; strong restructuring requires information on alternatively available categories and may require to build (a) new category/categories		
diSessa	*Development of a “sense of mechanism”*: Priority of p-prims being activated in specific situation changes (cuing priority), development of new p-prims, or established p-prims are expanded to more situations	*Development of coordination classes*: Causal nets or readout strategies are expanded, integration of causal net and readout strategy is improved, or coordination class can be aligned to a larger number of situations	Learning difficulties can be caused by single p-prims, not-well-established causal nets, or readout strategies Conditions for conceptual change not described in detail
	Conditions for development of coordination classes: Causal nets emerge when coherency across p-prims is established		
Marton	*Development from undifferentiated to differentiated way of experiencing*: More aspects of a phenomenon considered or more interrelation of aspects, reaching higher levels of ways of experiencing		Does not differentiate between weak and strong
	Conditions for development of ways of experiencing: Create focus on specific aspect of phenomenon (relevance structure) and vary aspect systematically		
Strike and Posner	*Assimilation*: Integration of a new concept into existing cognitive structure (alternatively: conceptual capture, Hewson 1981)	*Accommodation*: Major revision of existing cognitive structure in order to establish new conceptual understanding (alternatively conceptual exchange, Hewson 1981) *Conditions for accommodation*: Dissatisfaction with prior conception, new concept has to be intelligible, plausible, and fruitful	Description based on Piagetian theory and on philosophy of science Accommodation should not be confused with abrupt change, can be gradual and slow, but results in major revisions
von Aufschnaiter	*Development of concepts*: From exploration (level I) to formation of intuitive rules (level II) to the development of phenomenon-based concepts (level IIIa) which are established by generalizations over concrete experiences. Model-based concepts (level IIIb) are developed late in learning processes. Iteration in levels constitute learning dynamics		Does not differentiate between weak and strong Model-based concepts are considered being more difficult for learners Understanding can be “correct” or “incorrect” at all levels
	Conditions for conceptual development: Establish experiences that match the concept to be developed, create opportunities to rediscover already “established” concepts, do not introduce model-based concept at early stages of learning of particular content		
Vosniadou	*Enrichment*: New information is added to existing cognitive structure without alteration of structure	*Revision/replacement*: If new information is in conflict with existing conceptual structures, either elements or their interrelationship have to be revised/changed *Conditions for conceptual change*: Rather than a mental model itself, beliefs and presuppositions have to be changed; metacognitive reflections are important for this change	Revision of framework theory more demanding than revision of specific theory Revision slow and gradual because of stability of beliefs and presuppositions

Wells, and Swackhamer; its revised version was developed by Halloun, Hake, Mosca, and Hestenes and is available online (http://modeling.asu.edu/R&E/Research.html [accessed October 7, 2013], background articles can also be downloaded from that website). A prominent example of conceptual change interviews is Vosniadou's work about children's mental models of the earth (e.g., Vosniadou et al., pp. 3–34 in Vosniadou 2008). Both approaches, tests and interviews, seek to identify individual conceptions and, often via a pretest-posttest design, how these change as a result of instruction. Furthermore, conceptions of individuals at different ages or grades are often compared. Whereas interviews are often chosen to explore details of students' conceptions with a limited number of participants, tests are widely used to investigate students' conceptions with a large number of participants. Here, multiple-choice formats which offer common student misconceptions along with scientific answers can be analyzed objectively and quickly.

Research Debates About Conceptual Change

(a) *Replacement versus revision*

Even though the notion of "conceptual change" implies that prior concepts are replaced by scientific conceptions, it is widely accepted that conceptual change needs to be regarded as a more gradual and slow process (see also last column in Table 2 and Duit and Treagust 2003). Further, even if a scientific concept is already established, learners (and experts) may very well still use a prior/alternative conception depending on the problem or the context with which they are dealing. It is assumed that during learning, the status a specific prior conception has for a learner decreases over time while the status of a more scientific concept increases (e.g., Hewson 1981; see also the idea of cuing priority of p-prims in diSessa's framework).

(b) *Lacking focus on processes of conceptual development*

As noted above, conceptual change is typically either assessed by comparing results of interviews or tests between individuals of different age/experience or assessed pre- and post-intervention. These procedures can detect change as a result of instruction, experience, or age but they cannot inform research and practice about either the processes by which change has taken place or how new concepts have evolved. So far, only a limited number of projects have paid attention to the development of concepts while students learn (diSessa, p. 58 in Vosniadou 2008; von Aufschnaiter and Rogge 2010). It is noticeable that ideas on how to promote conceptual change (see below) and interventions based on these ideas are only rarely assessed by addressing the processes by which conceptual change occurs. Thus, for effects detected it is not fully clear which specific component of the intervention will have caused the effect. Also, information about what exactly "gradual" and "slow" might empirically mean is still lacking.

(c) *"Cold" conceptual change*

Conceptual change has frequently been criticized for its dominant focus on cognition. Pintrich and others (1993) have argued that this kind of research is about "cold conceptual change," paying little attention to emotional and motivational factors or the social environment which can affect conceptual change (see also Strike and Posner 1992). These noncognitive factors will help to understand why learners who seem to have a very similar knowledge base progress differently in their conceptual understanding. Assessments for conceptual change have also been criticized because they do usually not include interaction with peers which can have an effect on which understanding is demonstrated by a learner. Furthermore, as to whether concepts identified within a specific context can be transferred to other contexts (within the same topic) or are activated under varying social conditions is rarely investigated (see also diSessa, pp. 43–51 in Limón and Mason 2002).

Promoting Conceptual Change

In order to develop approaches for promoting conceptual change, it is helpful to analyze first why some conceptual change seems to be more demanding or difficult for learners (see also Table 2, last column). Some researchers argue that the stability of conceptual structures which already have a high integration makes the development of different structures difficult (Strike and Posner, Vosniadou). However, these researchers might not be able to explain well why knowledge which is completely new to a learner and not in conflict with existing ideas (especially likely for younger children) can still be difficult to learn. Other researchers, in contrast, assume that learning is challenged by the integration of unrelated elements (e.g., diSessa). These researchers might struggle with explaining why contradictory knowledge (at the same grain size) can also be difficult. For Chi, categories of the different ontological trees (see Fig. 2) over which a learner does not have command or assignment of ideas to a wrong category are major learning obstacles.

Across the different frameworks, several researchers stress that misleading, missing, or incomplete everyday experiences can cause learning difficulties. These existing and missing prior experiences may, for instance, cause a learner to create synthetic models being a mix of correct and incorrect ideas or the learner might add information rather than revise ideas (Chi, Vosniadou). In addition, prior experiences are assumed to often hamper a learner in focusing on relevant aspects of a situation (diSessa, Marton, von Aufschnaiter). Von Aufschnaiter and Rogge (2010) also stress that the nature of specific scientific concepts makes them difficult per se: Concepts that cannot be extracted from observable features (e.g., the concept of energy) are called model-based concepts. It is argued that learners fairly often do either not grasp these scientific concepts or misunderstand them. Researchers who adopt a Piagetian theoretical position may argue that children cannot establish particular concepts because of lacking general cognitive abilities to reach a formal operational stage. However, empirical evidence indicates that conceptual understanding can be reached at fairly young ages.

Even though different ideas exist as to what makes conceptual change difficult for learners, it is widely assumed that in order to promote conceptual change, learners need to be exposed to cognitive conflict (see also Table. 2 “Conditions for. . .”). Based on prior work, Strike and Posner (1992; see also Duit and Treagust 2003; Hewson 1981) have introduced four conditions necessary for conceptual change: (1) First a learner needs to be dissatisfied with his/her existing conception. Dissatisfaction is likely to occur if conflicting information is offered or problems cannot be solved successfully with existing conceptions. (2) Then the new concept which is introduced must be intelligible to the learner, (3) the new concept must be plausible, and (4) the new concept needs to be fruitful in helping a learner to solve problems. The more these four criteria are fulfilled during learning, the more likely it is that conceptual change will occur and scientific concepts receive a higher status for a learner (Hewson 1981; see also Duit et al., pp. 631–632 in Vosniadou 2008). However, it should be noted that how to identify which information is likely to be intelligible or plausible at a specific stage in learning is not yet well described. In addition to establishing cognitive conflict, it is often stressed that metacognition is an important process for a learner to become aware of the conflict (Chi, Stavy, Strike and Posner, Vosniadou). During metacognition, the differences between individual and disciplinary concepts should be made explicit and reasons should be identified why a learner holds a particular conception. In some contrast to other approaches, both Marton’s and von Aufschnaiter’s frameworks do not have a primary focus on cognitive conflict but rather stress the importance of specific experiences. For conceptual change, they argue, specific variations in phenomena are considered to help a learner to discover or “discern” (Marton) underpinning patterns and rules.

It is obvious for the frameworks described that conceptual change is considered as an individual process. However, as already mentioned at the beginning of this entry, conceptual change can also be observed and assessed among a community of (expert) learners. An argument for the common individual focus on conceptual change is the reference to constructivism:

Individual meaning making can be shaped but not determined by any social situation or artifact. On the other hand, individual contributions to a social environment change the environment and the artifacts everyone can use for his/her own constructions. Therefore, conceptual change has always a social component (see debates about "cold conceptual change" above). This interplay between a social and an individual plane for conceptual change and the necessity to create an optimal difference between what an individual knows and the knowledge of a community to which the individual can adapt is sometimes described with Vygotsky's zone of proximal development.

Research Trends in Conceptual Change

Over the last 30–40 years, conceptual change research has covered several science topics in great detail. These include mechanics and electricity in physics, the particle model in chemistry, and students' understanding of evolution in biology. However, various topics are not yet fully examined which are currently explored, for instance, students' understanding of radioactivity. Identifying fundamental concepts and how these have been developed by scientists and students does not exclusively belong to science education. Thus, conceptual change research has been expanded to other areas such as mathematics or social sciences. By expanding conceptual change research to domains other than science, the validity of frameworks which use categories not bound to specific content (e.g., Chi's categorization approach or von Aufschnaiter's level approach) can be analyzed.

In addition to expanding conceptual change to other topics and subjects, the focus has become more developmental: Rather than just identifying incorrect conceptions and aiming to change them to correct conceptions, the necessary and important intermediate steps are considered. Research on learning progressions takes into account that conceptual development is more a gradual process than a sudden shift from naïve to scientific ideas. Approaches towards learning progressions cover both the analysis of fundamental concepts and how their progression should be organized in a curriculum as well as how students' progress in their understanding of fundamental science concepts (Alonzo and Gotwals 2012). The latter approach considers current debates on conceptual change and stresses the relevance and usefulness of prior conceptions.

In addition to cognitive aspects of conceptual change, research has been addressing the challenge of expanding frameworks and empirical approaches towards including motivational, emotional, and social aspects. Even though it is obvious that a more inclusive approach towards conceptual change is needed, it is also evident that both theoretical frameworks and empirical approaches become more complex. Designing investigations which control variables such as motivation, emotion, cognition, and social setting is very demanding.

Besides more content-related aspects of future development, technological and methodological advancements offer new opportunities for conceptual change research. Video recording in classroom and laboratory settings has become more prominent and helps to understand better how concepts are established, used, and changed while students are exposed to learning material over a longer period (von Aufschnaiter and Rogge 2010). Whereas video is an approach typical for smaller sample sizes, item response theory (such as Rasch analysis) which has been established in science education research during the last years can be used to gather information on students' knowledge with larger sample sizes. Here, ordered multiple-choice items are helpful in understanding better how learners progress to a scientific understanding. Taking recent developments into account, it can be expected that a revised and extended conceptual change research will remain a major research focus also during the twenty-first century.

Cross-References

- ▶ Alternative Conceptions and Intuitive Rules
- ▶ Alternative Conceptions and P-Prims

- ▶ Alternative Conceptions/Frameworks/Misconceptions
- ▶ Constructivism
- ▶ Didactical Contract and the Teaching and Learning of Science
- ▶ Emotion and the Teaching and Learning of Science
- ▶ Inquiry, As a Curriculum Strand
- ▶ Learning Progressions
- ▶ Metacognition and Science Learning
- ▶ NOS, Measurement of
- ▶ Pedagogical Content Knowledge in Teacher Education
- ▶ Piagetian Theory
- ▶ Prior Knowledge
- ▶ Socio-Cultural Perspectives on Learning Science

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Conceptual Profile

- ▶ Heterogeneity of Thinking and Speaking

Conceptual Understanding

- ▶ Cognitive Preferences
- ▶ Conceptual Change in Learning
- ▶ Meaningful Learning

Concrete and Formal Reasoning

- ▶ Piagetian Theory

Construct Map

- ▶ Learning Progressions, Assessment of

Constructivism

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Introduction

For nearly 50 years, constructivist theory has been making a significant contribution to education, shaping the way we think about the active role of the mind of the learner, whether student, teacher, or researcher. But to answer the question “what is constructivism?” is not an easy task; it depends on which version of constructivist theory we are asking about. There are many versions of constructivism in the literature, with labels such as cognitive, personal, social, radical, cultural, trivial, pedagogical, academic, contextual, C1 and C2, and ecological. And there are also allied terms that have a strong family resemblance, including social constructionism, enactivism and pragmatism. For this entry, I consider four versions – personal constructivism, radical constructivism, social constructivism, and critical constructivism. These have had a major impact on science education and greater impacts than other forms/versions. I start with a brief consideration of Piaget's cognitive constructivism, which laid the foundations for the emergence of the "Big Four," and I conclude with an integral perspective on using different versions of constructivism to shape science teaching and learning.

Cognitive Constructivism

By the second half of the twentieth century, science educators had begun to move away from behaviorist theories of learning, especially classical stimulus–response conditioning which was criticized for shaping teaching approaches that privilege learning by memorization and rote recall. The successor to behaviorism was the cognitive constructivism of Jean Piaget, in particular his theory of mental operations and age-related developmental stages of reasoning (from the concrete operational reasoning of early childhood to formal reasoning of the mature adult mind). Piaget's ideas persuaded science educators to take account of the active "constructing" mind of the individual student which had been largely overlooked by the dominant teaching method of lecturing to silent classrooms. Teachers began to reevaluate their established practice of "transmitting" knowledge to the seemingly empty minds of students, realizing that students' failure to learn meaningfully could not necessarily be overcome simply by lecturing more slowly or more forcefully. A radical shift in pedagogical perspective from didactic teaching inputs to students' meaningful learning experiences formed the basis of the constructivist revolution in science education.

Personal Constructivism

Based on research in the 1970s/1980s on "children's ideas" by leading science educators such as Rosalind Driver, personal constructivism captured the imagination of science educators worldwide and led to an ongoing and fruitful program of research into students' conceptions of the physical world. Researchers discovered that students' intuitive understandings of their experiences are so strongly held that in many cases they block development of counterintuitive scientific concepts. For example, the child's experience of applying a constant force to the pedals of a bicycle to maintain constant speed is very often seen by the child as completely contrary to Newtonian dynamics which holds that constant force applied to a point mass on a frictionless surface yields accelerated motion. In the past 30 years, almost every topic in the science curriculum has been researched to identify sources of potential student misconceptions. As a remedy, researchers developed "conceptual change" teaching strategies that enable students to experience dissatisfaction with their naïve understandings and to experience the "intelligibility, plausibility, and fruitfulness" of scientific replacement concepts, aided by metacognitive strategies for reflecting on the meaningfulness of their new knowledge.

Personal constructivism drew on the personal construct theory of two cognitive psychologists. George Kelly's personal construct psychology emphasizes the role of "personal construction" in the development of both scientific community knowledge and children's attempts to make sense of their experiences of the world. David Ausubel's theory of cognitive learning argues that meaningful learning involves building on learners' prior knowledge or existing mental constructs. Both models of learning focus on concept development rather than on Piaget's generalized cognitive structures or "content-independent" forms of thought.

The popularity of personal constructivism owes much to its neat fit with the content of science curricula, providing prescriptive means for teaching more effectively the knowledge base of school science. In the hands of science educators, personal constructivism has inspired a range of research and teaching methods for monitoring students' conceptual profiles and facilitating the process of meaningful learning, especially by means of inducing cognitive conflict. Well-known methods include "concept mapping," "interview about instances and events," "predict-observe-explain," and "two-tier diagnostic tests."

However, controversy surrounds the term "misconceptions," with many arguing that it is not a good constructivist teaching practice to regard as misconceived (i.e., wrong) students' intuitive conceptions when they do not accord with canonical science. A deficit view of students' prior knowledge can lead to a didactic teaching approach in which the teacher's knowledge is imposed on the basis of his/her authority, eliciting little more than rote learning and social conformity among students. A preferred term is the more respectful "alternative frameworks." Controversy also surrounds the constructivist agenda of conceptual change when it is used as an "ideology replacement therapy" for students whose worldviews do not necessarily accord with the Western modern worldview, especially children of indigenous populations (see critical constructivism below for more on this issue).

Radical Constructivism

Ernst von Glasersfeld's radical constructivism was thrust into the limelight by science educators dissatisfied with the objectivism of personal constructivist pedagogy, where objectivism entails a naïve realist "correspondence theory" of truth, which regards scientific knowledge as an accurate depiction of physical reality. Radical constructivism draws on Piaget's lesser known background theory of "genetic epistemology" which emphasizes the inherent uncertainty of the constructed knowledge of the world by all cognizing beings, from children to scientists. According to the defining principle of radical constructivism, cognition serves an adaptive purpose inasmuch as it organizes our experience of the world, rather than enables us to "discover" an objective ontological reality. This is not to deny the existence of external reality, a world of physical things that we can sense, just that we cannot peer around our conceptual frameworks and see it directly in an unmediated or pure sense. Furthermore, from a proof-of-concept perspective, we do not have access to an objective "God's eye" standpoint from which to judge the match between the so-called essence of external reality and our cognitive constructions. We are, therefore, restricted to "dancing" with the shadows on the wall of Plato's cave, the shadows of our own taken-as-shared experiential realities. Thus, our knowledge can only be judged in terms of its "viability," or fitness, for representing or modeling the physical world. For radical constructivism, the cornerstone concept of "objectivity" is reconceptualized as consensual agreement by scientific communities of practice. This instrumentalist perspective on knowledge production and legitimation is in close accord with David Bloor's "strong program" of the sociology of science knowledge (SSK) and with the philosophy of science of Thomas Kuhn who argued persuasively that scientific knowledge is "paradigm bound."

Radical constructivism directs science educators to facilitate students' epistemological understanding of the nature of science, especially the inherent uncertainty and confidence limits of scientific knowledge. A legacy of earlier science education is the naïve view that science generates absolute truths about the workings of the physical universe. As a result, many "well-educated" people reject the Intergovernmental Panel on Climate Change report (IPCC 2013) that climate change is human induced. The skeptics are not happy with a finding (i.e., consensus by the scientific community) that is expressed "only" at the 95 % level of probability. This public controversy raises the question of how well science education enables students to understand the social and cognitive processes of scientific modeling. It also raises the question of how well science education enables students to understand the epistemological status of scientific concepts, theories, and laws (and to be able to differentiate between them). A naïve belief in the permanence and immutability of scientific knowledge can breed arrogance among "true believers" that debate with the skeptics is unnecessary; it is not uncommon to hear science educators claim, for example, that Darwin's theory of evolution is unassailably right and creation science is simply wrong, end of story! The tendency of science education to reproduce the ideology of "scientism" has been challenged by critical constructivism.

Within the science education constructivist movement, a "paradigm battle" between radical and personal constructivists broke out, with vociferous opposition evident in international conferences. Radical constructivists labeled (somewhat pejoratively) the objectivist standpoint of personal constructivists as "trivial constructivism," with the latter countering that the idealism of radical constructivism leads to rampant relativism. This battle was part of the larger war in educational research between the opposing epistemological armies of positivism, with its quantitative epistemology of objectivism, and interpretivism, with its qualitative epistemology of social constructivism. Another critical view of radical constructivism, articulated by social constructionism, is that it perpetuates the subject-object dualism of subjective idealism, rendering the individual mind as primary and failing to explain adequately the intersubjectivity of the social world.

Radical constructivism does not stand alone as a theory of learning; it works best in conjunction with social constructivism to support inquiry learning.

Social Constructivism

Social constructivism entered the pedagogical arena drawing on theories of social psychology such as the "socially situated cognition" of Jean Lave and Etienne Wenger, which recognizes that people co-construct meaningful knowledge in communities of practice, and the "social activity theory" of Lev Vygotsky, which identifies the essential co-development of language and thought. Social constructivism extends the "psychologistic" focus on the mind of the individual learner of both personal constructivism and radical constructivism, recognizing that learning is also a social process. A social constructivist perspective directs teachers to situate learning activities in the context of students' out-of-school lives, thereby enhancing the meaningfulness of learning science. Applying science to contexts that are familiar to students, such as testing water quality in a nearby river or monitoring energy use within the home, gives science a perceived relevance that is often missing when it is confined to the school laboratory or textbook.

In the 1990s, pioneering mathematics educators Grayson Wheatley and Paul Cobb developed pedagogies of problem-centered learning and inquiry mathematics, respectively, based on the principles of radical and social constructivism. What these approaches have in common is a perspective that students should be engaged in learning environments that allow rich inquiry-based dialogue within small groups and at the whole-class level, facilitated by the teacher. Students learn to construct explanations and justifications of their reasoning, share and negotiate with other students and the teacher, and develop the patterns of discourse of a community of mathematicians. For the teacher, eliciting students' multiple solution methods is more important than students obtaining "the correct answer" by following (robotically) a standard procedure. The teacher exercises his/her authority to legitimate students' solution strategies and does so indirectly by stimulating students to reflect critically on their assumptions and chains of reasoning.

For science education, social constructivism emphasizes the importance of engaging students in classroom discourse in order to develop the "social capital" of science (i.e., values, knowledge, skills, language), especially scientific ways of reasoning and negotiating to reach consensus in a community of practice. Engaging in discussion, whether it be teacher-directed whole-class question-and-answer or student-directed small-group work, gives students opportunities to put language to their ideas and test their viability against the ideas of other students. Peer learning is a powerful socializing process, involving a strong emotional relationship with significant others. Contributing actively to classroom discussion or listening actively to other students' questions and responses can help develop the metacognitive skill of reflective thinking (i.e., thinking about one's own thinking) which is an important step towards developing an ability to assess the viability of one's own prior knowledge and developing concepts. In collaborative learning, especially in small groups, students have opportunities to develop social inquiry skills, including active and empathic listening, learning to "take turns" in speaking, offering strategies for investigating a problem or issue, and negotiating a consensual solution or conclusion to their scientific inquiries.

The invisible frameworks that restrain teachers from creating vibrant social learning environments gave rise to critical constructivism.

Critical Constructivism

The next articulation of constructivist theory involved an extension into the cultural-political realm. Science educators sensitive to issues of social justice, such as Joe Kincheloe, were inspired by various social theories, including Peter Berger and Thomas Luckmann's theory of the "social construction of reality," Jurgen Habermas' critical social theory of "knowledge-constitutive interests," and Paulo Freire's "pedagogy of the oppressed." These social philosophers explained how the construction of socially sanctioned knowledge, such as science, is framed by powerfully invisible (i.e., hegemonic) value systems embedded in society's social structures that serve the interests of dominant sectors of society while disenfranchising others. From this perspective, science is a cultural activity, rather than being transcendental of culture, and thus, many sciences exist around the world, grounded in a variety of communities of practice (e.g., Masakata Ogawa's "multi-sciences perspective"). Critical constructivists argue that science educators, blind to this perspective, perpetuate oppressive ideologies lurking (like Trojan horses) in science curricula and assessment systems. By means of politically naive teaching methods, such as a narrowly conceived conceptual change approach, science teachers inject (unwittingly) into students' "cultural DNA" distorting ideologies such as scientism, masculinism, and Western imperialism. Cultural anthropologists describe this process of socialization as "enculturation" or "one-way cultural border crossing."

From a critical constructivist perspective, Western modern science is but one form of science, albeit the dominant form, that thrives in concert with modern technological developments and capitalist market economies to fuel twenty-first-century globalization. For postcolonial scholars, the culturally blind, one-size-fits-all Western modern science curriculum export industry is tantamount to neocolonialism. Although studies of the cultural history of science reveal that Western modern science owes much to earlier developments in Africa, China, Japan, India, Persia, and Arabia, little of this history is included in science curricula. Critical constructivism recognizes that science learning is situated in a cultural context of historical and political considerations. The science learner's construction of his/her social capital is recognized as a complex intercultural process involving the reconstruction of children's cultural identities. If science education is to become culturally inclusive, in a global sense, it cannot afford to ignore the potential "collisions" between the starkly contrasting worldviews of Western modern science and culturally different others. The mutually beneficial process of "acculturation," or intercultural borrowing, should not be left to chance.

Critical constructivism points out that science educators are deeply implicated in values education inasmuch as they are preparing future citizens to participate in their societies, not only as professional scientists, engineers, and mathematicians but also as community-minded citizens who have a stakeholding in the survival of the life-support system of the planet. It is essential, therefore, that we enable science students to develop higher-level abilities (e.g., Derek Hodson's "critical scientific literacy") such as critical reflective thinking, communicative competence, and a social conscience. These abilities and habits of mind are essential for participating in social decision-making about the ethical use of innovations in Western modern science and technology for resolving global crises such as climate change, pollution of the means of supporting life, loss of biocultural diversity, and so on, much of which has resulted from humanity's past misuse of science and its technological products. Critical constructivism calls for "socially responsible" science education.

An Integral Perspective

As science educators, how do we resolve these philosophically and politically contrasting views of constructivist theory? And how do we avoid turning constructivist theory into yet another privileged ideology that restricts science educators' evolving theories of teaching and learning? What is clear from this short history of constructivism in science education is its adaptability to a range of agendas driven by a variety of interdisciplinary interests. What emerges is an image not of a many-headed monster threatening the unwary (the Hydra of Greek mythology) but a multidimensional hologram that integrates a range of discrete images into a coherent and complex whole (for more on this, see Steffe and Gale 1995). To change metaphors, we can choose to be like the proverbial blind men and the elephant, each one identifying only one part of the whole, or we can choose to embrace the whole, making use of powerful synergies as we integrate the parts.

The power and adaptability of constructivist theory lies in its central metaphor – constructed knowing – which enables us to see ourselves as dynamic professionals undergoing constant reconstruction as we embrace and test the viability of diverse ideas. Dialectical reasoning is the catalyst that enables us to hold together in creative tension these competing and contradictory ideas, thereby immeasurably enriching our professional repertoires (e.g., Willison and Taylor 2006). But this is not to say that multidimensional, or integral, constructivism is the only game in town. Clearly there are a host of other theories about teaching and learning, including behaviorism, that are available to us now or that will emerge in the future. From a dialectical perspective, these too can be integrated into our ever-expanding repertoires.

As science teachers, at times it might make good sense to engage students in memorization and rote recall, and at other times, we might want to correct a common student misconception or enhance students' epistemological understanding of the nature of science or direct students to explore collaboratively indigenous knowledge systems or investigate the historical roots of contemporary scientific theories; and we might want to engage students in debate or role play or theater production or community projects and so on. All of this is possible; nothing is excluded by virtue of ideological conflict. The critical factor in choosing a teaching and learning strategy should be the professional judgment of the epistemologically astute science teacher as to which theory of knowing (or epistemology) is most appropriate for achieving a particular curriculum goal at a particular point in time.

As the past 50 years has shown, constructivist theory is adaptable to many science teaching and learning scenarios, not in a simplistic sense as a method of teaching and learning but, as explained by Tobin and Tippins (1993), as a powerful epistemological "referent" that enables teachers to think creatively about how to make learning science more motivating, memorable, and meaningful, no matter the number or mix of students or the quality of available resources or the constraints of the curriculum and examination system. If the challenge of engaging students in deeply meaningful learning seems too great for science education alone, then interdisciplinary collaboration offers an exciting pathway for school-based development and implementation of integrated curricula.

Cross-References

- ▶ Alternative Conceptions/Frameworks/Misconceptions
- ▶ Ausubelian Theory of Learning
- ▶ Conceptual Change in Learning
- ▶ Constructivism: Critiques
- ▶ Piagetian Theory
- ▶ Prior Knowledge
- ▶ Role-Plays and Drama in Science Learning
- ▶ Social Epistemology of Science
- ▶ Socio-Cultural Perspectives and Characteristics
- ▶ Sociology of Science
- ▶ Transformative Science Education

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Constructivism: Critiques

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There are three essential lines of criticism of constructivism in the literature:

1. That the constructivist perspective is indistinguishable from “discovery learning”
2. That the constructivist theoretical perspective is essentially attempting to make something out of a triviality
3. That the constructivist perspective has little or nothing to say about the nature of an effective pedagogy

Each of these is now discussed in turn.

Criticism 1: The Constructivist Perspective Is Indistinguishable from “Discovery Learning”

Central to the basic critique of those who see constructivism as a form of discovery learning is a questioning of the constructivist belief that all knowledge has to be personally constructed. The inference made by these critics is that constructivists believe that knowledge constructed by the students themselves is more valuable than knowledge which is modeled, told, or explained to them; for instance, advocates of discovery learning very commonly concur with Piaget’s assertion that “each time one prematurely teaches a child something he could have discovered for himself, that child is kept from inventing it and consequently from understanding it completely.” These critics also argue that constructivists believe that students are more likely to apply and extend that knowledge than those who receive direct instruction. Furthermore, there are some notable studies that provide evidence that purport to show that learning by direct instruction is more efficient than discovery learning. Hence, the empirical evidence contradicts the premises of constructivism. However, the model of discovery learning consistently used within this research was one where the students were simply left to discover, in a totally unguided manner, the role of the control of variables strategy in scientific investigation. Leading constructivists, such as Rosalind Driver, have pointed explicitly to the need for an “input from the teacher” and see teaching as a process of negotiating meaning. Adopting a constructivist perspective on learning does not mean, or even imply, that the child is left to reinvent, in a very limited period of time, what has taken very bright people years to create. Thus, this critique is overly simplistic and has erected a straw man – in short a vision of constructivist pedagogy which very very few constructivists hold.

Matthews (1993) offers a somewhat related but more philosophical and more sophisticated critique of constructivism. He argues that constructivists subscribe to a view that sees all knowledge as grounded in sense impressions or experience. Drawing on Hanson’s notion that all observation is theory dependent – that is, what we perceive is determined by our prior conceptions – Matthews argues that scientific ideas are abstractions of reality where phenomena are idealized, e.g., frictionless planes, point masses, and the absence of air resistance. Such ideas are not born of sense impressions but by imagining the world not as *it is* – but as it *might be*. If anything observation is an obstacle to the development of the scientific idea. For instance, observation would lead to the construction of an explanation for day and night being caused by a moving Sun rather than a spinning Earth. Therefore, constructivism is correct in stressing the invention of the theoretical ideas of science but flawed if it thinks that these can be developed solely by empirical investigations of the material world. Statements that science should be an attempt to "make sense" of the living world are not helpful as scientific advances commonly involve a "commitment to propositions that literally defied sense." Matthews essential criticism then is that what constitutes science is a set of ideas or theoretical propositions. These are not lying around to be discovered but must be explicitly introduced to children, and this requires the teacher to be competent in the subject in which they teach and accountable for presenting the commonly accepted knowledge in that domain.

While most people would agree with the details of Matthews' argument, the problem with his case is that he has equated "constructivism" as having a commitment to the pedagogy of "discovery learning." This is not so and nowhere do constructivists make such a commitment. Rather, in science education most of constructivist pedagogy has been guided by Ausubel's seminal statement that if he had to reduce the whole of educational psychology to just one thing, it would be that "the most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly" (Ausubel 1968). So widely cited has this statement become that it has required the status of a mantra for constructivists. Notably though, it makes no statement about the nature of the teaching that would be appropriate.

Discovery learning, in contrast, is based on a set of pedagogic commitments about how students should learn and be taught. The term "discovery learning" has been used in a quite wide range of ways and contexts. At the heart of these multiple usages is reference to a curriculum where students are exposed to particular questions and experiences in such a way that the designers suggest that students "discover" for themselves the intended concepts. However, the experiences and activities are carefully selected by the teacher to help reveal the ideas that are considered important. In that sense, the "discovery" process is very guided. Those who hold a view that teaching is a process of discovery see teaching and learning as an uncertain and contingent process. Curriculum in that sense is largely determined "in the moment" and emergent through a process where the teacher guides students with activities that are largely responsive to their students' ideas and the classroom discussion. Thus, discovery learning is essentially a contingent experience and a set of pedagogic commitments about how students best learn. Constructivism, in contrast, is a set of epistemic beliefs about how individuals come to know and it is not legitimate to equate the two. Thus, while Matthews makes salient points, his and others' critiques based on comparisons of constructivism with discovery learning essentially founded on a misconstrual of the pedagogic beliefs of constructivists.

Criticism 2: Constructivism Attempts to Create Significance from a Triviality

The second critique mounted against constructivism is that the basic tenet, captured by the Ausubelian mantra, is little more than a truism. Most people would agree that humans are born with some innate capabilities for conceptual and linguistic processing and that these develop through acting on the world and through social interaction. However, by and large much of what we commonly term to be knowledge – whether it be public or personal knowledge – is *constructed.* It cannot be acquired by a process of simply telling. Rather we all have to construct an understanding of something we are told. For instance, if you ask somebody for directions to the nearest train station, as they explain the route, in your mind you run a mental picture of the route to be walked constructing a mental map to retrieve shortly. Failure to do this means that the information does literally go in one ear and out the other. Thus, the only reasonable inference that can be drawn from Ausubel's dictum is that the construction of knowledge must be an active process even if the learner is simply listening to a lecture. Nothing will be understood and no change will occur in the individual's conceptual structures unless the learner makes a cognitive effort to assimilate the information presented. What then is the insight provided by constructivism?

The Ausubelian mantra clearly has value in reminding the teacher that the lens through which all new ideas are filtered is the existing set of knowledge and concepts that the student holds. As such it is essentially nothing much more than a statement of common sense (Osborne 1996). Yes it has value as a theory for reminding teachers that students' existing ideas are the foundations on which new ideas must be laid – but it has no predictive validity. Another criticism of this tenet is that it fails to acknowledge the social nature of knowledge construction. All knowledge can be seen as a product of a dialectic between construction and critique. While it is possible for the individual to engage in this process, most knowledge is generated by engaging in dialogue within a community. All scientific knowledge, for instance, is the product of an ongoing social interaction between scientists. Within that community, hypotheses are proposed, experimental designs are developed, and data are collected. A disposition to circumspection within the community means that only those ideas found not to be wanting survive to a later day. Argument from evidence is, therefore, very much a core practice of science. Strangely, however, it is notable by its absence in the science classroom. The constructivist overemphasis on the need to engage in construction, be it personal or social, has neglected the role of critique in helping students to identify flaws in their own thinking and generate dissatisfaction with their existing mental schemas.

A considerably body of evidence has now accrued that the learning of new concepts is essentially best done through social interaction with others where ideas are tested and challenged. In a meta-analysis of a range of studies on learning, Chi (2009) categorized activities on a continuum from passive (listening only) to active (any activity requiring physical activity) to constructive (the production of a physical artifact that transcends what was given to the student) to interactive (where the learner engages in dialogue with a partner). Her analysis shows that this hierarchy is supported by the empirical findings of research, with interactive being the most effective. Interactive approaches to learning force students to justify their views by constructing explanatory justifications for their views. In one study, for instance, students were instructed to explain to a partner what a text really said. Their interaction generated a large number of critical questions, something which is a feature of generative dialogue helping students to identify why the wrong answer is wrong as much as understanding why the right answer is right.

Criticism 3: Constructivism Has Little or Nothing to Say About the Nature of an Effective Pedagogy

Issues such as those discussed immediately above raise the third criticism about constructivism, that "a weak or at least a controversial epistemology has become the basis for a strong pedagogic policy" (Phillips 1995, p. 11)). The primary influence underpinning much of the theoretical commitments of constructivist pedagogy was a highly influential paper written by Posner et al. (1982). This paper, which drew heavily on Thomas Kuhn's work on conceptual development in the sciences and the structure of scientific revolutions, argued that learning was a process of conceptual change where prior conceptions were replaced by new conceptions if there was first initial dissatisfaction with existing ideas, and then if the new idea was "plausible," "intelligible," and "fruitful." Posner et al.'s argument was that for learning to occur, there must be a change in the student's conception, albeit gradual and piecemeal, such that there is a substantial reorganization and change in the conceptions held by the student. The problem is that there is little empirical evidence to support this view. In one of the most systematic examinations of conceptual change within young students, other research suggests that most students undergo a process of "weak restructuring" of their knowledge or "belief revision." Hence, the idea that any form of pedagogy could overturn or displace an existing conceptual schema rapidly was flawed. Rather students undergo a process of assimilation or accretion in which ontological categories are increasingly differentiated or in some cases coalesce.

Another view, developed by the psychologist Guy Claxton, goes further and argues for a triadic view of the nature of the conceptual schemas that people have for the material world. At one level, there is what he terms "gut science" which is the kind of tacit and intuitive knowledge we use to make calculations about whether it is safe to cross the road. Then there is the kind of overt knowledge which he characterizes as lay science – the kind of knowledge which is simply a commonsense interpretation of the world such as the idea that heavy things sink, light things float or that a force is needed to sustain motion. Such common sense knowledge is functionally effective for many everyday situations. Finally there is formal scientific knowledge which is the focus of what is taught in school and necessary for working within the scientific community. He argues that individuals use all three forms of knowledge and switch readily between them.

A further critique of Posner et al.'s theoretical framework is that their model is overly rational in focusing on student cognition without any consideration of the way in which students' motivational beliefs might affect the outcome of any learning experiences. Rather, students' cognition is heavily influenced by a set of four general motivational constructs that are their learning goals, the values they hold, their beliefs about their own self-efficacy, and their beliefs about the locus of control. In the case of the latter, for instance, whether they think that intelligence is fixed or mutable and dependent upon the effort they are prepared to make. The failure to consider any of these aspects within the writings on constructivist approaches to teaching is indicative of a theory which has failed to recognize that there is a significant affective component to successful learning.

Perhaps the most substantive criticism of constructivism is that as a theory of learning, it has little to say about teaching beyond the requirement to ascertain students' prior knowledge. Granted its message is that the learner must be active if they are to construct an understanding of scientific concepts, and granted that the argument of social constructivists would be that dialogue with others is essential if ideas are to be developed and comprehended. However, what are the instructional strategies and mechanisms that will generate conceptual change? Most constructivists borrow from Posner et al. and argue that the essential mechanism for generating conceptual change is conceptual conflict. For instance, if students believe that heavier things fall faster, that idea should be challenged by asking them to make a prediction and explain why they believe this. The phenomenon can then be demonstrated with a bunch of keys and a scrumpled piece of paper will both fall at the same rate. The disparity between their prediction and their observation generates conceptual conflict and forces revision of their concepts. Rosalind Driver, in her writings, argued that students should be exposed to conflict situations such as these and then constructed new explanations. But beyond the need to engage in small group work and discuss their ideas, little argument is offered about what might constitute an effective educational strategy. One exception to this is the work of Gunstone and White who developed the notion of predict-observe-explain as an instructional mechanism to generate conceptual conflict. However, even then, while undoubtedly an effective teaching mechanism, it offers no guidance about content. In contrast, neo-Piagetian theory does offer a framework for the selection of content and an argument for the nature of age-appropriate instructional activities. Likewise, those concerned with literacy in science do have a theory which drives what kinds of activities are needed to develop students ability to read and write science – essentially the idea that reading in science must be reflexive which requires tasks which are analytical where the text is summarized in either tabular or diagrammatic form or restructured by reassembling text to make meaning.

In Conclusion: Looking Across the Three Areas of Criticism of Constructivism

What is missing from constructivist writing then is an account of the processes that would support learning and a rationale for their justification. The point that Matthews is making is that if you want an individual to see the world in a new way, then they must be introduced to that way of seeing. Anybody who has tried to get students to observe a specimen down a microscope knows this. Students will not see what you see unless they are given an a priori conception of what to see. The teacher is thus reliant on the use of metaphor and analogy drawn from the familiar world of the student to help them "see" the scientific idea. Ultimately, the failure of constructivism is a failure to recognize the fact that most scientific ideas are unnatural – they do not make sense. Who in their right mind would ever come to the view that atoms are mainly empty space, that day and night are caused by a spinning Earth, or that we look like our parents because every cell in our body contains a chemically coded message about how to reproduce ourselves. Not surprisingly then, it is not immediately obvious how such ideas are fruitful let alone plausible when the standard misconception seems to be a more accurate description of the way the material world behaves.

What the constructivist perspective has been very successful at is challenging the notion that the child is a tabula rasa. The enormous body of research conducted in the last two decades of the twentieth century has shown that students do develop ideas about the material world from simply being in the world and acting on it. In that sense it has undoubtedly been helpful – for to teach any students something about science, constructivism shows that not only is it necessary to know something about science, but we also need to know something about the child. Moreover, in placing the emphasis on the need for learner to be active, it has helped to challenge the notion that simply presenting information in a clear and effective manner is the essential basis of good teaching. Indeed what much of the research in this paradigm has repeatedly demonstrated is that, contrary to the popular view that most communication is a simple act with failure being a rare event, most communication is actually a complex act with *success being the exception*. However, constructivist research has little to say about the selection or sequencing of content, how to build students capability to be metacognitive, or a rationale for any specific instructional strategy and its selection. Any theory which fails to help teachers make rationally defensible professional judgments for what they do is in essence an ideology. For a profession which desperately needs empirically tested theoretical arguments for the instructional choices that teachers make on a daily basis, the argument here is that constructivism is to be found wanting. That is not to say that there is no value in it – rather that the reader should be aware of the limitations as well as its much promoted strengths.

Cross-References

- ▶ Alternative Conceptions/Frameworks/Misconceptions
- ▶ Argumentation
- ▶ Conceptual Change in Learning
- ▶ Constructivism
- ▶ Dialogic Teaching and Learning
- ▶ Discourse in Science Learning
- ▶ Discovery Learning
- ▶ Socio-Cultural Perspectives on Learning Science

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Context

- ► Context of Discovery and Context of Justification
- ► Context-Led Science Projects
- ► Problem Solving in Science, Assessment of the Ability to
- ► Science, Technology and Society (STS)

Context of Discovery and Context of Justification

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Keywords

Context

Introduction

How scientists come up with new ideas, concepts, hypotheses, and theories is usually different from how they present and argue for them in published research articles and textbooks. Philosophers of science have conceptualized this difference into a more rigorous distinction between the context of discovery (for generating novelties) and the context of justification (for validating them). This distinction is also often aligned with the distinction between the descriptive (how science actually works) and the normative (how it ought to work).

History of the Discovery–Justification Distinction

With the development of the new sciences in the early modern period, philosophical discussions on scientific discovery arose in attempts to establish the scientific method. Francis Bacon (1561–1626) and René Descartes (1596–1650) offered the most prominent philosophical models among others to explain and encourage scientific discoveries. Their ideas, inspired by the emerging new scientific practices, in turn prompted groups of natural philosophers to embark on making new findings especially through concerted efforts via newly founded scientific societies. For Bacon, knowledge was gained securely through an inductive process, starting with the collection of unbiased observations and progressing toward more theoretical generalizations. For Descartes secure knowledge could only begin from indubitable foundations, from which the rest was logically deduced. In either the Baconian or the Cartesian view of ideal knowledge, there was no explicit distinction between discovery and justification, as their belief in the existence of the "scientific method" was supported by the conviction that the best method for making new discoveries was at the same time the best justification of the discoveries.

This conviction, however, was put to question starting from the early nineteenth century. An alternative view of scientific discovery, popularly captured by the "Eureka" moment and reinforced by the Romantic image of the scientific genius, made it difficult to conceive that there could be any fixed method for discovery. On the other hand, appreciation of the use of hypotheses in scientific practice paved the way for the rise of hypothetico-deductivism, which argues that the scientific method only concerns the testing of hypotheses, regardless of how they are conceived (Nickles 1980, Chap. 6). These developments drove a wedge between discovery and justification, culminating in the categorical distinction between scientific discovery and scientific justification by leading empiricist philosophers such as Hans Reichenbach (1891–1953) and Karl Popper (1902–1994) in the first half of the twentieth century. According to Reichenbach, the "context of discovery" is subject only to psychology, which deals with the processes of thinking as they actually occur. While any scientific theory consisting of a group of propositions can be justified by being in a correct logical relationship with observational statements, the discovery process was not amenable to this sort of "logic" for philosophers to seize upon. (Thus, there is a great irony in the English title of Karl Popper's masterpiece in the philosophy of science, *The Logic of Scientific Discovery*; there is no similar irony in the original German title, *Logik der Forschung*). Discovery is a subject of all kinds of empirical research, historical, sociological, and psychological. Epistemology is and should be confined to the "context of justification," in which the propositions produced in science are reformulated and rearranged so that their structures and logical relations are made explicit. Epistemology thus considers a rational reconstruction of scientific practice, rather than the actual practice of scientists. The "context distinction" between discovery and justification has exerted a deep influence on philosophers of science through the century (Nickles, Chap. 1).

The terms of debate began to change again, however, with the demise of the orthodoxy in Anglophone philosophy of science that was the legacy of the logical positivism of the Vienna Circle. For post-positivists such as Thomas Kuhn (1922–1996) and Paul Feyerabend (1924–1994), it is theories that give meaning to observations, not the other way around (Chalmers 1999, Chap. 8). Therefore, any truly novel discovery, even of facts, can take place only if it is directly tied to theoretical change. During a phase of "normal science," in which the ruling paradigm is not challenged, facts can pile up more or less cumulatively, and theories are improved only in a trivial way; hence, there is no philosophical problem about justification or discovery. But in the process of a scientific revolution, new theories and facts are discovered together because facts can only be assigned their meaning by underlying paradigmatic theories. Therefore, such discovery, according to Kuhn, is not a matter of a "Eureka" moment, but a difficult protracted process of adjustments of establishing paradigms and their relevant facts together that need to be agreed upon by a whole scientific community and then passed on to the next generation through laborious pedagogical efforts (Schickore and Steinle 2006, Chap. 7). Justification only happens through such processes of negotiation, in which Kuhn famously declared that there is no higher standard of judgment than the assent of the relevant scientific community. Kuhn's stance not only upset the traditional philosophers due to its anti-rationalistic implications even for the context of justification, but it also brought justification and discovery back together, this time in an untidy mix.

The emphasis on the social processes highlighted by Kuhn in his discussion on scientific discovery has been fully adopted and extended by social constructivists. Historians and sociologists of the constructivist bent have offered instructive case studies revealing diverse disagreements and complex negotiations among self-claimed discoverers and their allies or followers, and their political, social, and professional agendas with respect to the "authorization" of discovery. As shown in the classic case of the "rediscovery" of Mendel, scientific discovery in the social constructivist picture is a retrospective affair, a product of a discussion among relevant practitioners in a given discipline; a discovery as an achievement, its meaning, and its discoverer, it is argued, can only be retrospectively evaluated and acknowledged. In these social constructivist construals of scientific discoveries, the scientific realist commitment which implicitly underlay the traditional philosophical discussions has been explicitly problematized and severely attacked. There are various types of antirealists in this debate (Chalmers 1999, Chap. 15; Psillos and Curd 2008, Chap. 21): constructivists often draw on Kuhn's notion of incommensurability, while a majority of antirealist philosophers base their arguments on skepticism or agnosticism about unobservable entities, as in the philosophy of constructive empiricism advanced by Bas van Fraassen (1941–). What these antirealists have in common is that they do not take the notion of discovery for granted, as they reject the realist connotation implied in the term (if something has been "discovered," it must really exist). For them it is meaningless to distinguish sharply between discovery and construction, both being processes of finding a solution to a problem or contriving an empirically adequate theory to save the phenomena.

Discovery and Justification in Practice

With the long-lasting belief that there are some genuine methods for scientific justification (even if no simple logical algorithms), philosophers of science have principally explored its different strategies and procedures largely under the rubric of confirmation theory: inductivism, hypothetico-deductivism, Bayesianism, and value-laden comparative theory appraisal (Psillos and Curd, Chaps. 10, 11, 28, 31, 47). Yet, with the recent rise of a more practice-oriented view of science, it is now generally acknowledged that even justificatory practices are contingent on the context, not captured by either an ahistorical formalism with the belief in a pure observational language or a theory-dominated holism notoriously represented by Kuhn's notion of paradigms. This sensitivity to context leads us to ask in which epistemic situation a knowledge claim is justified and which method of justification can be intelligibly demanded of the knowledge claimant or rationally accepted by the relevant practitioners; this means accepting that an agent attempts to justify a scientific knowledge claim to her relevant epistemic community participating in specific epistemic activities with shared epistemic goals.

Notwithstanding the theory-ladenness of observation, for example, not all observations in practice are on a par. Some are more stabilized and robust in a relevant setting as is the case with middle-level regularities, being relatively independent of high-level theories and their changes, which could function tentatively as an empirical foundation to test and warrant a novel knowledge claim. Yet, these regularities can be made more elaborated and refined in terms of precision, scope, and the like through iterative processes. Moreover, there are various ways of testing a knowledge claim which are to be chosen by the actor depending on the relevant aims, resources, audiences, and even metaphysical values and principles. Even any plausible skepticism of induction could be avoided, for example, in a very well-controlled experimental setting which successfully removes as many extraneous non-observational hypotheses as possible. These, all in all, come down to a self-corrective and pluralistic attitude to scientific justification.

A shift of emphasis to scientific practice is more than welcome in relation to the study of scientific discovery, as traditional philosophical interest in the subject has been meager or just skeptical. Of course, it should be acknowledged that there has been considerable interest in "abduction," often equated with "inference to the best explanation," as a plausible "logic" of scientific discovery (Psillos and Curd, Chap. 18). There are even several automated discovery tools, as is well illustrated by statistical techniques and computer simulation programs to find out from given data abstract correlations or patterns or models, though it is still out of their reach to get at any deep theories or hypotheses. Yet, it would not be a surprise to see that existing philosophical frameworks are helpless when confronted with a sheer diversity of scientific discoveries in practice, given that typical philosophical discussions of scientific discovery pay exclusive attention on the discovery of theories. Therefore, it would be helpful to ask: What sorts of things do scientists discover in practice? A rough taxonomy should include theories and hypotheses, principles and laws, facts and phenomena, observable and unobservable entities, properties and processes, and the like. This again leads to another intriguing question: Are there different patterns in scientific discovery depending on what is discovered? For example, it is argued that discovering unobservable entities like electrons is inextricably interconnected with justifying their existence somehow. Here the complicated link between the contexts of discovery and justification comes up again (Schickore and Steinle, Chap. 12).

The discovery of unobservable entities illustrates that our understanding of scientific discovery would be enriched by a process model of scientific discovery. Anything that looks like a "Eureka" moment should be seen as a nodal point on a long research trajectory in ongoing interaction with the relevant research community; in this sense, the meaning of a discovery is often transformed as it is consolidated, often in ways that are not in accord with the original discoverer's own conception of it. The discovery of unobservables also links up with debates on scientific realism. Here, the descriptive task is to investigate the reason why the actors accept that something is “discovered,” not “constructed” or “invented.” Yet, normatively, the positions will be divided: entity realists would argue for the discovery of manipulable unobservables, whereas anti-realists might recommend a skeptical or agnostic attitude toward them. One of the ways out of this impasse could be to ask again in which context the question of existence or truth is meaningful or useful. That is, we could investigate various ways of accessing reality manifested and developed in scientific practice and evaluate their ontological and epistemological implications.

Implications for Science Education

What does the discovery–justification distinction imply for science education? It seems that the distinction is implicitly but strongly present in ordinary educational settings: students are typically not taught about the process of discovery, though they are usually given some justifications for the theories they spend countless hours learning to apply. In fact they only tend to get told about discoveries if there are striking stories associated with them (e.g., Fleming’s penicillin mold, Newton’s apple, Kekulé’s dream of snakes biting their own tails); these discovery stories are normally used to enhance the “human interest” in science, not especially to teach about real history or methodology.

One may question why we should want to teach students anything substantive about the processes of scientific discovery or justification. On the side of justification, at least many would agree that knowing how scientific justification works is indispensable for acquiring a proper critical appreciation of scientific knowledge; it is difficult to imagine how people lacking a sense of methods of justification can be competent to judge for themselves controversial issues such as policies concerning global warming, the risks associated with vaccination, or the legitimacy of including intelligent design in curricula. But how about discovery? For students who will go on to become research scientists, it is important that their habits and expectations do not become hampered by distorted or overly restrictive notions of how discovery works. Advocates of discovery learning, inquiry-based learning, and problem-based learning would go much farther to argue that going through one’s own process of discovery is the best way to learn anything at all (see Schwab (1960) for an early exposition).

Cross-References

- ▶ Biology, Philosophy of
- ▶ Chemistry, Philosophy of
- ▶ Context-Led Science Projects
- ▶ Discovery Learning
- ▶ Discovery Science
- ▶ Inquiry, as a Curriculum Strand
- ▶ Problem Solving in Science Learning

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Context-Led Science Projects

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Context; Contexts; PISA; SSI; STS; Thematic

Context-Based Science Curriculum Projects

Since the early 1970s, several science courses have been developed which could be labelled "context-based." In some areas of the world, these courses are named Science-Technology-Society (STS). The aims of such courses are usually to make science more relevant to students by linking science to contexts in personal life, local and global situations, and/or practices in science and technology. The course developers expect that this approach is motivating for students due to its focus on familiarity and relevance. Furthermore it might help students to be able to apply scientific knowledge and skills in real-life situations, such as is expected in the OECD Frameworks for Scientific Literacy of the Programme for International Student Assessment (PISA).

In practice a large variety of approaches have been developed, from a short series of lessons to full curricula, with aims which range from simply motivating students to preparing them for decision-making or social action. In some cases materials are monodisciplinary, linking specific science concepts to contexts; in other cases units deal with complex socio-scientific issues (SSI) from areas such as health, climate, and environment. Some projects have remained local, while others have extended to whole countries or have even been adapted across the world.

Most context-based science teaching materials are aimed at students in the age group 12–18. Some efforts have also been made to develop teaching materials for primary and undergraduate education.

Independent research on the effects of the context-based approaches has been limited. Direct comparison of regular and context-based approaches is difficult as aims are partly overlapping and partly different. Available review findings indicate that context-based approaches tend to result in improvement of attitudes to science and to higher quality reasoning and reflective judgments; the understanding of scientific ideas developed seems comparable to that of conventional approaches.

Examples (in Chronological Order) of Context-Based Science Projects

PLON

The PLON project (Dutch acronym for Physics Curriculum Development Project) developed between 1972 and 1986 full, context-based courses (including student's textbooks, teacher's guides, technician's manuals, and even to some extent examination papers) for secondary physics education in three Dutch ability streams. The PLON curricula were context based in the sense that the students' "life world" was taken as a starting point, with an emphasis on technological artifacts and natural phenomena in junior secondary education (grades 8–9, age 13–14), supplemented with an emphasis on socio-scientific issues and the nature of science in senior secondary education (grades 10–12, age 15–17). The aims of physics education put forward by the PLON project have evolved over a number of years into a balance between preparing students, on the one hand, for further education and/or future employment and, on the other hand, for coping with their (future) life roles as a consumer and citizen. An effort was made to find a balance between these two aims by developing teaching/learning units in which basic physics concepts and skills – covering most of the traditional content areas in physics education such as kinematics, mechanics, energy, electricity and magnetism, optics, sound, and matter – are dealt with in a personal, social, or scientific context. Hence the PLON curricula aimed at "physics for all" and not just for future specialists.

IPN Curriculum Physik

In the 1970s, a new curriculum for German school physics (grades 8–10, age 13–15) was designed by the Institute for Science Education (IPN) in Kiel. One aim was to strengthen the link between physics content and students' natural and technological environment. In some modules physics was related to technologies such as bicycles, electric cars, and cameras. Other units dealt with noise pollution, nuclear power stations, automation, and alternative energies, taking into account problems discussed in society.

Science in Society

The Science in Society Project was set up in 1976 by the UK Association for Science Education (ASE). The purpose of this upper secondary school course was to give students (age 17–18) a better understanding of the place of science and technology in the modern world and an awareness of the importance of using them wisely to assure the future of mankind. The developers took this to require an appreciation of the nature of science and a better understanding of industry, involving aesthetic, philosophical, moral, and economic considerations as well as scientific ones. The course was divided into nine units: Health and Medicine, Population, Food and Agriculture, Facts, Energy, Mineral Resources, Industry in the Economy, Land and Water, and Looking to the Future. Much of the work in the course was divergent and required teaching methods that were different from those commonly used in science lessons. Examples are project work, searching out information, reporting to the class, industrial visits, watching films, and decision-making simulation exercises.

Science in a Social Context (SISCON) in Schools

A series of eight books was published in 1983 by the UK project SISCON-in-Schools, an offshoot of the university-level SISCON project. The books provided a course in science and society for general studies at upper secondary school level (age 17–18), specially designed to make scientific problems accessible to nonscientists, as well as explaining the social aspects of science to aspiring scientists. The eight titles were *Ways of Living; How can we be sure?; Technology, Invention and Industry; Evolution and the Human Population; The Atomic Bomb; Energy: The Power to Work; Health, Food and Population;* and *Space, Cosmology and Fiction.*

SATIS

The first Science & Technology in Society (SATIS) project was launched in the UK in 1984. The materials were intended to enrich and enhance the teaching of science and designed to be incorporated into existing science programs. They did not make up a complete course but were a varied set of resource materials, to be used in a flexible manner by teachers to meet their own needs. The units were written by teachers and validated by experts. They included innovative teaching and learning activities such as role play, case studies, and structured discussion. More than 100 SATIS units were published for students aged 14–16 years by the UK Association of Science Education (ASE). In 1987 the SATIS project extended its work to 16–19 year olds with the publication of 100 units, clustered into themes such as materials, energy, environment, health, and ethical issues. More emphasis was placed on guiding the study of students while expecting them to gather the necessary information as a basis for discussion and debate. From 1989 the project also produced some materials for younger students (age 8–14).

Salters Projects

The UK Salters projects (named after an important sponsor of the projects and based at York) started in 1983 with the development of five context-based chemistry units for 13-year-old students. Subsequently a series of courses was developed, covering biology, chemistry, and physics for the high school range (age 11–18) in England and Wales: Chemistry; the Salters Approach (14–16); Science: the Salters Approach (14–16); Salters Science Focus (11–14); Salters Advanced Chemistry (17–18); Salters Horners Advanced Physics (17–18); and Salters-Nuffield Advanced Biology (17–18). Many of these courses have been adapted for use in other countries. Common design criteria for all Salters courses are that they should enhance students' appreciation of how science (1) contributes to their lives or the lives of others around the world and (2) helps them to acquire a better understanding of the natural environment. So units start with aspects of the students' lives drawing on both direct personal experience and ideas encountered through the news media. They introduce scientific ideas and concepts only as they are needed for understanding of the contexts and applications being explored. Units again suggest a range of teaching and learning activities. All courses try to combine a foundation for future studies with providing a satisfying course for those who will take the study of science no further.

ChemCom

The US Chemistry in the Community (ChemCom) project in the 1980s developed a year-long course primarily for students (age 16) who do not plan to pursue careers in science. Its purpose was to help students (1) realize the important role that chemistry will play in their personal and professional lives, (2) use principles of chemistry to think more intelligently about current issues they will encounter that involve science and technology, (3) develop a lifelong awareness of the potential and limitations of science and technology. Each of the eight modules centres on a chemistry-related technological issue, and the setting of each module is a community: school, town, region, or the world. Topics addressed are water needs, conservation of resources, petroleum uses, foods, nuclear chemistry, air and environment, health, and chemical industry. The first (trial) edition was published in 1985 by the American Chemical Society.

Chemie im Kontext

Chemie im Kontext (ChiK) has, since 1997, been a cooperative project involving teams at the Universities of Dortmund, Oldenburg, and Wuppertal and the Leibniz Institute for Science Education (IPN) in Kiel. ChiK is in the tradition of ChemCom and Salters Advanced Chemistry yet distinct from either one. While ChemCom introduces a sequence of topics without much conceptual relationship between them, Salters follows a more stringent line of conceptual development. The approach of ChiK is between these two, using contexts that are not in particularly systematic sequence, yet using them to develop a coherent set of basic chemical concepts.

The core of the project is a conceptual framework for chemistry teaching in grades 8–13 (age 13–18) in the German system of general education. The program provides teachers with guidelines, examples, suggestions, and collections of material that they can adapt to their specific needs in their particular environment by constructing their own lessons within the given framework. After this original framework had been developed by the core group of science educators, a large-scale project was undertaken (funded by the German Federal Ministry of Education) to implement these ideas in classroom practice. Regional teams of teachers were established and accompanied and supported by members of the project staff. Alternating between individual work and group meetings, the teachers produced, tried out, and reflected on teaching units that were then made available to other groups of teachers for adaptation.

The nationwide discussion in Germany in the past decade about science education standards has led to widespread adoption of the notions of basic concepts and context-orientation in the curricula of several German states.

Cross-References

- ▶ Curriculum Movements in Science Education
- ▶ Programme for International Student Assessment (PISA)
- ▶ Relevance
- ▶ Science, Technology and Society (STS)

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Contradiction

▶ Socio-Cultural Perspectives on Learning Science

Contrat Didactique

► Didactical Contract and the Teaching and Learning of Science

Conversational Analysis

► Discourse in Science Learning

Cooperative Learning

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Cooperative learning is a method of teaching and learning in which students work together in small groups to accomplish a common goal. The goal is reached through interdependent working, although students are also individually accountable for their work within the group. Cooperative learning can be used across a wide range of settings ranging from classroom to lecture, laboratory sessions, and online classes. There are five essential elements of cooperative learning:

- Positive interdependence – group members "sink or swim together"
- Face-to-face interaction – mutual support
- Individual accountability – individual contributions to the task are assessed
- Social skills – include trust-building, leadership, and decision-making
- Group self-evaluation – groups and their teacher reflect on the efficacy of the group

There are many claims from research that cooperative learning results in a higher level of student achievement, as well as social and economic benefits, than when students are engaged in competitive or individually based learning. Theories relating to how cooperative learning "works" suggest that the foundation for cooperative learning success may be explained by a combination of motivational, social cohesion, and cognitive theoretical perspectives. The most commonly reported strategy for developing cooperative learning activity in science classes is "jigsaw." In jigsaw, each group member is responsible for working on a specific task, for example, recording data. All "recorders" in the class are given specific instruction to become "expert recorders." Finally, groups carry out the activity with each member as "expert" in part of the task. Cooperative learning is distinguished from collaborative learning in that cooperative learning is highly teacher directed and more closed ended and has specific answers, whereas collaborative learning is characterized by student empowerment in working together on more open-ended, frequently complex tasks.

Cross-References

► Discussion and Science Learning

Creative Thinking

► Cognitive Acceleration
► Imagination and Learning Science
► Learning Science in Informal Contexts

Critical Issues-Based Exhibitions

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Keywords

Controversial exhibitions; Critical exhibitions; Informal science education; Socio-scientific issues

Introduction

Historically, science centers and science museums have emphasized cultural heritage through artifacts, collections, object displays, and curiosity cabinets – extolling the wonders of science to the public. Over time, however, exhibitions have evolved to include more hands-on components. Visitors interact with exhibits, by a combination of manipulating, reading, pushing, pulling, and generally using their senses. Information is typically structured through engaging, interactive displays.

A number of different typologies for mapping exhibitions have been proposed by researchers. For example, Wellington (1998) describes two types of exhibits (that are not mutually exclusive) usually found at the science center: experiential and pedagogical. The experiential exhibition allows the visitor to experience, and perhaps interact with, phenomena (e.g, soap bubbles, whirlwinds, water vortices, and air or water movements), while the pedagogical category actually sets out to teach something (e.g., positions of organs in the body, separation of dyes by chromatography, or reflection of light). These two types of exhibitions reflect a more dominant traditional way of (re)presenting science focusing on principles, phenomena, theories, and concepts. Little attention is paid to the status or generation of knowledge or the messiness of science – in other words, science is presented to the public as neutral, authoritative, and void of context. However, in recent years, informal science settings have witnessed increased attention to issues in science and technology and consequently have attempted to develop contemporary science and technology installations with all the social and political trappings of the day. This has led to the emergence of a third category – critical exhibitions (Pedretti 2002).

Critical Exhibitions

Critical exhibitions challenge politically safe, sterile, and authoritative images of science and technology usually encountered in science centers and museums. They acknowledge the tentativeness and purposefulness of knowledge creation and negotiation and view science as a human and social activity (i.e., they address nature of science (NOS) perspectives). For example, the exhibition *A Question of Truth* at the Ontario Science Centre is designed to examine several questions about the nature of science, how ideas are formed, and how cultural and political conditions affect the actions of individual scientists. The exhibition questions the nature of scientific truth and attempts to demonstrate how science is influenced by the cultural, personal, and political backgrounds of the practitioners, qualities that include bias, and points of view.

Most critical exhibitions are issues-based and explore complex relationships across science, technology, society, and environment (STSE), inviting visitors to consider issues from a variety of perspectives with an emphasis on involvement, activity, and ideas. These thought-provoking exhibitions are developed in an effort to represent science in context and to engage the public with issues (such as reproductive technologies, climate change, genetic engineering, and mining) that are important to our lives, to the environment, and to our well-being. For example, consider recent installations such as *Energy Tracker* presented at the Miami Science Museum in Florida that encourages the public to critically reflect on energy use and renewable sources. The Smithsonian Natural History Museum presents evidence for evolutionary theory in The David H. Koch Hall of *Human Origins: What Does It Mean To Be Human?* and von Hagens' travelling exhibition *Body Worlds* pushes boundaries using human cadavers to display issues related to health and well-being. Issues-based (or socio-scientific) exhibitions create possibilities for visitors to explore the intersections across science and society and to engage with the messiness of science that stems from social, political, ethical, and historical factors.

Critical exhibitions share common characteristics: they often cut across science, technology, society and environment (STSE), address nature of science perspectives (NOS), raise public awareness about issues, consider multiple points of view, personalize science, connect science and social responsibility, teach about participation and decision-making, encourage people to be active commentators on matters related to science and technology and to be agents of change, offer a forum for discussing and debating issues in society, provide more robust views of science, and encourage healthy public debate about controversial topics.

Courting Controversy

Critical exhibitions are usually controversial in nature due in part to their interdisciplinary subject matter and the coupling of science and ethics. Consider, for example, reproductive technologies, the use of stem cells, health-related research, space exploration, or evolution. Such issues are typically contentious, fraught with ambiguities, and subject to multiple perspectives. Individuals may interpret the same information differently, and reasoning based on science alone may not be enough to resolve the conflict. Controversial issues draw upon different players; stimulate analysis of the construction and deconstruction of facts and theories; draw attention to the social processes of science and how knowledge is negotiated and utilized; and involve struggles over meaning and morality, distribution of resources, and power and control (Delicado 2009; Macdonald 1998; Nelkin 1995). They often raise tensions between individual needs and community priorities. Controversial issues can spark intense and passionate responses from people and involve problems in which different individuals and groups support conflicting courses of action.

Future Directions

It is widely acknowledged that museums and science centers avoid controversial issues. They are difficult to mount, there is an underlying assumption that public institutions are in the business of transmitting science, issues can change quickly, and funding and patronage concerns arise. Future research agendas include questions such as the following: What kinds of exhibitions are appropriate for public consumption? What ethical concerns are raised? What tale(s) do we tell? Whose stories are silenced? What is the role of advocacy? What is the role of funding? How are different viewpoints presented? Furthermore, research should consider the forms of scientific communication that are most meaningful and valuable to the public and how critical exhibitions encourage and develop meaningful public engagement with complex socio-scientific issues.

Cross-References

- ▶ Interactive Science Centers
- ▶ Museums
- ▶ Visitor Studies

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Critical Reflection

▶ Science Teaching and Learning Project (STaL)

Critical Thinking

▶ Cognitive Acceleration

Cross-Disciplinary

► Integrated Curricula

Cross-Disciplinary Concepts and Principles in Science, Assessing Understanding of

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Assessing Cross-Disciplinary Ideas

Certain ideas expressed as principles or as concepts have explanatory power in all science disciplines. In the science education literature, these ideas are called cross-disciplinary concepts and principles, common themes, unifying concepts, and cross-cutting concepts. These ideas serve two functions, one as frameworks for structuring the science curriculum, the other as a facet of science students are expected to come to understand. The assessment challenge is how to describe these ideas in ways in which they can be measured. An example of a cross-disciplinary idea, expressed as a principle, that is applicable to all the natural sciences is as follows: In a closed system energy is conserved. This principle relates three concepts, system, energy, and conservation. These ideas can be assessed as a principle or separately as one of the three concepts.

Evidence of knowing cross-disciplinary ideas includes the capacity to provide examples of cross-disciplinary ideas or the capacity to select cross-disciplinary principles or concepts from lists of principles and concepts some of which are cross-disciplinary and some of which are not. Evidence of understanding cross-disciplinary concepts is provided by the capacity to illustrate by example how the principles or concepts apply to situations in contexts related to different disciplines. Understanding is also indicated by the capacity to distinguish cross-disciplinary principles or concepts from principles and concepts which are not cross-disciplinary. Examples of tasks to evoke responses to be evaluated are the following: What are three cross-disciplinary ideas? Give an example of an idea that is cross-disciplinary and one that is not. Then explain why one idea is cross-disciplinary and the other is not.

Cross-References

► Assessment: An Overview

Cultural Change

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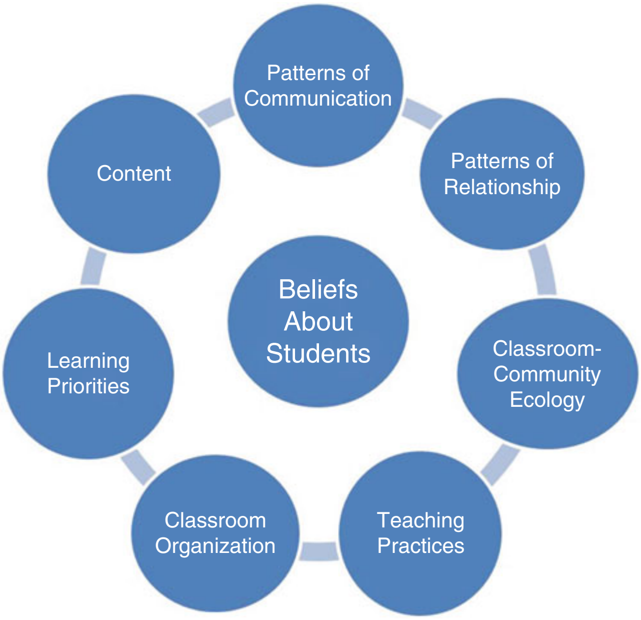
Keywords

Knowledge; Learning; Science

Culturally Responsive Teaching of Science in Canadian Indigenous Settings

Although the science education literature has given attention to the importance of recognizing Indigenous knowledge systems in school science, less attention has been given to the teaching practices that should accompany this knowledge system inclusion and the processes that might accelerate these changes to curricula, including teaching practice. More recent developments in Canada's three most northern territories, the Yukon Territory, Northwest Territories (NWT), and Nunavut, draw attention to how political changes have potential for accelerating practices in education, and science education, specifically, that are responsive to Indigenous people's cultural knowledge systems and practices. In contrast to other provincial jurisdictions in Canada, treaties were historically never negotiated in these northern territories. Over the past three decades, the governments of both Canada and these northern territories have moved toward actualizing policy developments with its Indigenous peoples. These policy developments are commonly referred to as Self-Government Agreements (SGAs). SGAs are complex and wide ranging and include financial compensation, land, harvesting rights, heritage resources, and governance structures in areas like education and justice. The SGAs set out the powers of the government to govern itself, its citizens, and its land.

In the Yukon, the SGAs provide self-governing First Nations (SGFNs) with law-making authority in specific areas of First Nation jurisdiction, including education. For example, the Tr'ondëk Hwëch'in SGA provides for program delivery, design, and implementation of education programs for the Tr'ondëk Hwëch'in First Nation in the Dawson City area with the support and sanction of the Yukon Territorial Government (YTG). With the establishment of SGFNs, each FN with the required cooperation of YTG faces the challenge of reversing assimilation and regaining a sense of identity especially within the processes that influence the education of their children. Typical of most Aboriginal peoples, YFNs presently participate in a school system that has been drawn from the dominant culture, in their case southern Canadian school system models. Because of this, school processes and practices such as decision making in regard to the content of curricula, pedagogical practices and language of instruction have both intentionally and unintentionally denied the inclusion of those aspects of [YFN] culture that have value and are important to [YFN] children (Bishop and Glynn 1999). Consistent with the tenor of SGAs to work toward education practice more responsive to the Yukon's 14 First Nations, "culture-based education" has been more recently identified by YTG and its Education Act as one of the foundational principles for school development in the Yukon. YTG policy requires the activities of organizations in Yukon communities to create, preserve, promote, and enhance their culture, including arts, heritage, and language classrooms. This policy is based upon the principle that culture in all its expression provides a foundation for learning



Cultural Change, Fig. 1 Pedagogical framework for informing culturally responsive teaching of science

Cultural Change, Table 1 Attributes of culturally responsive teachers of science

Category	Description
What are ***my beliefs about students****?*	Students are regarded as culturally located individuals having capacity to learn, like any other, and contribute to my and the entire class' learning. Students expect me to have high expectations for them as learners and as members of a community
What do I emphasize as the ***content*** *to be learned?*	The formal science curriculum becomes the vehicle for the development of personal attributes deemed as important. Learning is not abstract. It focuses on and is located in local context and connected to students' lives. Science ideas are embedded with contexts, enriched through "working to end" type projects involving tangible end products. Literacy and numeracy development are emphasized as we are learning science. Developing fluency in these areas is a priority. What is learned does not compromise on students' cultural background. Instead it uses this to engage students and support their learning
What ***patterns of relationship*** *contribute to learning?*	The teachers' role is to cause learning. Establishing a classroom environment that promotes learning is the priority. Manifest in the relationships is a priority on caring. Caring manifests itself in actions – it supports, expects, challenges, affirms and is responsive to each individual and their situation. To do this, classroom routines are very important. Expectations and learning goals are clearly communicated and upheld. There is little compromise on established priorities, especially in regard to learning. Families are on board with these priorities and support these priorities. There is opportunity for students to contribute to decision making. Classroom allows for student voice in establishing consensus, but such that they never compromise on learning
In what ways does this ***classroom ecologically represent the community****?*	The classroom is physically represented through a variety of cultural representations and artifacts. Most importantly local language and community members and their protocols are welcomed and encouraged to be expressed. Learning is promoted through the participation of community members. Much learning occurs outside of the classroom because the community is seen as a contributing resource for fostering learning
When I am teaching ***how do I teach, and what are my practices for causing learning?***	In teaching practice, modeling and demonstrating are common. Visual images are commonly used to inform especially as a pre-reading exercise. Repetition and focus on mastery are emphasized. Time provision is made to gain mastery and think things through. Students show learning in a variety of ways, not just in written form and are given feedback to support next steps in learning. Collaboration and reciprocation in learning are important. The teacher and students must involve each other in a student's learning. It is vital that students are receiving individual attention and are given feedback and affirmation as they learn. Story telling and the use of narratives focusing on local context are frequent. Connections always made between prior learning and new learning across curriculum areas
How can ***classroom organization*** *say about how we learn and what is important in learning?*	Classroom routines are very important. Expectations are clearly communicated. There is opportunity for negotiation and renegotiation, especially because we are a community of individuals. Organization provides time, opportunity, and support for students to learn and show learning. Working for learning allows for assistance and feedback from peers

(*continued*)

Cultural Change, Table 1 (continued)

Category	Description
*What should be the **patterns of communication** when teaching and learning is occurring*	The communication patterns are dialogical rather than univocal, voluntary rather than involuntary. Listening is as important as talking. Sharing circles are a common practice to provide each student time and space to contribute, without interruption. As a teacher, I undertalk more commonly than I overtalk. When I talk with students individually or collectively, I physically situate myself at their level. Students communicate their learning through a variety of modes, not just in writing. The communication patterns are encouraged by a learning environment that focuses on learning as a collective activity
*What are the **learning priorities**?*	Focus is on the development of individuals who believe in themselves as culturally located individuals that are self-reliant, resilient, and contributors to their classroom and community. Although academic knowledge is important, the learning must be broader focusing on the development of life tools such as perseverance and self- sufficiency as well as interdependence and respect. Fundamental literacy and numeracy skills are regarded highly

and growth and that YTG should support individuals, organizations, and communities to promote, preserve, and enhance their culture (YTG 2005). The educational experiences should be reflected not only in the management and operation processes of the school but also in the curricula and programs implemented and pedagogies used in classrooms. Although culture-based education may be rhetorically premised as the foundation of northern classrooms, what would classroom environments and teacher practices look like that are, indeed, reflective of YFN students' preferences? From the formal and informal learning of experiences of YFN community members, what would culturally responsive teaching look like, especially in science education?

Over the past decade (2002–2012), we, as researchers, have participated in and continue to participate in several research and development projects in our northern territories that focus on (1) determining Indigenous communities aspirations for education, especially science education; (2) identifying teaching practices, especially in science education, that are responsive to the learning interests, styles, and interests of students and the communities they represent; (3) developing with community members science education resources consistent with these interests, styles, and aspirations; (4) upon implementation, determining the influence of these pedagogies on student learning; and (5) based upon these findings, developing a description of what effective teaching looks like within our northern schools (Lewthwaite and McMillan 2009; Lewthwaite and Renaud 2009; Lewthwaite and Wood 2009; Lewthwaite et al. 2010). Likely of most consequence from these studies is the understanding of what a culture-based teaching entails.

In Fig. 1 below, we illustrate the various factors that consistently surface as indicators of effective teaching practice in influencing positively student learning. At the center of the visualization are "beliefs about students." In our experience with effective teachers in Indigenous settings, central to being a responsive teacher of science is a belief in the capability and cultural merits of each student. At the heart of many school systems' thinking is a belief or, at least, an assumption that Western ways are superior and that Aboriginal culture and specifically students may bring deficits to classrooms, not assets. Such thinking suggests that not only are students' background experience and knowledge of limited importance to promote learning, but so are their cultural foundations. Deficit thinking or theorizing, as it is called, is the notion that students, particularly low-income, minority students, fail in school because they and their families experience deficiencies such as limited intelligence or behaviors that obstruct learning. In contrast, those that effectively implement a culturally responsive pedagogy believe that students have a whole set of beliefs, skills, and understandings formed from their experience in their world and that their role as teachers is not to ignore or replace these understandings and skills, but to recognize and affirm them.

In Table 1 some more detailed insight into how teacher's practice can be responsive to students' cultural backgrounds. The table makes explicit the behaviors we commonly evidence in effective teachers. In brief, the actions of teachers are primarily focused on ensuring that their actions are *reflective* of students' backgrounds.

At the heart of these effective practices is teachers of science accepting that they are the central players in fostering change, first in themselves by altering their beliefs about students and the cultures they represent and, then, working collaboratively toward an environment where practices reflect the culture in which students and their teaching practices assist students in their learning.

Cross-References

- ▶ Cultural Influences on Science Education
- ▶ Culture and Science Learning
- ▶ Learning of Science – A Socio-Cultural Perspective
- ▶ NOS: Cultural Perspectives

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Cultural Imperialism

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Keywords

Science Education in the Non-West

While *imperialism* refers to the establishment and maintenance of unequal relationships between countries or societies through conquest and political power, the term *cultural imperialism* is used to identify a form of ideological infiltration that enables some dominant states, organizations, or groups to impose their worldview, values, attitudes, behaviors, linguistic patterns, and lifestyle practices on others, sometimes by deliberate policy, sometimes by means of economic or technological superiority and influence. The term came to prominence in the 1970s through the work of Herbert Schiller (1976) who used it to describe the ways in which multinational companies and the mass media seduce, persuade, force, bully, or bribe social institutions and individuals to act in conformity with, or even to promote, the dominant ideology. Use of the term by scholars in history, philosophy, sociology, anthropology, education, and cultural studies is strongly influenced by the writing of post-structuralists such as Michel Foucault and Jacques Derrida, while in postcolonial discourse it is used to identify and define the cultural legacy of colonialism through forms of social action and organization, language use, and value judgements that contribute to the continuation of western hegemony long after independence.

Whatever the precise definition of cultural imperialism employed, it is apparent that education plays a key role in the establishment, maintenance, and legitimization of the views, beliefs, values, and practices of the dominant group. It does so through two interacting influences: *curriculum experiences*, what students encounter during lessons, and *informal learning experiences*, what is learned via the media (movies, TV and radio, newspapers), Internet sites, advertising, and visits to museums, zoos, aquaria, nature reserves, field centers, and the like. Curriculum experiences are of two kinds: those that are explicitly planned and those that are not. With regard to science education, there are many explicit messages about science, scientists, and scientific practice in textbooks, especially in passages that tell students what science is about and what scientists do when they are conducting investigations; there are explicit references to the nature of science and the history of science in curriculum materials designed for a science-technology-society (STS) approach, and there are references to cutting-edge science and the ethical issues it raises in curriculum materials addressing socioscientific issues (SSI). Teachers often draw explicit attention to features of science and scientific inquiry during laboratory activities and class discussions. Just as frequently, however, messages about the nature of science and scientific practice are not consciously planned by the teacher. Rather, they are implicit messages located in the language used, the kind of teaching and learning activities employed (especially in laboratory work), the examples of science and scientists utilized, the illustrative and biographical material in textbooks, and so on. Many students assume that whatever they do in science lessons, particularly during hands-on activities, mirrors what scientists themselves do as they conduct investigations. Over time, these experiences build into a particular set of messages about science, scientists, and the scientific enterprise. What is at issue here is a very powerful *hidden* or implicit curriculum that conveys messages just as powerful as those of the formal, planned curriculum.

Curriculum decisions (whether consciously or unconsciously made) necessarily reflect the perspectives of the decision-makers. Hence the selection of knowledge for the science curriculum does not reflect a common heritage but one rooted in the knowledge, assumptions, and values of those who have dominated society and educational discourse – in Western society, mostly white, male, and middle class. Further, because many of the individual messages about science are conveyed implicitly via teachers' day-to-day, short-term decisions about the conduct of lessons, the teacher's views constitute a major element of the overall story about science. In many cases, these views are located within a Western tradition, often a positivist tradition that regards science as having an all-purpose, straightforward, and reliable method of ascertaining the truth about the universe, with the certainty of scientific knowledge being located in objective observation, extensive data collection, and experimental verification. Moreover, scientists are seen as rational, logical, open-minded, and intellectually honest people who are required, by their commitment to the scientific enterprise, to adopt a disinterested, value-free, and analytical stance, in conformity with the norms of scientific practice postulated by Robert Merton (1973): universalism, communality, disinterestedness, and organized skepticism.

In making decisions about what to include or exclude from the curriculum, we not only define and limit what counts as science, we erect potential barriers that restrict access or make access to science and science education difficult. It is here that the notion of cultural imperialism can be helpful in focusing attention on the subtext of science education – in particular, on the exclusion of knowledge about the natural world accumulated outside of conventional Western science (variously described as traditional knowledge, Aboriginal knowledge, Indigenous knowledge, and traditional environmental or ecological knowledge); the neglect of ideas drawn from contemporary philosophy of science, history of science, and sociology of science; and the disregard of the perspectives of practicing scientists and the insight provided by commentators on the sometimes harsh realities of contemporary scientific practice – what John Ziman (2000) calls "post-academic science." The notion also raises awareness of the ways in which traditional knowledge and practices in many colonized countries were forcibly replaced by Western science and Western agricultural practices, often with untold damage to local ecosystems and destruction of the social fabric.

Cross-References

- ▶ Acculturation
- ▶ Poststructuralism and Science Education
- ▶ Science Education in the Non-West
- ▶ Science, Technology and Society (STS)

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Cultural Influences on Science Education

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Keywords

Categories; Culture; Cultural reproduction; Culture; Identity; Indigenous knowledge; Instruments; Nature of science; Otherness; Science Education in the Non-West

Acknowledgement of the role of cultural influences on science education is a relatively recent development, initiated in part by anthropological and sociological explorations of how specific contexts influence teaching and learning. Kenneth Tobin (2006) has written of science education experiencing a "cultural turn" as science education and discourse researchers begin to acknowledge and explore the influence of culture on science education, increasingly scrutinizing and critiquing universal notions of science practices and knowledge production. As a construct, culture owes its existence to the field of anthropology. Other fields, like education, with interests in the production of ideas, processes, and material social practices, have found the construct of culture to be useful for their purposes also.

What Is Culture? Models of Culture

At an abstract level, culture can be thought of as a theoretical category of social life that can be differentiated from other categories of similar stature such as politics, economy, and history (Sewell 1999). Typically, when we talk of culture, we are seeking to differentiate between different groups, identifying bounded entities of beliefs, practices, and ways of knowing as different cultures. Research that initially sought to explore cultural influences on science education was influenced by Clifford Geertz's (1973) notion of cultures as clearly bounded, consensual, and resistant to change. This model supported productive research in science education on student negotiation of "border crossings" between students' lifeworld culture and the culture of science leading Aikenhead to argue that treating science as a cultural enterprise constituted a radical shift in thinking for some science educators (see Aikenhead 1996).

But studies from history and sociology of science and from science education research have challenged this model of culture, leading researchers instead to endorse cultures as fields of material social practice and worlds of meaning that internally are contradictory, contested, subject to constant change, and weakly bounded (see Sewell 1999). The power of this model is that it allows researchers to acknowledge and value contradictions as well as coherences in data of human action, such as that collected from working with learners and teachers in classrooms, rather than try to explain away the contradictions that inevitably exist in all data sources.

Science Education, Cultural Reproduction

Historically, the goal of science education was twofold. First, all students would be assimilated into the culture of science through practice and assessment, a desirable end because of the superiority of science as a way of knowing and being. Second, through education, students would come to adopt and reproduce this superior form of knowing and being, including the norms, values and practices, and acceptance of what is real according to science (Aikenhead 1996). A cultural evaluation of these goals indicates that schooling has a role in ensuring that one vision of what constitutes scientific knowledge and practice is reproduced. However, challenges for this vision emerge in the differences between the everyday culture that students experience, in which they are experts, and the culture of science they are expected to reproduce throughout their educational experience in a school. A nuanced understanding of culture suggests, even more strongly, that the practice of assimilation exerts violence on students who come to science with different understandings. This construction of culture may help researchers to understand why so many students present negative perceptions of science or do not see science as part of their lifeworld and so do not choose to persist in science. Teachers may experience similar cultural disconnectedness from science; Carter (2008) uses the metaphor of science as a cultural story in order to allow beginning primary (elementary) teachers to identify a starting place for themselves in science.

Science as Culture and the Nature of Science

According to Sewell (1999), because cultures are contradictory, contested, and weakly bounded, the powerful (e.g., white, middle class, male in Western cultures) use power, not to establish uniformity, but to organize difference by identifying what is normal or accepted for a culture and marginalizing those that diverge from the norm. Such practices create a map of culture and difference, which tells people where they belong and what fits. However, because cultures are weakly bounded, loosely integrated, and contradictory, their borders are fuzzy and friable, and science education illustrates this issue very well.

What Is Science? In science education, one of the obvious questions that educators are often asked to explore is "What is the boundary of science"; in other words, "What is science and what is non-science?" While some science education researchers may present this boundary as objective and definite, implying that identifying science from nonscience is straightforward, a cultural perspective serves to help us identify the porousness of even this most strongly held belief about this boundary (see Pedynowski 2003). Additionally, cultural perspectives lead researchers and educators to accept that internally, science is heterogeneous and not homogenous as it is often presented in science education resources and in schools. One implication of accepting the porosity of this boundary and the heterogeneousness of the model of what constitutes science is accepting that there is an equally valid place in science for both the observational studies of geological sciences and the explanatory studies of particle physics. Studies within a specific science field also highlight that scientific work is nationally variable (see Fujimura 2000), not universally homogenous.

Traditionally, the development of scientific understanding has been presented as universal; immune to the culture, ethnicity, gender, race, sexual orientation, or religion of the knower; and dependent only on the restrictions of the natural world. However, cultural perspectives reject universal essentialist claims of scientific knowledge, recognizing that the practices, norms, and products of scientific inquiry vary across time and fields (disciplines) and encourage pluralist claims associated with the nature of science. Pluralist models of science education accept that all forms of knowledge exist in a cultural context, so the knowledge must be imbued with the values that are espoused by a culture. A willingness to accept the value-laden nature of knowledge construction is one of the first steps towards developing a richer understanding of a discipline, like science. These perspectives are illustrative of ongoing debates in science education between proponents of pluralist and universalist models of science education and the role of indigenous knowledge in science education (see McKinley 2005)

Beyond Concepts. The notion of culture as material social practices leads researchers to recognize the role of historical context in the development of these practices and associated meanings. For example, in my exploration of the history of understanding the relationship between boiling point and pressure, shows that the development of the thermometer (material practice) was just as important as the conceptual development of an understanding of air pressure and boiling point (social practice) (Milne 2013). Without a way to measure temperature, the conceptual questions could not even be framed. Cultural sensitivity of social practice also leads researchers to acknowledge their cultural stance with respect to the field they are seeking to explore. For example, researchers developing a survey instrument or identifying questions they wish to ask research participants in an interview will always explain in their writings how their understandings, positions, and biases with respect to the concept or construct they wanted to investigate informed and influenced the questions they asked the participants. Typically, this is the practice most ignored by researchers without a cultural perspective.

Belonging to a Culture and Otherness: Categorizing Identity

One other area where culture has influenced science education is in helping us to understand the interaction between individuals and culture in terms of how individuals construct themselves or are constructed; that is their identity. Individual and group identities are culturally and socially constructed around categories such as ethnicity, gender, race, sexual orientation, religion, and occupation, and individual people are categorized in various ways. Identity can be thought of as an objective sense of oneself, which individuals present to others for confirmation. Categories, such as white, Asian, woman, and brainy, can also be inscribed on people as an identifier of belonging to a particular group whether or not they wish to be so categorized. An individual's identity is strongly connected to the cultural production (learning) she has experienced which can be disturbed if someone experiences a culture very different to that with which they are familiar and which they can experience as a form of "culture shock" (see Michie 2011). With greater cultural awareness, researchers and educators are more open to exploring how cultural categories, such as race and gender, are embedded in presentations of scientific knowledge. For example, Bazzul and Sykes (2011) examined heteronormative representations of gender in a biology textbook used with high school students raising the question of why such textbooks represent the constructs of sex and gender as identical and exclusively about men and women to such a vulnerable population.

Generalizing and Otherness. Cultural influences also induce researchers and educators to cast a critical eye on attempts to generalize behavior to a small set of principles. While we can celebrate Galileo's use of idealization to propose the existence of gravity or Piaget's attempt to find universal structures in learning and behavior, cultural perspectives support us to recognize that with this focus on sameness, we lose sight of difference. In many cases, difference becomes identified as otherness. A cultural perspective may prompt researchers to examine critically a catchphrase like, "Science for All," asking, "Whose science? Who is left out?"

Summing Up

This short entry provides just an inkling of how culture influences science education. But hopefully it has communicated how any exploration of cultural influences from coherence and contradictions to identity and instruments offers the potential for a richer, more nuanced understanding of some of the elements that could serve to develop a more humane and inclusive science education. An understanding of cultural influences reinforces the notion that we have a responsibility to look with a critical eye, locally and globally, at how science education and science construct and use knowledge. We must examine not only who is included and marginalized through our stances, but how science education can better support the science learning of all children and youth. Finally, cultural influences support educators to answer one of the most important questions in science education, How does education support learners to see a role for science in their individual identities?

Cross-References

- ▶ Borders/Border Crossing
- ▶ Cultural Imperialism
- ▶ Cultural Values and Science Education
- ▶ Culturally-Relevant Pedagogy
- ▶ Culture and Science Learning
- ▶ Gender
- ▶ Identity
- ▶ Indigenous Knowledge
- ▶ NOS: Cultural Perspectives
- ▶ Retention of Minorities in Science
- ▶ Science Education in the Non-West
- ▶ Socio-Cultural Perspectives and Characteristics
- ▶ Socio-Cultural Perspectives on Learning Science
- ▶ Values and Indigenous Knowledge
- ▶ Values and Western Science Knowledge

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Cultural Values and Science Education

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Cultural Values and Science Education

Culture is the cumulated experiences of a people group which shape their behavior and overall worldview. Cultural values are attributes that a people group considers to be critical to its survival. Science is a systematic endeavor which attempts to describe, explain, predict, and control nature. Science education is the field of study expressly concerned with two important goals: (1) the development of potential scientific human power and (2) the development of a scientifically (and technologically) literate society. In a world dominated by science and technology, the development of a scientifically literate citizenry is imperative. But in the pursuit of scientific literacy, it is worth noting that certain cultural values differ remarkably from those of science. Also, not all cultural values are associated with science, i.e., there are cultural values which strictly speaking are outside the realm of science. At times, science education must make connections between science and broader cultural values. A contest of values between science and culture serves neither the interests of the students, their communities, nor those of the scientific community.

Cross-References

- ► Culture and Science Learning
- ► Learning of Science – A Socio-Cultural Perspective

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Culturally-Relevant Pedagogy

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Keywords

Border crossing; Discourse; Funds of knowledge; Hybridity; Third space

A hallmark of science education near the end of the twentieth century was the recognition of the importance of culturally relevant pedagogy (CRP), a term first coined in 1995 by Gloria Ladson-Billings. Since the initial introduction of this concept, a deeper understanding of CRP has evolved through a variety of discourses, particularly in relation to its application in science education. Each of these discourses in some way reflects aspects of Ladson-Billings' (1995) criteria for culturally relevant pedagogy: (1) high expectations for all students to experience success, (2) the development or maintenance of cultural competence, and (3) the construction of a critical consciousness or critical literacy which fosters an analysis of the hidden forces of power which shape our logic, anesthetize our ethics, and even define what we call a problem. In today's twenty-first-century science classrooms, science educators must continue to employ sociocultural consciousness, which draws inspiration from and builds curricula around ways of seeing beyond our differences. Rather than melting difference to make us all the same, we must celebrate the backgrounds of students and make them equally valid in order to provide all learners with the opportunity to experience scientific success.

CRP is especially important considering the increasing diversity due to the mobility of today's world population. Students and families are much more transnational now than ever before due to increased air transportation and Internet. As Carter (2012) points out, our "everyday consciousness is now one of a global imagery, making us feel connected to far-flung places and events" (p. 899). As the world's population mobility continues to escalate, it is likely these changes will endure and increase the diversity in student populations. Thus, it is important to recognize that various conceptualizations or discourses surrounding CRP have, in recent years, been embedded in a larger macro-discourse, the complex sociopolitical-economic context of globalization. An alternative to this is a discourse of "glocalization," whereby a dialectical relationship between local and global practices creates opportunities for a more pluralistic science education.

CRP is an idea which merges conceptions of culture, relevance, and pedagogy in unique ways. From a sociocultural perspective, culture can be viewed as very fluid, lacking coherent boundaries, and ever changing. It is enacted or produced through agency, in which actors, both individually and collectively, consciously appropriate structures in ways that are goal oriented and intentioned. Culture is also created passively in ways that may be aligned to specific goals such that "an actor is aware of culture being created over which she/he does not have complete control" (Tobin 2012, p. 5). In this sense, culture can be depicted as a continuous dialectical relationship between agency and passivity. In contrast to mythical, romantic, and stable myths, pedagogy that is culturally relevant constantly asks the question of whose science and for what purposes are students learning. Pedagogy, often described as the art of teaching, involves the skills, mindsets, beliefs, and knowledge an individual constructs in order to teach subjects such as science. Taken together, CRP emerges as a concept historically described and sometimes used interchangeably with "culturally congruent" and "culturally responsive teaching." It has been compared to a bridge connecting home and school cultures and described as teaching that aims to create democratic and multicultural classrooms that empower students. However, CRP takes on new meaning in light of sociocultural perspectives on science teaching and learning.

In the context of science education, CRP can be viewed through the lens of various discourses, which develop our ability to see from multiple frames of reference. The complexity, integration, and overlap of these various discourses can help us discern further insight into some of the limitations of earlier conceptions of the term. Furthermore, these discourses are beneficial because they represent the ways people have discussed CRP and show how a deeper understanding of how it has evolved in science education.

One of the most often discussed discourses promoting CRP in science education is the notion of "border crossing." This discourse suggests that when students' life experiences differ from the culture of school science, they may feel alienated by science if no attempt is made by the teacher to understand and incorporate their cultures into the science classroom. Non-mainstream students may feel this even more strongly if the examples and topics presented in school are irrelevant to their lived experiences. This discourse further emphasizes the need for educators to use culturally relevant methods and topics to present material in ways that build on students' prior knowledges and experiences, making connections between the known and the unknown. Historically, the concept of border crossing was viewed as unidirectional (i.e., students crossing into school or western science). More recently, Aikenhead (2006) has emphasized the need for science education researchers to view border crossing as occurring in two directions: both into and out of school science. He suggests that Aboriginal peoples, for example, have certain indigenous knowledges that can and should be central to science learning. The discourse of border crossing argues that it is important to change the structures of schools to acknowledge the culture of students.

Another common discourse used in discussing and fostering CRP centers around the idea of community funds of knowledge. Funds of knowledge are the experiences, values, identities, and feelings that comprise a child's life. From the perspective of this discourse, student learning and interest can be maximized when educators build on the funds of knowledge of the learner and his or her community. By building on prior knowledge, language, traditions, ways of knowing, and place-based narratives, important connections can be made between students' everyday lives and science. For example, in many rural areas with a strong sense of community, intergenerational knowledge is passed down and this knowledge includes nutritional choices and values. Students could develop nutritional literacies, by investigating dietary lifestyles of members of the community. In this way, we can build curricula and our ways of seeing by drawing inspiration from individual and community funds of knowledge.

CRP can also be encouraged through a discourse centered around creating a practicing culture of science learners. A practicing culture of science learners is a community of people who are learning about science as they do science in ways that mirror the practice of scientists. A community garden, for example, is a place where students can learn about plant biology by producing science as their garden grows. The garden is a context in which students can come together with local people and share in making decisions about their everyday lives and natural environments. Local people are at the heart of a practicing culture of science learners. Students can practice science outside the classroom and learn by doing, even when new information and experiences may be at odds with students' existing understandings. A community garden grown in an urban setting might feel very foreign to students initially, but by growing some of their favorite foods and sharing with their families and friends, it could become familiar and foster a genuine interest in science.

CRP discourse has also taken a critical stance. It has challenged science educators to think critically about how knowledge can be used to educate students and make social changes rather than fuel social reproduction. This is an idea similar to what Ladson-Billings (1995) described as the critical consciousness tenant of CRP which encourages students to learn to critique and interrupt current and historical social inequities. Critical discussions can encourage and empower students to think individually and not just take for granted mainstream science ideology. Consider, for example, an ecology class in an urban setting where students might read about factories polluting the air of the neighboring countryside where their food is grown. Students could conduct research to become informed about this socio-scientific issue, use this information to make decisions about the health of their community, and take appropriate actions. The challenge is to apply examples in textbooks and other resources to something students might have experienced and give them the tools to make a difference in their lives and those of community members.

More recent discourses surrounding CRP are centered on notions of third space and hybridity. Third space involves the intersections between students' home-community culture and school culture. It is the arbitrary area where culturally relevant teaching connects students' life worlds. Third space is not just accomplished by building bridges between differing cultures, but by using what has been learned about the past and present to facilitate change. For example, Paris (2012) notes that children of migrant farm workers can learn about their culture, where their families came from, where they are now, and the possibilities for their futures. In this way, students join their homes and communities with schools in meaningful ways without devaluing their history and cultures.

Whereas third space is about locating the knowledge in an area, the concept of hybridity is about creating a new type of knowledge. This new knowledge is made by blending students' home culture with the culture of school science and results in a hybridized culture that emphasizes heterogeneity. The additional twist of hybridity, compared to third space, is that students must also come to know and understand the culture of the teacher. In this way, the classroom and participants are constantly embracing multiculturalism. To assist in the cultural blending process, culturally relevant examples are especially important. For example, traditional ecological knowledge (TEK) can be incorporated into science classrooms to facilitate hybridity for all learners. Both teachers and students would simultaneously expand their knowledge on various cultural systems and ecologies.

Moving beyond CRP is the next logical step in thinking about the kind of science education that will be meaningful to the twenty-first-century youth. Science educators are making a point of including relevant material in their classes, but the question "Relevant to what?" continues to be raised. Relevancy as curriculum-centered science and relevancy as community-based science are two concepts proposed as a next step. Curriculum-centered science involves input from various local educational and community sources in developing applicable materials and approaches to teaching science. In this case, the curriculum would be built from the bottom-up using local educational and community sources, instead of top-down from state or national standards. Community-based science changes the curriculum and connects it to the community where students live. It involves meeting students' families, learning about their home life, investigating issues within the community, and developing what is taught from what has been observed and suggested from community members.

Questions have been raised about the implications of CRP for the twenty-first-century learners. Is emphasizing high expectations, cultural competence, and critical consciousness enough to promote CRP and establish sociocultural consciousness and caring? While it is necessary for students to experience a diversity of curriculum materials and pedagogies reflecting a range of ideologies, educators must be cognizant to transcend “tip of the iceberg” conceptions of culture. Many times, curriculum materials and pedagogies are designated as culturally relevant because they include dress, folk dancing, cooking, or music from a variety of cultures. However, while these surface conceptions of culture may promote cultural awareness, they might actually lead to more ridicule and stereotyping of certain students. Besides being relevant and responsive, curriculum and pedagogies should be culturally sustaining. Culturally sustaining pedagogies, such as encouraging the use of student’s first language as they communicate amongst themselves during a lab session, will perpetuate and support cultural pluralism. The discourses and educational frameworks that shape our understandings of CRP should be constantly challenged, amended, and extended by “testing out” their theoretical soundness through diverse research methodologies. As demographics change, science education must also evolve to include culturally relevant pedagogies and curriculum that will promote and enhance science achievement for the twenty-first-century learners.

Cross-References

- ▶ Borders/Border Crossing
- ▶ Cultural Change
- ▶ Culture and Science Learning
- ▶ Ecojustice Pedagogy
- ▶ Worldview

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Culture

- ▶ Cultural Influences on Science Education
- ▶ Culture and Science Learning
- ▶ Socio-Cultural Perspectives on Learning Science

Culture and Science Learning

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Keywords

Culture

This entry seeks to summarize our understanding of the processes of science learning that occur within and at the intersection of diverse worldviews and knowledge systems, drawing upon experiences of various indigenous societies. The curricula, teaching methodologies, and assessment strategies associated with mainstream schooling are based on a worldview that does not adequately recognize or appreciate indigenous notions of an interdependent universe and the importance of place in their societies (Kawagley 2006). Many indigenous as well as nonindigenous people have begun to recognize the limitations of a monocultural education system, and new approaches have begun to emerge that are contributing to our understanding of the relationship between indigenous ways of knowing and those associated with western society and formal education. Our challenge is to devise a system of education for all people that respects the epistemological and pedagogical foundations provided by both indigenous and western cultural traditions.

While western science and education tend to emphasize compartmentalized knowledge which is often decontextualized and taught in the detached setting of a classroom or laboratory, indigenous people have traditionally acquired their knowledge through direct experience in the natural world. For them, the particulars come to be understood in relation to the whole, and the "laws" are continually tested in the context of everyday survival (Cajete 2000). Western thought also differs from indigenous thought in its notion of competency. In western terms, competency is often assessed based on predetermined ideas of what a person should know, which is then measured indirectly through various forms of "objective" tests. Such an approach does not address whether the person is actually capable of putting that knowledge into practice. In the traditional native sense, competency has an unequivocal relationship to survival or extinction – if you fail as a caribou hunter, your whole family may be in jeopardy. You either have it, or you don't, and it is tested in a real-world context.

Indigenous people do a form of "science" when they are involved in the annual cycle of subsistence activities. For a student imbued with an indigenous, experientially grounded, holistic worldview, typical approaches to schooling can present an impediment to learning, to the extent that they focus on compartmentalized knowledge with little regard for how academic subjects relate to one another or to the surrounding universe.

To bring significance to learning in indigenous settings, the explanations of natural phenomena are best understood by students if they are cast first in indigenous terms to which they can relate and then explained in western terms (Aikenhead 2001). For example, when choosing an eddy along the river for placing a fishing net, it can be explained initially in the indigenous way of understanding, pointing out the currents, the movement of debris and sediment in the water, the likely path of the fish, the condition of the river bank, upstream conditions affecting water levels, the impact of passing boats, etc. Once the students understand the significance of the knowledge being presented, it can then be explained in western terms, such as flow, velocity, resistance, turbidity, sonar readings, tide tables, etc., to illustrate how the modern explanation adds to the traditional understanding (and vice versa). All learning can start with what the student and community already know and have experienced in everyday life. The indigenous student (as with most students) will then become more motivated to learn when the subject matter is based on something useful and suitable to the livelihood of the community and is presented in a way that reflects a familiar worldview (Kawagley 2006).

There is a growing awareness of the depth and breadth of knowledge that is extant in many indigenous societies and its potential value in addressing issues of contemporary significance, including the adaptive processes associated with learning and knowledge construction (Battiste 2002). The new sciences of chaos and complexity and the study of nonlinear dynamic systems have helped western scientists to also recognize order in phenomena that were previously considered chaotic and random. These patterns reveal new sets of relationships which point to the essential balances and diversity that help nature to thrive. Indigenous people have long recognized these interdependencies and have sought to maintain harmony with all of life. With fractal geometry, holographic images, and the sciences of chaos and complexity, the western thought-world has begun to focus more attention on relationships, as its proponents recognize the interconnectedness in all elements of the world around us. Thus there is a growing appreciation of the complementarity that exists between what were previously considered two disparate and irreconcilable systems of thought (Kawagley and Barnhardt 1999).

The incongruities between western institutional structures and practices and indigenous cultural forms are not easy to reconcile. The complexities that come into play when two fundamentally different worldviews converge present a formidable challenge. The specialization, standardization, compartmentalization, and systematization that are inherent features of most western bureaucratic forms of organization are often in direct conflict with social structures and practices in indigenous societies, which tend toward collective decision-making, extended kinship structures, ascribed authority vested in elders, flexible notions of time, and traditions of informality in everyday affairs (Barnhardt and Kawagley 2008). It is little wonder then that formal education structures, which often epitomize western bureaucratic forms, have been found wanting in addressing the educational needs of traditional societies.

When engaging in the kind of comparative analysis of different worldviews outlined above, any generalizations should be recognized as indicative and not definitive, since indigenous knowledge systems are diverse themselves and are constantly adapting and changing in response to new conditions. The qualities identified for both indigenous and western knowledge systems represent tendencies rather than fixed traits and thus must be used cautiously to avoid overgeneralization (Gutierrez and Rogoff 2003). At the same time, it is the diversity and dynamics of indigenous societies that enrich our efforts as we seek avenues to integrate indigenous knowledge systems in a complementary way with the system of education we call schooling.

Cross-References

- ▶ Acculturation
- ▶ Cultural Influences on Science Education
- ▶ Science Education in the Non-West
- ▶ Transmission of Culture

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Curriculum

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Keywords

Aims; Assessment; Attained; Intended; Policy; Laboratory; Subjects; Taught; Teaching; Theoretic

The word “curriculum” referred originally to the track around which Greek and Roman chariots raced, but its first educational use was at the University of Glasgow in 1824 to refer to the course of study followed by undergraduates. While the word has been defined in a variety of ways, it is almost always associated with formal education (i.e., schools, colleges, and universities) and refers to the content of a student’s educational program. The term is used throughout the English-speaking world, but, despite its Latin origin, it is not commonly found as a cognate in other European languages.

The curriculum, both the overall curriculum and the curriculum of any specific subject, such as the science curriculum, expresses the purposes, goals, or *aims* for education. While informal learning (such as that taking place in play) can be random and aimless, formal education in schools always has aims or purposes that permeate instruction, and these are usually stated in curriculum documents. In addition, the curriculum also has subject-matter *content*. An overall curriculum can consist of any number of subject fields (or they can be integrated), and within each one there are usually topics or themes to be taught at each year or group of years. A curriculum may also contain statements about the processes of teaching and learning, and these are often a logical consequence of the curriculum aims. For example, a curriculum could have, as one of its aims, that students will develop the skills of investigation. Such an aim would imply that the teaching of the subject-matter topics would include providing opportunities for pupils to undertake investigations into those topics. Finally, a curriculum may contain explicit or implicit statements about the assessment that should be carried out in relation to both the aims and content.

But a curriculum is much more than a static statement or document. The curriculum that an individual student actually experiences is the result of decisions made at various levels, some far removed from the classroom. In many jurisdictions, some of these decisions are taken at the government level, where Ministries or Departments of Education set out curriculum policies relating to schools under their control. These may outline, for example, the subjects that students should study at each level of schooling; they may include more detailed lists of topics to be taught at each year or grade; and they may also specify textbooks or published courses that teachers must follow. All such policies exemplify what is called the *intended* curriculum. Regional or local school authorities below those of the national government, examination boards, and even schools themselves may also issue curriculum or syllabus specifications. These are all elements of the intended curriculum, and most teachers develop their instructional activities on the basis of some externally mandated curriculum policies of this nature.

At the classroom level, each teacher delivers what has been described as the *implemented* or *taught* curriculum. This curriculum is based in part on the intended curriculum (or at least on a teacher's understanding or perception of it), in part on resources available and used by the teacher (such as textbooks and other curriculum resources), and in part on the teacher's own philosophy, ideas, and perceptions of the students' needs. As a result of this combination of inputs, the taught curriculum can often differ in significant ways from the intended curriculum, and these differences have been the subject of much empirical research over the years.

Finally, at the level of each individual student, there is what is known as the *learned* or *attained* curriculum. This is obviously related to the taught curriculum but also differs from it. While the taught curriculum is usually delivered to a whole class of students, learning takes place within the mind of each student and is the result not only of the instruction but also of what was known before, of each student's interests and abilities, and of the circumstances of the classroom situation. Sometimes little of what was intended or taught is actually learned. Sometimes, additional, unintended learning takes place (what Dewey called "collateral learnings"). These additional learnings have also been called the "hidden curriculum" because they are not part of the intended curriculum or even an explicit aspect of the taught curriculum.

The curriculum aims, content, teaching processes, and assessment can be thought about and observed at the levels of the intention, teaching, and learning. But the intentions in a given curriculum may not be fully realized in the taught curriculum, and those of the taught curriculum may not be attained in the learned curriculum. These differences have given rise to much curriculum research but also point to one of the central realities of curriculum: while much can be written as policy, as textbook, as advice to teachers, and so on, all of these are *theoretically* based. And ultimately, as Joseph Schwab pointed out, curriculum is *practical* in that it is set in the situations of particular classrooms and the needs of specific pupils. This tension between theoretic and practical lies at the heart of much curriculum discourse.

Cross-References

- ▶ Curriculum and Values
- ▶ Curriculum Evaluation
- ▶ Didaktik
- ▶ History of Science in the Curriculum
- ▶ Learning Progressions
- ▶ Transposition Didactique

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Curriculum and Values

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Keywords

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Links Between Curriculum and Values

As pointed out by Graham Orpwood in this encyclopedia, "The curriculum…expresses the purposes, goals and aims for education" (see curriculum; emphasis in original). Inherent in this statement is some notion of what is judged by experts to be important in education. In developing any curriculum, the belief system underpinning the political, cultural, and economic contexts of the system will be represented. However, such representations are very often implicit and often not even recognized by those developing the curriculum.

Curriculum also consists of subject matter content (Orpwood). This content, science in this case, is also linked to values in three ways (Allchin 1998): values that guide scientific research itself, values that enter science through its practitioners, and values that emerge from science (both product and practice).

Values

There are many definitions that can be used for values (Halman 2010). This may be due to the nature of values as mental constructs; consequently the values people hold can never be observed, but only inferred. Halstead (1996, p. 5) captures the essence of these many definitions in characterizing values as "the principles . . . or life stances which act as general guides . . . in decision-making or the evaluation of beliefs or actions and which are closely connected to personal integrity and identity." He highlights the more enduring and basic nature of values as compared to beliefs and attitudes. Values also can underpin a disposition or a person's tendency to act.

Values of Science

It has been quite a common notion amongst some scientists, science educators, and the general community that science is "value-free." Such ideas have often been perpetuated in the study of science and in science communication, particularly through the focus of science being objective. But objectivity is not really possible as science is a human construction – a way of explaining our natural world.

Science is a way of thinking (and acting) as it is a knowledge-seeking enterprise. It is therefore important to establish the values that underpin this way of thinking (and acting or disposition to acting).

Values in science can be seen as epistemic or sociological in nature. Epistemic values distinguish knowledge that is intrinsically worth knowing and includes the knowledge currently accepted by the scientific community in the form of theoretical explanations for the real world. These values emerge from science as both a product and a practice (see Allchin 1998).

Sociological values include consideration of both external and internal sociological perspectives. External sociological perspectives will include those values that guide scientific research, while internal sociological perspectives include values that enter science through its practitioners. External sociological values of science include the way in which scientists are viewed as experts or possessing some authority within their field of expertise, whether their research should be funded based on decisions about its benefits to society and how scientists communicate their research findings to the public. Internal sociological values of science include the personal values that scientists hold as scientists and consequently as members of the scientific community as well as the personal values a scientist has as a member of society.

Values that underpin science often include curiosity and skepticism, rational thinking, empiricism, parsimony (which could include reliability), robustness, fruitfulness, community practice (as in the community of scientists), interdependence (with other scientists and their research), accuracy, reduction of bias (rather than complete objectivity), open-mindedness, and creativity (which might encompass imagination, innovation, intuition, and informed guesses).

Many of these values may be common to other disciplines such as mathematics and history, but the way in which such values play out in science, both individually and as a collective of values, is very different. For example, while rational thinking is an important value in both science and mathematics, the way it plays out in each of these disciplines can be very different. Rational thinking includes the notions of argument, reasoning, logical analysis, and explanations. It concerns theory, and hypothetical and abstract situations, and thereby promotes universalist thinking. The value can be demonstrated by developing skills in argument and logical reasoning. In mathematics it involves understanding the role of proof and proving, while in science is more about validating the development of knowledge, engaging in discussion and debate, seeking explanations for experimental data, and contrasting alternative hypotheses in terms of available data.

For the individual, then, the interpretation of seemingly the same value has different representations or manifestations in different disciplines, and, while the similarities enable the individual to make sense of the different disciplines, the differences create tensions and can limit their ability to make sense of these disciplines.

Other values such as empiricism (the view that experience, especially of the senses, is the only form of knowledge) are quite unique to science. Science as a way of thinking and acting (or a disposition to act) then is underpinned by the set of values highlighted above that are quite diverse in their nature as they cross epistemic and sociological perspectives.

Values in Science Education

Science as a discipline can be viewed as a particular way of thinking and acting. In science education, experiences of such thinking and acting need to be provided if students are to develop some expertise in the discipline of science. The thinking and acting required in science and science education means that people need to be curious enough to explore their natural environment and try to explain it. In this process of curiosity and/or inquiry, a person needs to engage in some sort of observations (through direct or indirect use of the senses) for some purpose. For example, if you want to know whether you will find a particular bug in a particular place, it is not enough to just look at a bug, but rather you need to look at where the bug is or what it looks like, what color is it, does it have wings, does it have a hard shell, and so on. There is a purpose to your observations, purposes that in essence generate data (which is often uniquely empirical in nature as these are from observations). You then need to look at these data and decide if there are any patterns, ways you can group the data or classify the data (rational thinking). In considering what is the same or different about these data means that you are beginning to place your own meaning (or inferences) on these data. Some of these inferences will be more meaningful than others according to the grouping or patterns. So at this point there are judgments being made about which data are more relevant to the purpose of collecting the data. Those data with the most meaning will contribute to evidence you will use to create an explanation or a model, while data that are less helpful will often be ignored. From here more investigation is required if you are to decide how useful is the explanation or model (often framed as how robust is it) in explaining what I have seen and in enabling me to make predictions about other similar situations/scenarios. If it is useful (or robust) it will explain or fit most situations (not all) – so these explanations or models are useful (plausible, fruitful, and testable). It is also often the case that the simplest explanation/model is the one that suits the most situations (parsimony). If these explanations or models can be combined in ways that build up more complex structures to explore more complex systems, then their use becomes important in terms of understanding how systems will respond if changes are made to them. A fundamental aspect of all of this process is the need to communicate your explanations/models/systems to others to see what they think and to clarify your own thinking (community, collaboration, interdependence, consensus).

The process outlined above is one way that highlights many of the values that underpin science as a way of thinking and acting, many of which are indicated in the brackets in the previous paragraph. The experiences students have in science education must also be inclusive of these values.

Values and the Curriculum

It is rare for curriculum documents to explicitly articulate either the general values underpinning the curriculum or the specific discipline-based values that are included. Nor do curriculum documents highlight the evolving nature of how such values may be interpreted or manifested over time. For example, the recent rapid growth of systems science and interdisciplinary science fields such as biomolecular chemistry and bioinformatics have meant that the thinking and acting needed in these instances are still consistent with the underpinning values but can be represented or manifested in very different ways. Similarly, continued technological developments mean the notion of empiricism has gone far beyond simple observation.

In expressing the purposes, goals, and aims for education, curriculum documents need to also express the values that underpin these purposes, goals, and aims, both in a general sense and in a discipline-specific sense. For science education to provide more authentic experiences of science, teachers and students alike need to be aware of the values that underpin the experiences they engage in and how these contribute to the development of the values that underpin science as a way of thinking and acting.

Cross-References

- ▶ Authentic Science
- ▶ Bildung
- ▶ Curriculum
- ▶ Curriculum Emphasis
- ▶ Didaktik
- ▶ Empiricism
- ▶ History of Science
- ▶ Hypothetico-Deductive Method
- ▶ Process Science
- ▶ Transposition Didactique
- ▶ Values and Learning Science

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Curriculum Design Curriculum Models

▶ Curriculum Structure

Curriculum Development

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Science curriculum development can involve changes in what is taught, to whom (target audiences), and how (ways of teaching and learning). This entry is concerned with the following questions: *Why* change the science curriculum? *What* should be changed? *How and by whom* is the change process initiated and sustained? The entry discusses various models for initiating and sustaining change.

Why and What to Change? Goals and Driving Factors

Throughout the last 60 years the goals and objectives for science teaching and learning have undergone changes many times, often leading to reforms in the way the science curriculum was developed, taught, and learned. Five key factors influence a change in curriculum goals: the learners (target population), the teachers, the science content, the context of learning and teaching both in and out of school, and the assessment of students' achievement and progress.

The Learners

A long tradition of research on learning and teaching science suggests that learners are

> Goal-directed agents who actively seek information. They come to formal education with a range of prior knowledge, skills, beliefs. In addition, they are directed by their concepts, interest, motivation, and attitudes that significantly influence what they notice about the environment and how they organize and interpret it. This, in turn, affects their abilities to remember, reason, solve problems, and acquire new knowledge. (National Research Council 1999, p. 10)

Studies also indicate that affective (interest, motivation, and attitudes), meta-cognitive, and sociocultural aspects play an important role in the learning-teaching process (Linn et al. 1996). There is agreement among many science educators that the range (or repertoire) of the learners' ideas and ways of making sense of the world should be a key factor in setting curricular goals and in developing teaching strategies and learning materials. Learners' prior ideas and those developed in the process of learning have been researched extensively, indicating that they often depart significantly from the normative ones. The abstract nature of scientific concepts and principles and the need to understand phenomena and interactions that are not directly observable, in particular large or very small spatial and temporal scales, are examples of challenges facing science learners. Some learners' ideas are resistant to change while others may stem, for example, from missing knowledge or confusing use of terms and can be easily remedied. Departmentalization of using science differently in different contexts has been documented extensively (e.g., "school science" vs. out-of-school science ideas or the use of a certain concept differently in different disciplines). Therefore, characterizing the sources of learners' ideas and how they are used has a significant impact on the design of curriculum.

In the process of science learning, learners, either as individuals or as a group studying together, may grapple with a repertoire of ideas that are not necessarily consistent with each other. Science educators hold different opinions regarding the repertoire of learners' ideas. Some regard them as barriers to the process of learning and design strategies to eliminate them, while others regard the repertoire as an essential and useful resource enabling learners to build on their experience and intuitions. Therefore, the curricular goals, the teaching strategies, and the assessments differ in these approaches.

It should be noted that some aspects of learning and teaching science described above hold for all science learners, yet changes in the target population of science learners over the last decade have had a significant impact on science curriculum development. For example, in the USA in the 1960s, the goals were strongly based on the view that science learning should serve students who plan to embark in the future on a career in the sciences, engineering, or medicine. The American Association for the Advancement of Science in 1962 summarized the goals of these curricular initiatives as follows:

- Science education should present learners with a real picture of science, including theories and models.
- Science education should present an authentic picture of scientists and their method of research.
- Science education should present the nature of science (NOS).
- Science education should be structured and developed using the discipline approach (key concepts in each of the subjects).

To attain these goals, a series of science curricula, such as PSSC in physics, BSCS in biology and CHEMStudy in chemistry in the USA, and the Nuffield courses in the UK, were developed. The development teams were led by scientists. All teams included teachers, but the teachers played different roles in the development process. For instance, the development teams in the Nuffield courses consisted mainly of leading teachers. About 20 years later, in the 1980s, there was a shift in many countries toward addressing the needs and abilities of all citizens. For example, an NSF sponsored project, *Project Synthesis*, which analyzed science curricula in previous years, led to a call to change the scope and goals for science teaching and learning, advocating that science education should:

- Include major concerns regarding science as a means of resolving current societal problem.
- Provide a means to attend to the personal needs of students.
- Provide greater awareness of potential careers in science, technology, and related fields.

These goals led, for example, to curriculum projects focusing on science, society, and technology (STS) around the world. Attempts have been made to make science more relevant to learners and adjusted to their backgrounds (e.g., the Chemistry in Context and the Chemcom curricula), attending to characteristics such as equity; gender; students' attitudes, interest, and motivation; conceptual understanding; creativity and curiosity; and knowledge integration.

The Teachers

One of the key factors regarding curriculum change is the teachers. In general, teachers are reluctant to accept radical changes and often do not implement them in accordance with the rationale for the change suggested by the curriculum developers. Such changes may not be aligned with teachers' existing views and practices and may require new knowledge, perhaps content knowledge (CK), or its related pedagogical content knowledge (PCK), or curricular knowledge. Important factors influencing teachers' response to change include personal characteristics, cultural norms (e.g., the role of questioning), the professional status of the teacher, the teacher's understanding of the proposed change and its rationale, and systemic approaches to students' future career opportunities.

The Scientific Content and Organization

The scientific content and the skills or scientific practices to be learned constitute the major fabric of the curriculum. Criteria for choosing scientific core ideas may relate to the importance of concepts within and across disciplines; the provision of key tools for understanding, investigating, and problem-solving; enhancing interest; the relevance to life experiences and the connection to personal and societal concerns; and being teachable and learnable over multiple grades at increasing levels of depth and sophistication (e.g., "learning progressions"). Changes in conceptions about how topics should be organized have also influenced curricular change. For example, "context-based science" (e.g., in the PLON curriculum in the Netherlands and the Salters' projects in the UK) and "knowledge for use" approaches depart significantly from the traditional "structure of the discipline" approach often used for science curriculum development.

Aligning school science with contemporary scientific knowledge is an important consideration in areas that change at a very rapid pace such as molecular biology or nano-science, as well as topics that are interdisciplinary in nature such as brain science and medicine. Changes of this kind in the fields of science and technology are the driving force behind many innovations in school STEM curricula.

Another central issue is the methodologies used for enhancing the acquisition of skills in science curricula. There is a consensus that skills should be developed in the context of content and that in order to develop a generalizable skill (transfer), it must be studied explicitly and practiced in different topics. However, different ways of doing this lead to different curriculum structures.

The Context of Learning and Teaching: The Learning Environment

Learning and teaching science takes place in-school and out-of-school learning environments. Each setting has important benefits as well as limitations. Changes in the learning environment have been shown to influence students' motivation and learning. These changes involve instructional approaches (e.g., inquiry and project-based learning, small group cooperative learning, debates on issues, use of games, and digital simulations) as well as the physical settings in which learning takes place (e.g., outdoors, science museums, authentic research laboratories, and industry). Rapid technological developments and the easy access to information resources in all formats for many of today's students add to the mix of opportunities now available. This proliferation of learning environments raises issues such as: Do students integrate the ideas that they learn in different contexts? Do they have the skills required for autonomous learning, namely, learning to learn skills? What are effective ways and tools to scaffold learners? How can we provide rich opportunities to help socially and culturally deprived students? Responding to these issues influences the goals for learning and teaching and hence influences the design and development of new curricula.

Assessment of Learners' Achievement and Progress

In countries with centralized educational systems, policy decisions concerning the assessment of students may have a radical impact on what and how students learn. Examples of such decisions involve, for example, participation in international testing projects such as PISA and TIMSS; changes in the format of matriculation examinations (e.g., in Hungary and Israel); and decisions made by governments to implement school-based continuous assessment conducted by teachers, allowing more flexibility in the curriculum content and the instructional techniques used. In some countries, as part of educational reforms, alternative assessment methods using tools such as portfolios or e-portfolios are integrated into the curriculum process.

The Curriculum Development and Implementation Processes

Ideally, a curriculum development process should be a holistic, continuous, and long-term endeavor involving several components often carried out in parallel. Key components include initial setting of goals, analysis, and selection of the topics aligned with official syllabi; diagnosis of students' ideas as well as analysis of the inherent characteristics of the science concepts; design of learning, teaching, and assessment materials (e.g., crafting tasks, uses of representations and didactical aids); and small-scale implementation and teacher development cycles accompanied by research (teaching experiments). This process often leads to reconsideration of goals, the pedagogical resources, and the teacher development activities. Advanced stages of the process can lead to large-scale implementation and evaluation studies.

There are many open questions that require further study concerning the ways to enhance the development of useful practical and research-based knowledge relevant to curriculum development in specific topics (Kortland and Klaassen 2010), such as: How can one communicate detailed knowledge about teaching and learning sequences? How can one encapsulate and conceptualize practical knowledge of teachers? How can one develop cumulative research-based knowledge on the development of learning and teaching resources on specific topics?

Models for Curriculum Development: Initiating and Sustaining Change

Over the years, the need for changes in science teaching and learning has been raised by different interest groups such as policy makers, scientists, science educators and curriculum developers, teacher associations, and local initiators (e.g., a school, a school district, or schools networks). Pressure for change has also come from societal or socioeconomic sources.

In recent years, in many countries, curriculum change is often initiated and influenced by national and international standards and frameworks that characterize desirable change and are prepared by national academies, ministries of education (e.g., the Institute of Education in Singapore), and other organizations. Examples of such initiatives include the National Standards in Science Education developed by the US National Research Council in 1996 and revised in 2013 as the Next Generation Science Standards and the Benchmarks of Science for all Americans arising from Project 2061, developed by the American Association for the Advancement of Science. The resulting frameworks have been used for developing curricula and evaluating their quality. Teacher associations have been very influential in initiating curriculum change through the development of frameworks (e.g., the National Science Teachers Association in the USA, the Association for Science Education in the UK, the Irish Science Teachers' Association in Ireland, and the Australian Science Teachers' Association in Australia). Another mechanism for initiating change has been through influential reports discussing goals, methods, and recommendations related to teaching and learning science. Examples of such reports are the ROSE project (Sjøberg and Schreiner 2010) and *Beyond 2000* (Millar and Osborne 1998).

Calls for change have led to two key models of curriculum development efforts that differ in their methods of design and implementation and in the constituents involved in the curricular process: a center-periphery **top-down model** in which a central development group tries to influence those on the periphery and a **bottom-up model**, responding to local needs through school-based (or teacher-based) curriculum development or where change is instigated and implemented by leading teachers and then adopted by others. These two key models often differ in the nature of teacher involvement in the development process, in the activities of implementation, and in the professional development of teachers. The change processes associated with each of these models sometimes differ in the scope of curriculum adoption, in the relationship between the intended and implemented curriculum, in teacher ownership and ways of adaptation, and in the degree of sustainability. In both models, a major concern is how to prepare "educative materials," namely, materials that promote teacher professional growth in addition to student learning, and how to assure effective implementation and sustainability.

Center-Periphery Curriculum Development Models

Big curriculum projects often use a center-periphery model in which a central group develops the curriculum and then tries to disseminate it to the periphery. These groups may include in their teams teachers, science educators, scientists, and other relevant experts (e.g., experts in technology and assessment), who together carry out a comprehensive development and implementation process as described above.

In the past, curriculum change in many countries has been dominated by central governments and/or official stakeholders in charge of curriculum development and implementation, who imposed curricula and assessment methods, sometimes taken from other countries. For example, the *adoption* by developing countries of curricula and assessment methods from developed countries prevailed throughout the 1970s and 1980s and still continues. Unfortunately, these methods often lead to unsatisfactory learning outcomes because they overlook the need to *adapt* the curriculum and assessment methods to the local conditions, taking into account aspects such as the availability of teachers with appropriate CK and PCK to implement the adopted curricula; the local culture and environment (e.g., attempting to introduce advanced open inquiry in a culture where asking questions is not the norm); the availability of laboratory equipment, technology, and lab technicians; conditions for studying at home; and problems of language. Present efforts to adapt new curricula emphasize working with teachers and are more sensitive to local conditions, building on the benefits offered by the local environment and the pedagogical and educational workplace.

Some center-periphery approaches of curriculum development involve intensive ongoing collaborations among school teachers, science educators, scientists, and other relevant professionals. For example, the Salters science curricula in the UK were initiated by a group of concerned teachers, academics, and industrialists whose goal was to make chemistry more relevant to the learner. Teachers were intensively involved in the process of developing the pedagogical ideas and collecting instructional approaches. A similar model is used by the Israeli Center for Science Education in a long-term collaboration between the Israeli Ministry of Education and several academic institutions. In addition to intensive involvement in the development process, lead teachers have a central role in working with other teachers through national centers for science teachers. Learning materials resulting from such intensive teacher involvement have more potential to be adopted in schools. The involvement of leading teachers in the long-term professional development and implementation of new curricula enhances effective customizations aligned with the original rationale of the developers, yet responding to local needs.

School- and Teacher-Based Curriculum Development Models

A growing body of evidence suggests that imposing a curriculum by central professional bodies in what is called “top-down” fashion, whereby teachers are expected simply to implement the developers’ philosophy, ideas, and intentions, has proved in many cases to be ineffective in introducing educational and curricular innovations into schools. One conclusion that comes out of decades of studying the success and failure of a wide variety of curriculum innovations is that imposed innovations are generally ineffective and that innovations succeed when teachers feel a sense of ownership of the innovation (Connelly and Clandinin 1988). In general, teachers tend to accept a new curriculum more easily when it is aligned with learning goals they personally value or when they perceive that the innovation provides an effective solution to problems they currently encounter. Several factors seem to be relevant for teachers in adopting curricular changes, such as judgments about the likely success of a new course, the teachers’ perceptions of its effects on students’ learning and attitudes, teachers’ views about students’ interest and motivation, perceived learning outcomes, and enhancement of self-regulated learning. The importance of supplementing the curriculum with materials developed by school teachers either in schools or districts, in the context of long-term professional development initiatives, has long been recognized.

School-based curriculum development (SBCD) can be viewed as an endeavor aimed at diminishing dependency on centralized national science curricula, increasing the schools’ autonomy, and enhancing teachers’ sense of ownership. A central aspect of SBCD relates to teacher professional development and entails the transfer of responsibility or ownership to the teacher. The basic assumption is that SBCD and teacher professional development are two coupled processes. Although ownership by teachers may be high in these models, often the extensive everyday demands on teachers’ time and the lack of competence in curriculum development have a negative impact on the quality of change. Another aspect that has to be taken in consideration is the time that is required for the new curriculum to be implemented. Without adequate time for teachers’ professional growth, it is unlikely that they will effectively develop and implement new teaching practices.

To sum up, curriculum development and change is a complex endeavor in which many factors need to be considered: the learners, the teachers, the scientific content and organization, the context of learning and teaching, the learning environments, and assessment of students' learning. Years of experience of curriculum development and change provide evidence that it is important to carry out the curriculum development process in a holistic manner that goes beyond writing textbooks and teacher guides. Rather, it should involve cycles of developing innovative learning materials and pedagogical models, implementation, teacher development, and research. There are different models for curriculum development and change that can be roughly grouped into center-periphery models and teacher- or school-based models. No matter which model is adopted, the important role of experienced teachers in the curricular process should not be overlooked. Moreover, the professional development of teachers, and providing them with opportunities and tools to customize instruction to their needs, is essential for effective implementation.

Cross-References

- ▶ Curriculum
- ▶ Curriculum Movements in Science Education
- ▶ Curriculum Structure
- ▶ Primary/Elementary School Science Curriculum Projects
- ▶ Science for All
- ▶ Teaching and Learning Sequences

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Curriculum Emphasis

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The curriculum emphasis concept was developed as a way to understand and distinguish among broadly different educational objectives that have characterized school science programs in recent history. Seven different curriculum emphases were identified originally (Roberts 1982). These were detected through analysis of school textbooks, other high-profile classroom materials, and curriculum policy statements from about –1980 in North America and England especially. A key feature of the methodology was recognizing at the outset that school science programs have two kinds of intended learning outcomes. The more obvious "content" to be learned is selected from within science, i.e., from the concepts, laws, theories, and methodologies that are the basis of scientific explanations for natural phenomena. In addition, there is *context* material that is to be learned *about* science and the reasons for learning it. The latter constitutes the curriculum emphasis. Reasons for learning science are sometimes stated explicitly and are sometimes communicated implicitly by the context.

Curriculum emphases are objects of choice, influenced by societal forces and concerns at different times in history (Roberts 1988). For example, a curriculum emphasis dubbed **Everyday Coping** permeated secondary school science textbooks widely used throughout North America in the 1940s and 1950s. In physics and chemistry textbooks, scientific principles and explanations were presented in the context of having students understand some common mechanical and electrical appliances (e.g., steam shovels, electric motors) and chemical processes (e.g., making steel). In biology textbooks the science was related to understanding aspects of the environment and to personal and public health. Overall, the message this curriculum emphasis communicates to students is that it is important to learn scientific explanations in order to demystify objects and events of fairly obvious personal relevance.

By contrast, **Structure of Science** is prominent in the high-profile classroom materials developed for secondary school science courses in North America and England during the late 1950s and 1960s. Sponsored and funded by the National Science Foundation in the USA and the Nuffield Foundation in England, these materials are silent about demystifying familiar objects and events. Instead, the message to students is about the importance of demystifying science as an intellectual enterprise. The materials concentrate on such matters as the role of mental models in developing explanations, the interplay between observations and interpretation, the reasons accuracy is important, and other aspects of the internal functioning of scientific disciplines. The emphasis remains active in science education today as NoS (nature of science).

Also in the 1960s, AAAS (the American Association for the Advancement of Science) sponsored development of a widely used science program for elementary schools that looked inward to science in another way. Known as "Science: A Process Approach," this program has K-6 students concentrate on the procedures and skills of science in a curriculum emphasis dubbed **Scientific Skill Development**. The materials are carefully sequenced to develop such "basic" skills as observation, measurement, and classification in grades K-3 and more "advanced" skills such as hypothesizing and designing experiments in grades 4–6. The message communicated to students is that the material is to be learned so that appropriate (i.e., scientific) methods can be used for developing proper explanations for natural phenomena. This emphasis is currently recognizable in school science programs (both elementary and secondary) as "scientific inquiry skills."

Two curriculum emphases are much older than those just discussed. Both are evident in school science textbooks from early in the twentieth century, but instances can be found as recently as the 1960s and 1970s. The curriculum emphasis **Correct Explanations** stresses how important it is to learn correct scientific information. The products of science (concepts, laws, and theories) are presented as correct, but very little assistance is given to help students clarify how scientific processes, skills, or reasoning are responsible for the correctness. For example, ideas that have been replaced (e.g., caloric theory of heat) are simply said to be wrong. Closely allied is an emphasis dubbed **Solid Foundation**, in which the message for students (implicitly) is that the purpose of learning the science at hand is that it fits into an overall development and sequence of ideas. In other words, the student needs this in order to get on to the next bit of the sequence. The ideas of science are presented authoritatively, in a style that resembles many university science texts (with appropriately modified language level).

At the time the original study was done, in the early 1980s, there were promising examples in several countries of a curriculum emphasis dubbed **Science, Technology, and Decisions**. This approach brings out the interrelatedness among scientific explanation, technological planning and problem solving, and decision making about practical matters of importance to society.

Two high-profile examples are the "Science in Society Project" in England (developed under auspices of the Association for Science Education) and the "PLON Project" in Holland. (PLON is a Dutch language acronym for "Physics Curriculum Development Project.") As discussed below, this emphasis was a prominent component of the developing STS movement in science education.

One more curriculum emphasis was detected in the original study, although it was not very widespread at the time. As the name suggests, the message to students in a **Self as Explainer** emphasis is about the importance of a personal understanding of the process of explanation itself. Using the development and change of theories in physics and astronomy as examples, the "Project Physics" course materials developed at Harvard in the late 1960s introduce students to the influence of intellectual and cultural frameworks on scientists' ways of explaining in their own time and culture. Students can thus become more aware of the influences on their own ways of explaining events. Both constructivism and conceptual change keep this emphasis active in science education today.

Two significant changes related to curriculum emphases have occurred in the 30 years since the original study. Both are at a more general level than a single emphasis. First, science-technology-society has grown into one of the most prominent and successful movements in science education history. STS is not a curriculum emphasis. The movement has obvious roots in environmental education, of course. Indeed, some school programs call it STSE, adding an "E" at the end to call attention to the link. Also, STS/STSE has many aspects, so it is not helpful to think in terms of a single "ordinary" curriculum emphasis. It was noted earlier that **Science, Technology, and Decisions** is a component of STS; so also are portions of **Everyday Coping** and **Self as Explainer**. These three emphases – all of which "look outward" *from science* to the larger world of human affairs – were effectively sidelined in the 1950s and 1960s. The STS movement has rejuvenated them after an era dominated by the prestige of the two scientist-sponsored emphases **Structure of Science** and **Scientific Skill Development** – both of which "look inward" *toward science* (Roberts 2011).

Second, over the past 30 years the slogan *scientific literacy* has been a major topic of discussion about the overall aims and goals of school science. Like STS/STSE, scientific literacy has too many aspects to be usefully discussed as a single curriculum emphasis. Actually, the term has had so many definitions that it has come to incorporate every conceivable objective for school science programs (Roberts 2007). Thus it is tempting to think of scientific literacy as some sort of mega-blend of all seven curriculum emphases, offering students the best of each perhaps. Not so.

Instead, two distinctly different "visions" of scientific literacy have emerged. Since the early 1990s, AAAS Project 2061 has stopped using the term *scientific* literacy, in favor of the term *science* literacy. The shift is significant because, generally speaking, AAAS-type science literacy is inward looking, while scientific literacy as the term has been used historically is outward looking. The two visions have been dubbed, respectively, "Vision I" and "Vision II." The following summary shows the difference starkly (Roberts 2007, 2011).

Vision I: *Science* literacy (AAAS style) incorporates some aspects of four curriculum emphases:

- Structure of Science
- Scientific Skill Development
- Correct Explanations
- Solid Foundation

Vision II: *Scientific* literacy (historically) incorporates some aspects of three other curriculum emphases:

- Everyday Coping
- Science, Technology, and Decisions
- Self as Explainer

This discussion is not intended to suggest that one of these visions is "better" or "more correct" than the other. The visions, like curriculum emphases, are objects of choice for curriculum policy makers. Comprehending the broad array of curriculum emphases in science education history can be helpful in unpacking what is at stake in making such a choice.

Cross-References

- ▶ Companion Meanings
- ▶ Curriculum Development
- ▶ Inquiry, as a Curriculum Strand

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Curriculum Evaluation

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Keywords

Program evaluation; Science education evaluation

To understand curriculum evaluation, it is important to first understand what is meant by curriculum and evaluation. Curriculum may be interpreted broadly to mean instructional materials or processes, courses of study, and educational programs or interventions. In other words, curriculum may be considered as anything related to promoting educational growth. Evaluation may be considered a process of delineating, obtaining, and providing useful information for judging decision alternatives. Evaluation is the determination of the merit or worth of something, in this case curriculum. Evaluation can take many forms and follow several different theoretical paths, but it is a process of “valuing” and as such directly related to the perceptions of the stakeholders of the entity being evaluated. In a curriculum evaluation the stakeholders could be the designers of the curriculum, the deliverers of the curriculum, the receivers of the curriculum, and others impacted or having an interest in the curriculum. An evaluation should take the values of all of these stakeholders into account when designing, conducting, and disseminating the evaluation. Evaluation is an applied science; it needs to be used to be effective. Evaluation differs from research in terms of the motivation of the inquirer, the objective of the inquiry, the outcome of the inquiry, the role played by explanation, and the generalizability. Evaluations are almost always conducted at the request of someone and to provide information for decision

Curriculum Evaluation, Table 1 Possible evaluation questions for curriculum evaluation

Type of questions	Possible evaluation questions
Quality of a curriculum	Are the curriculum developers doing what they said they were going to do?
	Are effective management structures in place to support participants?
	Are communication channels open and operating between providers, participants, and administration?
	Are goals understood and shared by all stakeholders?
	Are the deliverers of the curriculum well qualified?
	Is the delivery of the curriculum well planned?
	Do the participants believe they have benefited from the curriculum?
	Do the participants expect to change their behavior or attitudes as a result of the curriculum?
Outcomes of a curriculum	Has the behavior of the participants (including teachers, students, principals, and others) changed?
	Have others benefited from the changed behavior of the participants?
	Have schools been affected?
	Have student behaviors changed?
	Has student achievement changed?

Curriculum Evaluation, Table 2 Possible curriculum effects and methods of measurement for curriculum evaluation

Possible effects	Methods of measurement
Delivery of curriculum	Observations
	Participant observer
	Participant opinion
Effects on teachers	Discourse analysis
	Phenomenological studies
Effects on classrooms	Classroom observations
	Teacher logs and surveys of what takes place
	Artifact analyses
	Student or teacher opinion, surveys, and environment instruments
	Ethnographies
Effects on students	Pre-post testing of motivation, beliefs, achievement, and behaviors
	Comparison of student outcomes with outcomes from different curricula
Other effects	Case studies
	Policy analyses
	Networking analyses

Curriculum Evaluation, Table 3 Science curriculum examples of Stufflebeam's evaluation models

Model of evaluation	Science curriculum example
Decision/ accountability	Examining the strengths and weaknesses of a science curriculum to make decisions about how to improve the curriculum
Consumer oriented	Rating two science curricula using a set of criteria to determine which curricula is best for students
Accreditation	Evaluating a science curriculum to determine whether the curriculum meets the minimum requirements set by the state or an accrediting agency
Utilization focused	Assessing stakeholders' needs for evaluating a science curriculum and providing them with information they can use to make decisions about the curriculum
Client centered/ responsive	Working with school board members, administrators, and teachers to develop, implement, and evaluate a science curriculum
Deliberative democratic	Involving school administrators and science teachers to be part of the curriculum evaluation through collecting and interpreting the data and discussing the findings to ensure that perspectives and opinions are represented fairly
Constructivist	Partnering with stakeholders in the evaluation process to understand the different perspectives and experiences of different groups of students receiving a science curriculum
Case study	Conducting an in-depth analysis of one science class of several classes to highlight how a science curriculum is being implemented
Outcome/value-added assessment	Analyzing trends in student science assessment data to determine whether results show adequate outcomes and whether changes need to be made to improve a science program

making, whereas research is conducted to provide reliable information about educational matters, to identify patterns and trends that may be of educational significance, to identify factors that correlate with specific outcomes, and to seek and test explanations for them. For example, evaluation is purposefully tied to a specific object in time and space, while research is designed to span these dimensions.

There are many different approaches to curriculum evaluation. The approach taken is related to the values of the stakeholders or one group of stakeholders and is designed to assess the quality of the program though examination of the program processes or the quality of the program outcomes. For example, an evaluation of a new chemistry course might address the needs of students or of their teachers or of the students' parents or any combination of stakeholder groups. Examples of evaluation questions related to the quality of the curriculum or the quality of the curricular outcomes are provided in Table 1.

The first step in a curriculum evaluation therefore is determination of what information is needed. This is a complex step that requires working closely with the commissioners of the evaluation and helping them to articulate the information they will need to make value decisions. For example, if stakeholders are not interested in whether or not students become more cooperative in class, the evaluation should not

Curriculum Evaluation, Table 4 Three examples of science curricular areas by evaluation method and questions

Curriculum area	Evaluation method	Questions the method addresses
A curriculum about making the school culture more supportive of underrepresented groups pursuing science within a school district	Case study of one or two schools	What is an in-depth description of the institutional culture at one or two schools within the district regarding science and underrepresented student groups?
	Retrospective opinion surveys of those within the school and those who interact with the schools	
	Artifact analysis of policies, procedures, and public statements over a period of time	What do administrators, teachers, staff, students, and parent think the culture of science is within their school? What do people who interact with the schools think the culture is? How has changed the culture changed?
		What changes have occurred in the policies, procedures, and expressed public image during the program?
	Ethnography	What is the culture of the classroom regarding climate change? How is the classroom culture evolving?
	Pre and post assessment of students' perceptions of climate change	How do students perceive climate change before and after participating in the curriculum?
A curriculum about climate change	Observations of the classroom by experts	What are observers' opinions of climate change before and after the curriculum and/or in comparison to other classrooms without the curriculum?
	Phenomenological studies	What are the lived experiences of a few selected students? How are students impacted by the change in implementation?
Effect of changing the implementation of a high school earth science curriculum from face-to-face to online instruction	Assessment of student knowledge and attitude and application of HLM analyses	Which individual student variables are predictive of student achievement and attitude? How much does the type of instruction contribute to the relationship?
	Value-added analysis of student scores over time	What changes have occurred in the longitudinal patterns of student achievement and attitudes since implementing the online instruction?

be designed to gather that information. Evaluators often use logic modeling techniques to help define how the curriculum will produce the desired effects and the consequent underlying needs for data. A logic model is a graphic depiction of the curriculum showing inputs, activities, outputs, and outcomes (Frechtling 2007). Once the desired information is delineated, questions about how best to obtain that information need to be considered. Answers to these questions are based on a variety of criteria, but the amount of time and effort that is available to be applied to the evaluation and the alignment of rigorous methodologies for data collection with the evaluation questions are primary concerns. Table 2 presents a sample of methods that might be used to evaluate different curricular effects.

The different methodological approaches to evaluation are grounded in different philosophies mainly along two continua: the objectivist-subjectivist epistemologies and the utilitarian-pluralist values. The objectivists rely on reproducible facts, while the subjectivists depend upon accumulated experience. Utilitarians assess overall impact, while pluralists assess the impact on each individual. These can be collapsed into two methodological approaches to curriculum evaluation: positivistic and interpretive. Positivistic methods are hypothesis driven, consider randomized control trials to determine causality as a "gold standard," and include methods such as regression discontinuity, structural equation modeling, path analyses, quasi-experimental techniques, ANCOVAs, and propensity scores. Interpretive methods are more interpretive and inductive philosophically and use methods such as case studies, life history, phenomenography, phenomenology, critical theory, ethnomethodology, symbolic interactionism, hermeneutics, semiotics, and structuralism. It is also possible to mix methods in a variety of ways and at various points of time in an evaluation.

Stufflebeam (2001) describes 22 different approaches to evaluation and recommends nine that best meet the four dimensions of the Program Evaluation Standards of the Joint Committee on Standards for Educational Evaluation (see Yarbrough et al. 2011): utility, feasibility, propriety, and accuracy. These nine approaches include three improvement- or accountability-oriented approaches, four social agenda or advocacy-oriented approaches, and two method-oriented approaches. The models are defined below and listed in Table 3 along with an example of how each could be operationalized in science curriculum education.

There is also a variety of other issues that need to be considered when conducting curriculum evaluation. One important issue is to make sure the evaluation meets all the human subjects Institutional Review Board (IRB) regulations for both the evaluator's institution and for the institutions in which the evaluation is taking place. Additionally, although logic models can be useful, it is critical that they accurately reflect how the curriculum actually operates and that they be revised as changes are made. As with all evaluations, care must be taken to conduct the evaluation in accordance with the Program Evaluation Standards (Yarbrough et al. 2011) and to provide the information to the evaluation stakeholders in a timely and appropriate manner. The evaluation information can be supplied in a variety of formats ranging from a formal report to poems written using participants' voices. The important thing is to present it in a way that the stakeholders receive an accurate picture of what was found in a manner that they find most relevant. Table 4 presents three sample curricular areas along with questions and methods that might be appropriate for a curriculum evaluation.

Cross-References

- ▶ Curriculum
- ▶ Evaluation
- ▶ Program Evaluation

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Curriculum Exposure

- ▶ Opportunity to Learn

Curriculum Frameworks

- ▶ Curriculum Structure

Curriculum in Play-Based Contexts

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What is Play?

The maxim that "children learn through play" is a pedagogical given in early years settings.

Teachers and parents recognize that play serves many valuable purposes. It fosters children's physical, intellectual, emotional, and social development. It provides opportunities for high-level reasoning, insightful problem solving, and creative thought. Play-based curriculum is developed from the children's interests and gives rise to their creative explorations of the environment. Despite play traditionally being defined as engaging in activity for enjoyment and recreation rather than a serious or practical purpose, many educationalists have pursued other definitions. For example, Somerset (1995) wrote:

> To children, play is work, hard work, their business in life . . . This self-activated learning . . . is termed merely play perhaps because children choose what they learn, take their own time about it, and enjoy it all. (p. 15)

It has been argued that play has a quality that enables players to transform their world through their active engagement, imagination, flexible thought, and creative storytelling. They can combine and blend ideas into new creative possibilities and reinterpret familiar settings in novel ways. As such, play creates possibilities for learning. It provides a way of framing new ways of knowing, being, and relating to the experienced world. Rather than viewing play as the opposite of work and thereby associating it with limited purpose or value to learning, Davis et al. (2008) have suggested that:

> The opposite of play is... *rigidity* or *motionlessness*. In this sense, a vital quality of all living forms is play and, conversely, a likely indicator of an inert (or dead) form is lack of play. (p. 84)

As the above suggests, play then is a powerful strategy that drives learning in a dynamic, ever-changing world. It is the basis for cultivating imagination and innovation, providing opportunities to take risks, experiment, fail, and continue to play with different outcomes (Thomas and Brown 2011).

Science in a Play-Based Context

Early childhood teachers appreciate that young children are exploring and expanding the way they know about their world in a myriad of ways. They experience an environment where they develop their own workable theories for making sense of the natural, social, physical, and material worlds based on play, observation, and exploration. As Esach and Fried (2005) have argued:

> Whether we introduce children to science or whether we do not, children are doing science. We are born with an intrinsic motivation to explore the world. This means that children will be taking their first steps towards science with or without our help. (p. 332)

To ensure children's first steps toward building their understanding of science concepts are not missteps, teachers have a strategic role in planning for play and engaging in informed scaffolded interactions that create opportunities for the co-construction of knowledge as they emerge from children's interests, curiosity, imagination, and participation. The following examples are designed to illustrate these points in practice.

Example #1

The teacher watches 5-year-old Maddy banging rocks on the Nature Study table. Maddy systematically picks up a rock from the collection, studies it carefully, and then taps it on the table. Each rock is then consigned to one of two piles. "What are you doing?" the teacher asks. Maddy looks up and says "I'm listening to the rocks. These are quiet ones and these are noisy ones." The teacher looks at the two piles and sees that Maddy is classifying the rocks into loud, mostly igneous rocks and metamorphic rocks and quiet, soft, mostly sedimentary rocks. She joins Maddy in tapping rocks on the table. When they are finished, Maddy says "I wonder why these ones were quiet. Do you know?" Before the teacher has a chance to answer, Maddy sweeps the rocks into a single pile and starts sorting them again. "This time," she tells her teacher, "let's put them in their colors."

In this real-life example, the teacher developed the above experience into a project that spanned several sessions. Maddy brought photographs of a family trip to a volcanic area. The teacher took a piece of pumice (volcanic rock) to school, and they discovered that it was the only rock that floated. The teacher and several rockhounds went online together and explored other properties that scientists use to classify rocks.

This example draws attention to the novel perspectives which children can bring to exploring their world. It also illustrates the importance of the teacher's role in fostering and following the children's interests in order to help them construct new understanding. In this situation, children learned about physical properties of rocks and how scientists classify and identify them. Children also learned about floating and sinking as they tested which rocks floated and which did not. Future possibilities coevolve with the children's interest. For example, they could have designed ways to make rocks float, perhaps by building boats or attaching buoyancy devices to them. The teacher's role is to create a playful situation where the children want to learn more about a topic and are active participants in making and taking meaning from the situation. Children who are engaged in knowledge construction are involved in the interpretation of meaning, the reflection of experience, and the reconstruction of the experience to become more knowing. Playing with ideas, reinforced through exploration in practice, builds knowledge.

Example #2

The teacher asked the parents if they had any objection to her burying some bones from a sheep skeleton in the early childhood center's sandpit over the weekend. She assured them the bones were well weathered and clean. On Monday morning, several of the children headed to the sandpit with spades and diggers to start their usual excavations. They were amazed to discover "fossils." The teacher encouraged the students to uncover more bones and then to see if they could fit them together to find out what the mysterious buried creature was. They spent many hours deciding which bones went in which positions and eventually decided that they had discovered a dinosaur. The bones of *Tyranosaurus sheepi* were duly threaded together and hung on the early childhood center's fence for all to admire. It became the backdrop for adventures and the focal point for much storytelling. Indiana Jones was never such an inspiration to become an archaeologist as this teacher!

In this example, the teacher created a rich learning environment in which imagination and narrative became as important to the learning as observation and inquiry. While burying bones in the sandpit had provided an opportunity for the children to create and make meaning, the teacher directed the activity to develop the science experience. She extended the children's play over many hours and consecutive days to establish which bones were part of the skull and which were limbs. What were the functions of the various teeth they uncovered and how did they differ from the teeth the children had in their mouths? In hanging the skeleton together, the children investigated the properties of different threads – wool was too thin and broke too easily. Wire was difficult to work with but sturdy. Nylon fishing line was difficult to knot securely but easier to manipulate. The conversations, trials, and experimentations in this play setting all added to the children's learning about science.

Example #3

David was chasing after a piece of paper that was being blown around the playground. Finally he stamped on it with his foot and stopped it from moving. The teacher asked him what made the paper move. "Naughty Mr. Wind," he replied, mimicking a children's television program.

"Hmm, where's the wind coming from?" the teacher wondered aloud. David was stumped by that question as you can imagine, but by the end of the session, he had flapped his arms like wings and felt the pressure of the air all around him. He had explored running as fast as he could with a piece of newspaper in front of him and made a kite to fly. "Did you know the wind is just moving air?" he asked his mom knowledgeably when she came to pick him up.

In this example, the teacher seized the opportunity to expand David's science understanding through a series of hands-on activities and experiences. She was confident of her own science knowledge and her ability to teach about science in a variety of engaging ways. In the back of her mind was the thought that children spend many hours in front of television or computer screens without social or physical interaction with others. What impact would this have on children's play? One impact could be that technology creates a gap between effort and observable results that may mean that children are reluctant to try tasks that require real effort. Perhaps technology will promote such "magical" virtual experiences when chasing a piece of paper becomes too frustrating in the real world (Bergen 2008). Will tomorrow's children still make a game out of chasing paper in the playground?

Conclusion

Each of these examples highlights the teachers' responsibilities in managing and organizing an environment that offers a wide variety of opportunities to explore and challenge children's developing ideas. Teachers should encourage children to know what is happening and why; they should respond to children's questions thoughtfully to extend their ideas; they should help children problem solve, remember, predict, and make comparisons. An understanding of basic science concepts is important in providing teachers with the flexibility to engage children in learning about science ideas in such play-based contexts.

Cross-References

- ▶ Early Childhood Science Teacher Education
- ▶ Learning in Play-Based Environments

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Curriculum in Teacher Education

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Introduction

Curriculum most often refers to the formal documentation designed to provide guidance about what school systems, schools, and teachers should teach. It is generally produced on behalf of governments through sometimes complex processes managed by the appropriate education bureaucracy in an attempt to offer guidance about the content for (and sometimes approach to) teaching. It is, then, a product that reflects the political, cultural, and economic contexts in which it is written. This is sometimes referred to as the "envisaged" curriculum. However, many educators also recognize the existence of an "enacted" (or active) curriculum as something distinct, that is, the reality of what is actually taught, and the range of student experiences, in the classroom.

The enacted curriculum may partially reflect the belief systems and knowledge base of the teacher or local school system delivering it. Teacher education students often receive considerable instruction about the formal curriculum, to some extent because accreditation of teacher education programs is often managed by the same bureaucracy or one closely related to the one that develops the formal curriculum. Teacher education students may receive some exposure to the enacted curriculum, but this may be dependent on the particular philosophies of the teacher educators involved in teaching them in their program.

Curriculum Design

There are a number of different traditions in curriculum design and implementation, varying both with respect to time and place. The 1970s, for example, represented a period of considerable experimentation with a school-based curriculum movement evident across many English-speaking systems. Many teachers involved in this reform found it to be an exciting and challenging experience, which came alongside a number of other educational innovations, such as child-centered curricula and cooperative teaching practices. A decade later, however, there was a resurgence in the development of more prescribed national curricula with a much greater level of political control over curriculum development processes, which now came to regard teachers as agents for the delivery of curriculum. In fact these reforms quite overtly intended to reduce the control of teachers over curriculum decisions (for a thorough and interesting analysis of these historical perspectives in three English-speaking countries, see Guilfoyle (1992)).

Superimposed on these temporal variations are some significant national differences. The German *Didaktik* tradition sees the state curriculum as a broad guide to what should be taught and not as something that could or should explicitly direct a teacher's work. It takes a very "professionalized" view of the role of teachers and encourages them to exercise a degree of self-determination with some limitations on systematic and bureaucratic regulation. The Anglo-Saxon tradition on the other hand, at least over the last 20–30 years, has tended to produce curricula that are designed to be "implemented" by school systems and are intended to provide a significant level of control over how teachers do their work (Westbury 2000). These different traditions can have a significant effect on the relationship between teachers and the curriculum they are responsible for delivering.

Science Curriculum

A significant area of tension in the development of science curricula exists between the knowledge base of science and other aspects of the scientific enterprise, such as the nature of science and the complex interactions between science, society, and culture. The *Science in Society* approach, developed by the Nuffield Foundation in the UK (www.nuffieldfoundation.org/science-society), aims to provide a strong context for science learning through the teaching of important societal issues, such as cloning, genetic engineering, and global warming. *Project2061*, developed by the American Association for the Advancement of Science in the USA (www.project2061.org), includes *The Scientific World View* and *The Scientific Enterprise* as components of its *Benchmarks for Science Literacy* within a Nature of Science strand. A new national curriculum currently being developed in Australia includes *Science as a Human Endeavour* as a learning strand (www.acara.edu.au). These approaches all promise to enrich the science learning of students. However, how teacher education programs can effectively prepare new teachers with the capacity to successfully incorporate these elements into their teaching in a coherent way is still an area of difficulty with which teacher educators continue to grapple.

The resurgence of national curricula in the 1980s also saw the inclusion of laboratory work, often mandated in quite precise ways, in curriculum documentation. Laboratory work and practical experiences in general are a central part of a science teachers' life. At some levels laboratory work is a pedagogical process, designed to enhance the learning experiences of students, and for many teachers, is not seen as necessarily belonging in curriculum documentation. On the other hand, an argument can be made that it is part of the knowledge base and skill set that students should achieve. The problem that remains is the lack of an agreed understanding of what it should involve. A range of terminologies, such as "inquiry," "open-ended and first-hand investigations," "problem solving," and "experimentation," have all been used in the context of laboratory work, and it can be difficult for teachers to decipher what these terms mean in the context of their classroom practice. While the place of laboratory work in teaching, and in curriculum documentation, may seem assured, it is always under some level of scrutiny if only because of the expense of providing it in schools. Implementation of laboratory work will continue to be one of the challenging aspects of a teacher's role in putting science curriculum into action. For a recent review of these challenges in the UK context, see Toplis and Allen (2012).

Conclusion

Curriculum is a complex part of a teacher's life. While individual teachers may not feel that they have much of a role to play in the development of modern curricula, as Smith and Lovat (2003) pointed out in the introduction to their book, for any curriculum "it is the teacher, with the learners, who finally makes it work" (p. xii).

Cross-References

- ▶ Curriculum
- ▶ Curriculum Movements in Science Education
- ▶ Curriculum Structure

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Curriculum Movements in Science Education

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Keywords

Curriculum; Didaktik; Science for all; Scientific literacy; STS science

The Latin meaning of the word "curriculum" as the race course for athletic sports is a good place to start to describe the use of this word in science education. It conjures up senses of contest and of challenge that have been part of the science curriculum since its earliest beginnings in schooling. Curriculum also had a Latin meaning associating it with the "deeds and events for developing a child to an adult" that also finds resonance in how the teaching and learning of science has in some places and some occasions been conceived. It is this sense of the prescription of an intended curriculum – what is to be taught and learnt in science – that this entry discusses the science curriculum's movement over time. Others in education, and indeed in science education, use the word "curriculum" much more widely to include the pedagogies in classroom practice, the many other explicit and implicit experiences that make up schooling, but this entry uses the more restricted meaning.

The race courses for different athletic events provide some useful metaphors for the contests over the science curriculum. For example, orienteering is a race course with a few checkpoints, but no prescribed route in between. A parallel science curriculum would list a number of big scientific ideas and investigative aspects, but leave it to the science teachers to determine the detailed science they will cover to achieve the learning of these idea and aspects. The German and Scandinavian approach to the science curriculum is somewhat of this type. Again the difference between long jumping and high jumping is breadth of ground coverage versus height upwards (or negatively, depth). Science curricula influenced by the Anglo-American tradition (see below) tend to have science curricula that are quite diffuse, that is, in each year of schooling, a large number of topics are introduced, and these appear again in later years for further development. In other countries, such as Japan and Hungary, the curriculum for each year is more focused on fewer topics, but these are expected to be dealt with more completely. The difference between a long sprint like 400 m and the long distance 10,000 m can be seen in countries like USA and the Philippines which cover a disciplinary science subject in one school year, compared with European countries that devote many years to such a subject.

When the science curriculum is seen as the set of things the learners should learn, it is evident that deciding which set will be a highly contested matter among a number of stakeholders who have an interest in the shape and direction this set of learnings takes. That the science curriculum will be contested stems from many things about science and modern society. These include the strong link between science and technology (S&T) and the national economy, the critical role S&T plays in public health and environmental well-being, and humankind's curiosity about the natural world in which life of incredible variety exists and the expectation that a science curriculum could (and should) provide insights that answer and excite this curiosity. This, in turn, means that the supply and preparation of science-based professionals is of critical interest to academic scientists, who are also well aware that outstanding scientific discoveries are a matter of national pride and international competition. Within schooling there is also tension arising from the fact that science is one of the most expensive aspects of a school's budget because of its specialized laboratories, equipment, and extra professional staff.

An early example of this contest is wonderfully described by David Layton (1973) in his book *Science for the People*. In the mid-nineteenth century, a village school teacher and an educational inspector in England tried to introduce some basic science into the primary education of future agricultural and industrial laborers. There was strong resistance from a number of groups, including scientists, and the contest was lost around two issues – *science as useful knowledge* and *science as moral knowledge*.

Historically, science commonly first entered the curriculum of schooling at the senior levels only. Not surprisingly, it was taught as separate science disciplines, since its main purpose was preparing those students who had an interest in the study of these sciences at university. The contest for the content of these science curricula was dominated by academic scientists, and, as a consequence, the detailed topics for learning changed quite slowly. More scope for new topics arose as some existing ones began to make their way to lower levels of secondary schooling during the twentieth century and eventually in its last decade into the primary years. Even when the school subject in these earlier years had an umbrella title like General Science, its curriculum was usually set out as separate strands of physical, chemical, biological, and earth sciences, maintaining a strong and distinct disciplinary nature.

A major hiatus in this process for changing science content occurred in the 1930s and 1940s because of the great depression and World War II. In the aftermath of the war, during which science played a decisive part and had been developed in many ways, university scientists set about reformulating the science they taught, making it much more conceptual and hence less descriptive. A decade later it was the turn of school science, and substantial national and philanthropic funding was made available on both sides of the Atlantic for curriculum projects that would develop new materials for teaching science in schools. To be consistent and aligned with the conceptual character of university science teaching, the new materials also were to have more conceptual content, and this meant that much of the previous descriptive, applied, and historical aspects of science were deleted. With names like PSSC, BSCS, CBA, and

Nuffield, these new approaches to reforming science curricula became known as the Alphabet phase.

Consistent with the view that school science teaching was introductory and preparation for study at university, the first wave of these new materials was for the disciplinary sciences in the senior years. Subsequent projects developed materials for other levels of schooling including the primary years and for nonacademic streams of students. A number of projects followed an interesting division of science and of developmental effort. The projects for the secondary levels of schooling were characterized by their use of science concepts and principles. Those for elementary or primary schooling were much more concerned with scientific processes, probably because it was recognized that many teachers at these levels had very weak science backgrounds. The Science Curriculum Improvement Study (SCIS) was an exception to this division as it did try to include both conceptual science and investigative processes.

No sooner were the new materials from the Alphabet projects available than their relevance as science curricula were challenged by an upsurge in many countries of the idea of comprehensive schooling that should meet the needs of the increasing numbers of young persons who were now in many countries continuing at school for a full secondary education. These "new students" were not attracted to the academically oriented Alphabet courses nor were they content with the alternative nonacademic ones. By the later 1970s the proportion of senior students enrolling in the sciences were declining, and educators and policymakers were looking for new possibilities to attract students to the sciences. A premature example occurred in Victoria, Australia, in 1975 when a new senior project was established to develop a single subject, covering both physics and chemistry. It emerged as *Humans and the Physical World*, where the "and" was meant to emphasize that both the interactions of scientists in producing science, and of nonscientists making use of this science in applications, were to be the source of content. This was an excitingly new conception of science at this final level of schooling, but it was then strongly opposed since, despite attracting new students, it was felt likely to reduce still further the numbers taking the traditional separate subjects. Although failing to be accepted by most schools, some of the ideas in this curriculum were soon included in the curricula for physics and chemistry.

As confusion and disappointment in the 1970s followed the major efforts of the Alphabet projects to produce new materials for school science, there were calls in a number of major reports for a "Science for All," an expression of hope that the school science curriculum would contribute to the needs of a wider population of students (see *Science for All*). As part of preparing the Canadian report, *Science for All Canadians*, Douglas Roberts, from an analysis of the Alphabet projects, introduced the idea of a curriculum emphasis or purpose (see Curriculum Emphasis). He was able to identify and describe seven of these – *Everyday Coping*, *Solid Foundation*, *Structure of Science*, *Scientific Skills*, *Correct Explanations*, *Self as Explainer*, and *Science/Technology Decisions*. He went on to argue that when one of these emphases (or purposes) becomes the criterion for selecting content for science learning, a very different curriculum results, and that if too many of them are intended in 1 year or at one level, some will fail to have an appropriate share of the intended learnings. Roberts went on to contend that as the science content changes to reflect the different emphases, so also should the pedagogy and the forms of assessment (Roberts 1988).

The idea of *curriculum emphasis* made much more explicit the implicit purposes that lay behind the contest for the science curriculum and enabled some stakeholders to be more articulate. The emphasis, *Science/Technology Decisions*, was taken up with enthusiasm in a number of countries in the 1980s, producing exciting materials to support its teaching, such as the *PLON* project in the Netherlands and *Logical Reasoning in Science and Technology* in Saskatchewan, Canada. By the end of the decade, a new movement, Science/Technology/Society (STS), for teaching science had emerged and with it the possibility of setting out the curriculum for science as a set of thematic- or issue-based modules, each occupying a significant amount of a teaching/learning year (Solomon and Aikenhead 1995) (See Science Technology and Society (STS)). This modular format enabled the integration of science content with investigation and the effect of applications, much more easily than did a list of science topics with a separate list of investigative skills.

The heightening concern for the environment during the 1980s, and the need for a hands-on practical science in the early years, meant that several other curriculum emphases became quite well established – *Science for the Environment*, *Science for Technologies*, *etc*.

Soon after, and independently, a number of older subjects like Art & Design, Industrial Arts, and Domestic Science became linked with the emerging computer technologies to be newly defined under the subject umbrella of Technology. This was a setback to the STS type of curriculum thinking since "Technology" was now a curriculum term in its own right, but with a different meaning than it had as "applications of science" in STS, providing the bridge between Science and Society. This, together with the emergence of a new slogan, "scientific literacy" (perhaps to catch some of the priority being given to numeracy and literacy in the primary years), meant that the science curricula of the 1990s were more concerned with establishing science content throughout all the years of schooling using rather traditional approaches, than with giving it a new direction. These later redefinitions of a curriculum for school science, unlike the earlier ones that were just for science at a particular level (or levels), were carried out as part of a total reform of the compulsory school curriculum. A prevailing market view of social practices promoted a template approach to listing each subject's curriculum. The horizontal levels in this template are the years of schooling, and the vertical ones are disciplinary stranded lists of science content and of science processes. Such an expression of the curriculum gives a false air of progression of learning and lends itself to simplified external forms of assessing learning (and of teaching) that are part of the accountability that the market view requires. This approach is, however, at the expense of the intended integration of these strands and of the denigration of those newer goals of the science curriculum that are not accessible to external assessment. Millar and Osborne (1988) provide a helpful critique of this still prevailing approach to the science curriculum in the report, *Beyond 2000*.

"The curriculum" is a familiar term in countries in which education has been primarily influenced by British and American patterns and values of education (the Anglo-American tradition). In countries more influenced by European educational traditions, words like the German, *Bildung* and *Didaktik*, are more familiar. Conversations between representatives of these two traditions in the 1990s helped to clarify some quite significant differences that have a bearing on "what learnings" should be included in science education (Hofmann and Riquarts 1995) (See Didaktik).

In Anglo-American contexts, the curriculum for the sciences has, as its primary goal, been directed to the purpose of introducing students to the basic concepts, principles, and investigative procedures of the various sciences and, in this way, preparing those students who choose to continue science-based studies beyond school. In the European tradition, a primary purpose of school education, and hence of the sciences in this education, is quite explicitly about the maturing of students as whole personalities. Since the various fields of science have developed to serve purposes that are different from this, their bodies of knowledge are not automatically useful in schooling. In the first tradition, the responsibility for the content learning in the science curriculum is usually held centrally, but in the second tradition the individual teacher takes more of this responsibility.

This difference in tradition was very evident in the early 1990s when many countries were redefining their whole school curriculum or their curriculum for science(s). In the Anglo-American countries, there was much concern with identifying Key Learning Areas. Science, as a set of science disciplines, or as combined in some way, was always one of these KLAs. At the same time the Norwegian Government adopted in 1994 the **Core Curriculum** which defined itself not in terms of KLAs or subjects, but as a set of human characteristics that education should strive to develop – *Spiritual Human*, *Working Human*, *Aesthetically aware Human*, *Environmentally responsible Human*, *Social Human* and *Integrated Human*. It is possible to find many learnings in the sciences that would contribute to each of these aspects of a rounded person, but how to structure these into a program for the years of schooling proved very difficult, even in Norway. Nevertheless, the **Core Curriculum** serves as a reminder that a science curriculum should aim to serve educational purposes that are much wider than it often does.

After lying fallow through the 1990s, but again in response to recent evidence from the two international assessment projects TIMSS and PISA of a decline in student interest in science, the ideas of STS are reemerging as science curricula begin to include Context-based Science and Socio-scientific Issues Science. These international projects are conflicting in the sense that TIMSS is concerned with comparing the curriculum content that is common across countries – an inevitably conservative view – whereas PISA, not primarily curriculum oriented, has pushed for students' active use of scientific knowledge in everyday contexts.

In the last decade or so, several of these other emphases have gained strong support among a number of science educators and their innovative teacher colleagues –*Scientific Argumentation*, *Context-based Science*, *Socio-scientific Issues Science* – each of which can also be recognized as developments of the STS movement but in terms of the S, T, and S, respectively. Roberts' early emphases could be accommodated within the teaching of individual science or in more integrated science teaching, but some of these more recent emphases only make sense within an interdisciplinary view of science teaching, since real-world contexts and SSIs rarely involve just a single science discipline.

A recent challenge to the science curriculum has come from stakeholders who see the impact of the digital revolution on society being so great that knowledge is becoming more of a verb than the noun it has formerly been. This Knowledge Society emphasizes skills like *thinking*, *creating*, *communicating*, *problem solving*, *knowing how to learn*, *etc*. These are being described as generic, but they challenge the science curriculum which has hitherto been much more concerned with students acquiring a store of established knowledge and standard procedures than with these more dynamic practices, despite the importance they have in science itself. New science curricula in New Zealand and Australia have been much concerned with how this new challenge is best accommodated.

Cross-References

- ▶ Context-Led Science Projects
- ▶ Curriculum Emphasis
- ▶ Didaktik
- ▶ Inquiry, as a Curriculum Strand
- ▶ Science, Technology and Society (STS)

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Curriculum Organisation

- ▶ Curriculum Movements in Science Education
- ▶ Curriculum Structure

Curriculum Projects

- ▶ Context-Led Science Projects
- ▶ Curriculum Movements in Science Education
- ▶ Primary/Elementary School Science Curriculum Projects

Curriculum Structure

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Keywords

Curriculum design Curriculum models; Curriculum frameworks

The nature and purpose of science education as a component of the school curriculum have a contested history. For example, DeBoer (2000) identified "scientific literacy" as a common curriculum goal for science education but over time there has not always been a shared meaning of that term. In any event, such a goal can be expressed in curriculum terms in different ways. Curriculum structure is therefore as much a social construct as it is an objective description of the shape and function of a particular curriculum. Disagreements over curriculum structure have often reflected deeper philosophical and political differences about epistemology and the purposes of schooling.

In this entry, curriculum structures will be reviewed paying attention to the multiple senses in which the term is often used: first, as differences in curriculum form; second, as different ways of making scientific knowledge accessible; and third, as an aspect of society's expectations of scientific learning. These different ways of viewing curriculum structure are often underpinned by theories of different kinds and these will also be referred to.

Curriculum Structure as Form

Posner (1974) referred to the many different ways in which the curriculum could be structured: these structures depend on the theoretical disposition of the author, the particular social and political context of the time, and the purposes that a school subject like science is meant to serve. Thus, when the acquisition of scientific knowledge, or learning to "think like a scientist," is seen to be important, the focus of school science subjects will be the science disciplines themselves. This is almost always the case at the senior levels of schooling, but arguments have also been made for younger students to be introduced to science disciplines so they can be adequately prepared to become scientifically literate and have the very real option of taking up a scientific career. The structure of such a curriculum is likely to be topic based, linked to individual science subjects, and characterized as the traditional academic curriculum. Pedagogy is likely to consist mainly of direct instruction.

Psychologists such as Jerome Bruner have suggested that the key concepts of the academic disciplines, whether in science or social science, can themselves form the basis of a school curriculum. Such concepts can be visited and revisited at different stages of schooling so that students can develop a deeper and deeper understanding of them. The resulting curriculum structure is likely to focus on the major concepts in one or more academic subjects and the ways of thinking that characterize that subject. Bruner's views on learning led him to argue that such a curriculum would also highlight students' active engagement with the subject. Thus, while its focus would be the academic disciplines, its pedagogy was more linked to discovery learning.

For other curriculum theorists, such as John Dewey, there needed to be a more integrated approach to knowledge in the school curriculum, and this thinking has had a considerable impact on science education. Integrating knowledge from different science disciplines has been a popular approach to science curriculum development. Key ideas of different kinds can be used as curriculum organizers, such as social issues (e.g., sustainability and environmental degradation) or health issues (e.g., water quality in developing countries) or issues concerning the application of science in society (e.g., the role of nuclear energy). In this form of curriculum organization, scientific knowledge is not abandoned but it is applied in different ways to address important social issues. It is these issues that form the basis of the curriculum. Accompanying pedagogy is likely to be inquiry oriented.

A related curriculum structure to that of the integration of scientific knowledge has been supported by the Salters' Institute for Industrial Chemistry in the United Kingdom. It is based on the identification of everyday contexts, sometimes called authentic contexts, that require both social and scientific knowledge to understand them (Campbell et al. 1994). The importance of such contexts is that they should have particular relevance to the lives of young people. This approach to scientific understanding is reflected in large-scale assessments such as the Programme for International Student Assessment (PISA) but also in curriculum developments in several countries including the United Kingdom and the United States. In a sense, this approach to science curriculum is not so much built on integrating knowledge from different disciplines (although it does this) as bringing together scientific and social explanations for important phenomena influencing young people. Students learn science and its processes but as well and they learn about its social applications in relevant contexts (Solomon and Aikenhead 1994). The curriculum is structured around relevant social contexts that require scientific and social explanations and pedagogy is likely to be inquiry oriented.

Ways of Knowing and Learning Science

It is clear from the above descriptions of different forms of science curriculum that, while they represent different curriculum forms and structures, they are by no means value neutral. Discipline-based approaches assume that scientific knowledge within disciplines should be transmitted exactly in that form to students, and this is why such approaches are usually associated with a pedagogy of direct instruction. Bruner's version of this discipline-based approach both changed the nature of science (from facts to concepts) and saw the need to develop a more engaging and meaningful pedagogy. Integrated curriculum designs did not deny the importance of scientific knowledge but sought to draw on multiple disciplines where they were relevant in addressing particular issues. Authentic context-based approaches went further still by linking the curriculum to daily living and the application of scientific and social knowledge to addressing issues of immediate relevance to students. This trajectory from the disciplines to contexts is not so much about the nature of science as about the ways young people can best access scientific knowledge. If it is assumed that in a democratic society all students ought to have access to key knowledge about science, then different curriculum structures can be seen as different ways to achieve this objective.

It is for this reason that approaches to pedagogy have been referred to alongside each description of a particular curriculum structure. If knowledge is believed to be fixed and static as embodied in the scientific disciplines and only has to be "absorbed" by students, then direct instruction will be the pedagogy of choice. If students themselves need to integrate new knowledge into their existing knowledge structures, then learning processes will need to provide the opportunity for this. There is no single pedagogy that can be prescribed, but, where issues and problems form the structure of the curriculum, then inquiry or problem-based pedagogies will work best. So the "what" and the "how" of science learning are closely related.

Society's Expectations About Science Learning

Schools operate in social and political contexts so it should not be unexpected that what is taught and how it is taught will be of interest to society at large. In the post-World War Two period, the relationship of science to national security led to a focus on the strategic and instrumental purposes of teaching science, and the "race to space" in the 1960s highlighted the need to produce scientists who could assure victory in this race. Thus, the focus on scientific disciplines and Bruner's concept-based curriculum is that students needed to understand "real" science. At the same time, some community groups have often advocated for more “rigor” in the curriculum, and this is generally seen to be achieved with a discipline-based approach to school subjects. It is in this sense that curriculum structure can be said to be socially constructed because it is a response to social pressures.

Yet these social pressures can change. For example, when governments change, there can also be a change in educational philosophy and direction. This can then create spaces for alternative curriculum structures that may be more student focused or more supportive of adopting structures and pedagogies that are known to meet the needs of a broader range of students. Educators themselves can be responsible for promoting these alternative approaches especially where they can show there will be benefits for all students rather than just some. It is important to understand that curriculum structures can be used for important social purposes as well as educational purposes.

Conclusion

Curriculum structures give shape to the form the curriculum takes, but this form may be determined as much by social influences as educational rationale. Choice in curriculum structure ranges from the use of pure science disciplines to the selection of scientific knowledge that addresses issues of immediate relevance to students. Related to this choice are questions of pedagogy and how students can most effectively learn science. Society will always maintain an interest in the form and structure of the science curriculum so that changes can be expected over time and in response to what are seen as key social and political priorities.

Cross-References

- ▶ Curriculum
- ▶ Curriculum Development
- ▶ Curriculum and Values
- ▶ Dewey and the Learning of Science

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Curriculum-Embedded Formative Assessment

▶ Embedded Assessment

Cut Scores

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Keywords

Cut scores; NAEP; Test; TIMSS

Cut scores are points on a distribution of scores representing the minimum scores required for performance at specific levels. They are used to categorize performance on assessments into each of the performance levels. In high-stake tests the cut score becomes the passing score determining either passing or failing the test.

The measured achievements have to be considered as continua. Dividing each of these continua is essentially arbitrary. The result consists in a number of divisions (cut points) that mark the boundaries of the divisions. The establishment of cut scores represents one of the most critical test development issues, especially for test with any consequences for examinees. Standard-setting methods used to determine cut scores require expert judgments about the expected performance at each level. The cut scores determining each level are available with the descriptions because there is a need of reporting student performance not just as scores, but also in terms of content; the usefulness of the data collected can be proved when there is an understanding of what is measured and its connection to what these measures reveal about students.

In Trends in International Mathematics and Science Study (TIMSS), there are selected four cut points, 625, 550, 475, and 400, on the achievement scales. These cut points corresponding to the international benchmarks were selected initially to be as close as possible to the percentile points – 10 %, 25 %, 50 %, and 75 %. The National Assessment of Educational Progress (NAEP) uses a set of cut scores on the scale that defines the lower boundaries of basic, proficient, and advanced levels being determined for each grade through a standard-setting process.

Cross-References

- ▶ Achievement Levels
- ▶ High Stakes Testing
- ▶ National Assessment of Educational Progress (NAEP)
- ▶ Scale Scores
- ▶ Third International Mathematics and Science Study (TIMSS)