A

Academic Engagement

► Opportunity to Learn

Academic Support or Development Programs

► Access of Historically Excluded Groups to Tertiary STEM Education

Access

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Access of Historically Excluded Groups to Tertiary STEM Education

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Keywords

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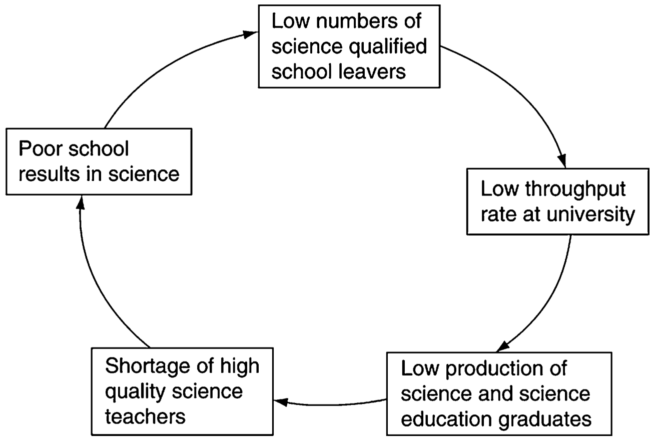
Access programmes

In most countries access to tertiary STEM (science, technology, engineering, and mathematics) study is restricted to those who attend schools that offer prerequisite preparation, predominantly in mathematics, the main gatekeeping requirement to STEM study in almost all contexts around the world. This restriction leads to either a shortage or a lack of diversity among STEM students, as these schools usually serve the middle and upper socioeconomic groups in any population. In developing countries this pattern is exaggerated even further to the extent that students of first-year undergraduate science classes are often drawn from just a few schools in the whole country. For example, in 1999/2000, 65–75 % of students admitted to two of Ghana's most prestigious universities were drawn from only 50 out of the 500 plus secondary schools in that country. To address this problem, many countries institute special programs known as access programs to increase the number and diversity of students in these programs. This is an attempt to break the vicious circle in science education, illustrated in Fig. 1 below (Rollnick 2010, p. 13). Access programs generally intervene in the cycle both by providing greater numbers of school leavers into the system and by improving throughput at university.

R. Gunstone (ed.), *Encyclopedia of Science Education*, DOI 10.1007/978-94-007-2150-0,



Access of Historically Excluded Groups to Tertiary STEM Education, Fig. 1 The vicious cycle of science performance

Type of Model	Year 0	Year 1	Year 2	Year 3
Normal course and extra tutorial/enrichment model	Non Existent	Normal Degree Structure		
1+3	Foundation year	Normal Degree Structure		
2+2	Two year Access programme		Senior years of main degree	
Complete restructuring	Year 1	Year 2	Year 3	Year 4

Access of Historically Excluded Groups to Tertiary STEM Education, Fig. 2 Schematic description of different models

Access programs serve different clientele depending on the country context. In developed countries access program students would most likely be mature adults making late decisions to enter tertiary education or ethnic minorities. Both groups may have been excluded from mathematics and science in secondary school. In developing countries those students able to enter higher education in science tend to come from a few elite schools, while the more able students from the majority of schools are not able to gain access.

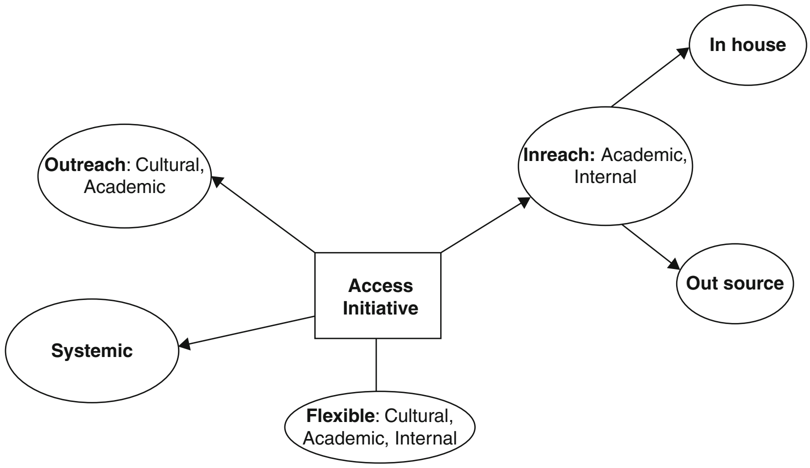
Access programs differ in their structures but in most cases increase the duration of the undergraduate program. Figure 2 below summarizes the most common models assuming a 3-year undergraduate degree (Rollnick 2010, p. 17). Four-year degrees would be similar with an additional year.

The first two models are the most common and the least transformative in their orientation but can be further classified according to whether the institution directly offers the program or whether it is outsourced. A study of various initiatives internationally led to the characterization shown in Fig. 3 (Rollnick 2010, p. 46).

"Inreach" in Fig. 3 refers to programs aimed at getting students from underrepresented communities into programs such as summer schools and adult access programs. These may be offered by the university itself or outsourced. Flexible programs are described as those that involve adjustments to the HE delivery, structure, or administration and include cooperation between different types of institutions, open learning, and part-time provision. Systemic initiatives are large scale, commonly at the school level, aiming to improve access by improving the school system as a whole.

Within these categories, the type of support that is provided is categorized as follows:

– Academic: Support aimed directly at assistance or offering of relevant content
– Cultural: Support aimed at providing broader epistemological access (see below)
– Internal: Support provided either through an extended curriculum or add-on support



Access of Historically Excluded Groups to Tertiary STEM Education, Fig. 3 Categorization of access programs (Adapted from Osborne 2003)

Access of Historically Excluded Groups to Tertiary STEM Education, Table 1 Comparison of types of support in developed and developing countries

Types/characteristics	Developed countries	Southern Africa
Systemic	4	1
Flexible	6	2
Inreach in-house	9	36
Inreach outsource	6	3
Outreach	25	3
Total	50	45

Table 1 below shows how the different types of support differ between developed and developing countries using Southern Africa as an example.

As can be seen, programs are commonly outsourced in developed countries while universities in Southern African countries feel the need to take institutional control of the programs, probably to ensure that students exiting the access programs enroll in their institutions.

Accounts of the purposes of the programs differ but common elements are:

- The development and provision of quality SET education, particularly for students from disadvantaged backgrounds
- Delivery of SET education for meaningful employment for all
- Provision of alternative access routes to students who may not otherwise have had the opportunity to participate in tertiary study
- Increasing the pool of competent STEM graduates
- Provision of the STEM-specific and more general skills and knowledge for success at tertiary study
- Providing outcomes relating to more than content alone – for example, ability to communicate, problem solve, and work as part of a team
- Increasing the knowledge base and confidence of students in STEM fields

Program Ideologies

The mode of operation and success of the program depends on the ideology associated with the access courses. These ideologies would be closely linked to ideologies of admission, as those in access programs are those who do not gain direct admission.

Brennan (1989) outlines four ideologies of admissions:

1. Relation of admissions to the reputation of institutions: The ability to attract good students is a sign of the institution's quality and is thus easily linked to the performance of the school leavers admitted.
2. Emphasis on equity: The concern is with fair competition for places, so admission to higher education becomes an award for diligence. Nonstandard routes into higher education

other than access programs are suspect because they allow admission through unfair means.

3. The social engineering approach: Like the equity approach, it is concerned about equality of opportunity but wishes to level the playing fields by recognizing that some applicants are disadvantaged. Concern is about the social composition of the cohorts admitted.
4. The "shortage-of-students" approach: This arises when universities have difficulty filling places with conventionally qualified students.

A useful concept to describe the essential nature of access work has been provided by Morrow (1994) who coined the term "epistemological access" to the university. Essentially the term describes the extent of access to the culture of the institution. This relates to working to make students excel rather than avoid failure. It highlights the importance of making the program part of the academic enterprise, rather than isolating it. This issue goes to the heart of epistemological access – students need to become part of the community of practice.

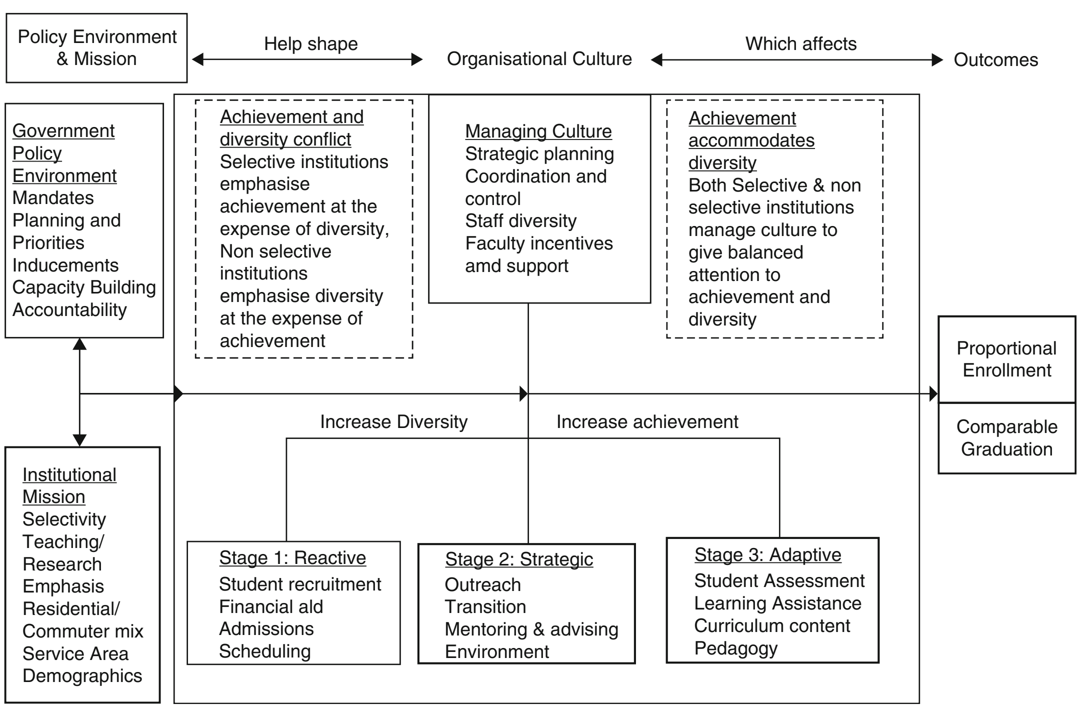
Grayson (1996) translates epistemological access into pedagogy as follows:

- Reasoning and practical skills must be taught explicitly.
- Learning must be rooted in specific content.
- Thinking and reasoning skills needed for science must be identified and explicitly taught.
- Disciplines should be broadly integrated.
- Teaching and learning are interactive.
- Content should be restricted in scope and covered in depth so as to promote conceptual understanding.

Relationship to Higher Education Policy

Richardson (2000) has designed a model of institutional adaptation to student diversity, shown in Fig. 4 (Rollnick 2010, p. 32).

Richardson (2000) suggests that when an institution is put under pressure to accommodate diversity, they initially respond by behaving in a reactive fashion (Stage 1), emphasizing recruitment and



Access of Historically Excluded Groups to Tertiary STEM Education, Fig. 4 Model of institutions adaptation to student diversity admissions and providing extrinsic support such as financial aid, without the deeper support structures needed to retain nontraditional students. Such reactive strategies are of necessity shallow and result in a revolving door admissions policy.

When these strategies fail, the institution becomes more strategic (Stage 2) and responds by trying to change the students in such a way that they provide a better fit for the institution. Stage 2 is characterized by outreach, transition programs, and the use of mentors who have already been successfully socialized into the institution's culture. The improved socialization in the institution may result in improved retention, leaving the institution satisfied that they have successfully managed a transformation process.

Stage 3 strategies, which require the institution to adapt its practices to take account of a changing student population, can only take place in the context of transformative state policies combined with committed institutional leaders. Stage 3 strategies are characterized by a change in culture of the university resulting in new curricula (or curricula adjusted to changing demands in the outside societies) and new pedagogies.

In countries where change is slower, it is easier for institutions without a long history to achieve this transformation. So traditional elite institutions would experience more difficulty in adapting in this way. However in a society where rapid social changes have taken place, state policies exert pressure on the institutions to change.

Richardson cites various characteristics of effective programs in the hard sciences and medicine:

- Provide students with more time to master the same material
- Use socialization experiences primarily to contribute to academic objectives rather than as ways of protecting the student from the campus environment
- Involve academic staff members in curricular reform to articulate access programs with those involving advanced work
- Emphasize changes in pedagogy to increase student success rates

Grayson (1996) outlines six different areas in which access students experience difficulties:

- Background knowledge: Mainly mathematics and language, but also general knowledge gained from living in an inquiring environment
- Attitudes: Rote learning, accepting knowledge without question
- Behaviors: Failure to do homework and preparation, failure to seek help, poor time management, lack of punctuality, meeting deadlines, becoming dependent on the lecturer, not studying with peers
- Cognitive skills: Logical reasoning, critical analysis, interpretation, and abstract representations
- Practical skills: Lack of experience in laboratory
- Metacognitive skills: Monitoring own thinking/understanding, studying effectively, responding to particular demands of a task, making unrealistic assessment of requirements and own performance

The above shows that the difficulties are only partially cognitive and intimately associated with epistemological access to the university as outlined previously. Recognition of this has had an impact on the content of the curriculum in most access courses. Most courses have the following elements: discipline-specific courses, mathematics, language support, life skills, and computer skills.

The importance of mathematics as a gatekeeping course for most science studies needs to be recognized. As mentioned above where these are absent, they frequently require extra attention and carry no credit when taken at university.

Language support takes many forms at different institutions. More superficial approaches consider the required program to target technical English, while others recognize the deeper issue of changing discourse and communicative competence. Most programs recognize the need to integrate the language support into the teaching of the discipline-specific subjects.

In addition to purely academic skills, many programs address what could be termed "para-academic" skills to enable students to succeed and survive tertiary study. These skills address students' needs for assistance with metacognitive skills, behaviors, and attitudes as outlined by Grayson above. Some institutions offer these skills in a separate course or through counseling services as well as integrating them into the teaching of the courses.

Cross-References

- ▶ Code-Switching in the Teaching and Learning of Science
- ▶ Discourse in Science Learning
- ▶ Language and Learning Science
- ▶ Metacognition and Science Learning
- ▶ Retention of Minorities in Science

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Accommodation in Assessment

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Keywords

Effectiveness of accommodations in assessment; English language learners

The purpose of accommodation is to allow students to best demonstrate their development, understanding, and achievement. There is, however, a lack of consistency in the design, development, and provision of accommodation which is a controversial issue. The types of accommodation adopted include extended time such as time and a half, double time, or unlimited time; small group/individual assessment to reduce distraction to other test takers; providing test directions such as interpretation for students taking tests not in their first language or for English language learners (ELLs); test items read aloud or interpreted; and student sign response for those students having difficulty expressing themselves in writing. Further, there are accommodations in settings such that the environment setup is changed, which is a common practice for students who are easily distracted. Many of these accommodations are not limited to science but are also common in other subject areas.

Considerations of accommodation in assessment in science are recent. Other studies aim to identify the effectiveness of the various measures for accommodations in assessment. Effectiveness is measured or represented in a number of ways including student satisfaction, test score validity, and verifying scores from accommodated tests to see whether they measure the same attributes as the unaccommodated tests.

Cross-References

- ▶ Alignment
- ▶ Assessed Curriculum
- ▶ Assessing Students at the Margins
- ▶ Assessment Framework
- ▶ Assessment of Doing Science
- ▶ Embedded Assessment

Accountability

- ▶ Assessment to Inform Science Education
- ▶ Test

Acculturation

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Acculturation is a concept borrowed from cultural anthropology and applied to education (Eisenhart 2001; Aikenhead 1996), in which teaching-learning is understood as cultural transmission-acquisition and meaningful learning is assumed. Within cultural anthropology, science has been described as a cultural entity (an ordered system of meaning and symbols, in terms of which social interaction takes place; according to Geertz 1973). As a subculture of Euro-American cultures, Eurocentric science (ES) can be distinguished from other cultural ways of rationally and empirically describing and explaining the physical world (Aikenhead and Ogawa 2007).

Accordingly, conventional science education seeks to transmit the culture of ES to students so they can conceptualize, talk, value, and behave scientifically – being scientific. Two extreme reactions can result. Science-oriented students are eager to be identified with being scientific because their worldviews tend to harmonize with a worldview endemic to ES conveyed by school science (e.g., they often embrace a mathematical idealization of the physical world). The way these students' experience the cultural transmission-acquisition of ES is called ► *enculturation*, in which being scientific enhances their everyday world. However, for non-science-oriented students whose worldviews are discordant with a worldview endemic to ES in varying degrees, the school is attempting to get them to comply with being scientific and to significantly change or add to their self-identities and everyday thinking, more or less. This is a transmission-acquisition experience called ► *assimilation* (Aikenhead 1996). Most non-science-oriented students resist assimilation successfully.

Between the extremes of enculturation and assimilation lies the transmission-acquisition experience of *acculturation*: the selected modification of one's currently held ideas and customs under the influence of another culture (Aikenhead 1996). An ideal goal of school science acculturation is to have students master and critique ES without, in the process, diminishing their own worldviews, self-identities, and culturally constructed ways of knowing the physical world.

When participating in acculturation, a non-science-oriented student most often changes a concept or belief, or adds new ones, to their understanding of the physical world. A key phrase in the definition of acculturation is "selected modification," because selections can be made either in an explicit, informed, autonomous way or in an implicit, uninformed, pressured way. The former is called *autonomous acculturation* (Aikenhead 1996), while the latter could be seen as *coercive acculturation*.

Examples will help clarify these categories of acculturation. A non-science-oriented student experiencing autonomous acculturation makes a decision in a fairly deliberate way to adapt from the culture of ES attractive aspects of being scientific. For instance, a non-science-oriented student takes on sufficient aspects of being scientific to become more critical of science-related advertisement claims. Another example is non-science-oriented American Indian students adding the scientific concept of disease to their Indigenous understanding of poor health (i.e., the imbalance among the physical, mental, emotional, and spiritual dimensions of humans) because they anticipate gaining power by addressing ill health from two cultural perspectives. In both examples, students autonomously appropriated knowledge from the culture of ES. Their decisions were guided by intellectual independence.

On the other hand, selections can happen under mild coercion, that is, made subconsciously or without full cognizance of the consequences. Intellectual independence is mostly absent. An example of coercive acculturation is a situation in which reductionist and/or mechanistic metaphors in ES replace a student's holistic and/or aesthetic images of nature and thereby causing angst for the student. Another example is an isolated American Indian community purchasing a satellite dish, only to discover that the next generation of children has become fluent in English at the expense of their native tongue and therefore losing a critical aspect of their culture. In other words, the community has experienced coercive acculturation into mainstream American culture by the community's selection of a technology without understanding the consequences. If instead of offering satellite dishes, the dominant society implemented residential schools harmful to American Indians or refused to include American Indian perspectives in school science courses, that act would be assimilation.

The line between coercive acculturation and assimilation is a vague one. On the one hand, coercive acculturation is associated with inadvertent action by educators who perhaps have not critically considered how their policies or teaching indoctrinate non-science-oriented students and how these students risk unconsciously altering their self-identities or worldviews without the benefit of considering the consequences. On the other hand, assimilation is associated with actions by educators who achieve their *intended* consequences of indoctrination.

The degree to which non-science-oriented students actually incorporate being scientific into their self-identities and everyday subcultures reflects the degree to which acculturation has taken place (Aikenhead and Jegede 1999). Such students can be empowered to draw upon the culture of ES in appropriate situations, such as working at a job or profession, judging a -science-related personal or social issue, participating in a science-related event, or making sense of one's own community or society increasingly influenced by ES.

The process of acculturation, however, does *not* apply to those non-science-oriented students who are able to acquire enough content from the culture of ES to pass science courses but without understanding that content in any meaningful way, in other words, without integrating aspects of the culture of ES into their self-identities or everyday world. Those students tend to avoid any of the cultural transmission-acquisition processes related to science education. The process these students follow has been labeled "playing Fatima's rules" (Aikenhead 1996), and the "rules" comprise various strategies of resistance against any attempt to enculturate, acculturate, or assimilate these students.

Cross-References

- ▶ Alienation
- ▶ Borders/Border Crossing
- ▶ Classroom Learning Environments
- ▶ Cultural Change
- ▶ Cultural Imperialism
- ▶ Cultural Influences on Science Education
- ▶ Cultural Values and Science Education
- ▶ Culturally-Relevant Pedagogy
- ▶ Culture and Science Learning
- ▶ Emotion and the Teaching and Learning of Science
- ▶ Epistemology
- ▶ Ethnoscience
- ▶ Indigenous and Minority Teacher Education
- ▶ Indigenous Knowledge
- ▶ Indigenous Knowledge Systems and the Nature of Science
- ▶ Indigenous Students
- ▶ Indigenous Technology
- ▶ Learning of Science – A Socio-Cultural Perspective
- ▶ Multiculturalism
- ▶ NOS: Cultural Perspectives
- ▶ Science Curricula and Indigenous Knowledge
- ▶ Socio-Cultural Perspectives and Characteristics
- ▶ Socio-Cultural Perspectives on Learning Science
- ▶ Teacher Preparation and Indigenous Students
- ▶ Teaching and Sociocultural Perspectives
- ▶ Values and Indigenous Knowledge
- ▶ Values and Learning Science
- ▶ Values and Western Science Knowledge
- ▶ Values in Science

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Achievement Differences and Gender

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Achievement Differences and Gender

It has been asserted that achievement differences in certain fields – the sciences in particular – can be explained by innate differences in boys' and girls' ability, specifically their representation among those with the highest ability in mathematics. Although some research evidence supports this hypothesis, scholars have also argued against this claim. For example, a meta-analysis of US state assessments found that female and male 2nd through 11th grade students did not significantly differ in mathematics performance, but limitations in these data did not allow for analyses of the areas in which extant research finds that gender differences may be more likely to emerge – complex problem solving and advanced mathematics (Hyde et al. 2008). If not ability, what does explain variation in male and female secondary school students' selection into scientific disciplines, in postsecondary and beyond?

Importantly, extensive research suggests that gendered differences are most likely shaped more strongly by social, psychological, and cultural forces rather than biology. Recent research shows cross-national variation in sex segregation of career fields as well as in the level of gender differences in students' performance on mathematics assessments. Importantly, differences in science achievement and choice of career pursuits in these fields appear to develop over time.

Socialization begins early in life, including messages girls and boys receive about what careers are appropriate for them. Notably, US girls perform as well as US boys in mathematics and science in elementary and early secondary school on the National Assessment of Educational Progress (NAEP). Male students have been found to slightly outperform females on these tests at the end of high school, particularly on advanced curriculum. One hypothesis for the emergence of this gap could be that males are simply stronger in advanced mathematics and science than females.

But another pattern emerges in secondary school that suggests a different causal path. It is in secondary school that students can choose which courses to take, and females may be less inclined to pursue areas that are not associated with female success. Indeed, males have been found to enroll in more advanced secondary school physics courses than females. Notably, of those students who completed the most advanced mathematics and science courses and went on to major in the most male-dominated sciences – physical sciences, engineering, mathematics, and computer sciences (PEMC) – there is a negative association between female gender and tenth grade perceptions of their mathematics ability on their chances of selecting these majors instead of other college majors – controlling for mathematics ability and other potentially confounding factors (Perez-Felkner et al. 2012). This finding corresponds with research on career task values. When children internalize their society's expectations for their career-related achievement, they may in turn devalue and turn away from tasks related to areas in which their group is not expected to perform well (e.g., mathematics for girls) (Eccles 2011). It may be that gender differences in scientific career achievement can be explained by these social psychological differences in female and male students' orientations to mathematics and science.

Cross-References

- ► Attitude Differences and Gender
- ► Careers and Gender
- ► Gender
- ► Gender-Inclusive Practices
- ► Interventions, Gender-Related
- ► Participation, Gender-Related
- ► Socio-Cultural Perspectives and Characteristics

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Achievement Levels

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Keywords

Achievement levels; Advanced International Benchmark; High International Benchmark; Intermediate International Benchmark; Low International Benchmark; TIMSS

Achievement levels are performance standards describing what students who achieve a given level on a scale typically know and can do. They refer to academic achievement providing a context for interpreting students' scores on different assessments. Each achievement level description reveals a picture across a broad range of performance levels with corresponding details related to the framework. They are cumulative, students performing at one of the superior levels also displaying the competencies associated with the lower levels.

For example, Trends in International Mathematics and Science Study (TIMSS) utilizes scale anchoring procedure to summarize and describe achievement at four points on the mathematics and science scales – Advanced International Benchmark (625), High International Benchmark (550), Intermediate International Benchmark (475), and Low International Benchmark (400). The first step was to identify those students scoring at each cut point followed by determining which particular items anchored at each of these benchmarks. To determine which items students at each benchmark are most likely to answer successfully, the percent correct for those students was calculated for each item. The delineation of sets of items that students at each international benchmark are very likely to answer correctly and that discriminate between adjacent anchor points takes into consideration the percentage of students at a particular benchmark correctly answering an item and the percentage of students scoring at the next lower benchmark who correctly answer an item. The experts based on the items' descriptions within each benchmark elaborated the descriptors according to the frameworks. The result is a summary of the international learning outcomes in terms of acquiring skills and knowledge reflecting demonstrably different accomplishments by students reaching each successively higher benchmark.

Cross-References

- ► Assessment Framework
- ► Cut Scores
- ► Scale Scores
- ► Third International Mathematics and Science Study (TIMSS)

Acquisition Metaphor

► Metaphors for Learning

Action and Science Learning

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The Actional Turn in the Sciences of Culture

We argue that an actional turn is currently taking place across all the social and human sciences – the "sciences of culture." By "actional turn," we mean the fact that each studied phenomenon is seen through practice, as a practice. For example, Science is studied "in action" (Latour 1987), in a research process which privileges Science "in the making" over "ready-made" Science.

In Educational Sciences, in particular Science Education Research, this conception has two major consequences. The first one refers to the fact that, in order to understand Education, one has to understand two fundamental actions, the teaching action and the learning action, both in their conceptual structure and their empirical unfolding here and now. The second consequence rests on the same logic and refers to the knowledge ontology within the educational process. This knowledge is not seen as a thing, but as a praxeology (Chevallard and Sensevy 2014): a praxis (a practical action) and a logos (a body of discourse) related to this action. Knowledge is seen as a living organism, and the researcher's work consists of understanding the life of knowledge (Tiberghien et al. 2009) from the sphere in which it has been shaped in scientists' practice to the settings where it is transmitted, as it is enacted and embodied in student's and teacher's practices.

What Kind of Action?

We argue that acknowledging this actional turn in Science Education Research is a point of departure that enables the educational process to be conceptualized in a different manner. In this way, the Joint Action Theory in Didactics (Sensevy 2012; Ligozat 2011; Tiberghien and Malkoun 2009; Venturini and Amade-Escot 2013) conceives the educational action as a specific kind of joint action, in which the teacher's action and the student's action are deeply interrelated through the growing of common knowledge.

It is important to note that the Joint Action Theory in Didactics (JATD) does not see these actions as symmetrical. In particular the teacher's work consists of managing learning situations in which the current student's strategic system of action (the didactic contract) may enable him/her to deal with the emerging symbolic structure of the knowledge in the problem at play (the didactic milieu), so that the student may endorse the specific thought style (Fleck 1981; Sensevy et al. 2008) that this knowledge embeds. In that way, in JATD, the art and the science of teaching could be seen as a way of monitoring the relationship between the student's work and the milieu.

The Didactic Joint Action: What Methodological Consequences?

Such an "actional ontology" of the didactic action entails some consequences from a methodological viewpoint. Among them, it is important to emphasize the following idea. If didactic joint action is conceived as a fundamental dialogic action between the teacher and the student through the piece of knowledge at play in the didactic activity, the research method needs to document this specific relationship. That is to say that a prominent place is given to the study film (Tiberghien and Sensevy 2012), which enables the researcher to describe and understand the relational tridimensional patterns that links the knowledge growing, the student's action, and the teacher's action. Such study films constitute the central component of what one may call hybrid text-pictures systems (Sensevy et al. 2013) in which different kinds of "pictures" (e.g., systems of photograms) and different kind of "texts" (comments, content analysis, statistical analysis, etc.) are thought of in mutual annotation and as specific to these systems. One of the major features of a hybrid text-picture system is that it puts in relation different scale levels, from the briefest transactional moment to the longest duration teaching-learning process. Some of these hybrid text-pictures systems may be considered as practical exemplars (Kuhn 2012) and, according to Hacking (in Kuhn 2012), be seen as "shared examples" in Kuhn's essential perspective.

Cooperative Engineering: Research as a Joint Action

In the first three parts of this entry, we have focused on didactic joint action, which refers to knowledge transactions between the teacher and the student.

As we previously argued, this "actional turn stance" stemmed from a more general conception pervading through the sciences of culture. Within such an actional conception, the very process of research itself may be modified. In particular, a prominent place has to be given to design-based research according to the fact that the sciences of culture are in part engineering sciences, sciences of the artificial, which help modify human practices in order to make them achieve new ends for a better life. The consequences of such a viewpoint for science education may lie in the development of a specific form of design-based research, cooperative engineering (Sensevy et al. 2013), which can be characterized by the common definition of educational ends between teachers and researchers, and by their common proposal and test of work hypotheses relating to the students' learning. This teacher-researcher joint action does not erase the differences between teachers and researchers. On the contrary, it asks for a common grasp of consciousness of these differences. But it rests also on the sharing of a common stance, that of an engineer of the educational action, an engineer of the culture.

Cross-References

▶ Didactical Contract and the Teaching and Learning of Science
▶ Evidence-Informed Practice in Science Education
▶ Milieu
▶ Transposition Didactique

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Activity Theory

▶ Activity Theory and Science Learning
▶ Socio-Cultural Perspectives on Learning Science

Activity Theory and Science Learning

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Keywords

Activity theory

What Is Activity Theory?

Activity theory represents the application of principles of human development and learning from the Russian psychologist Lev Vygotsky and his contemporary interpreters such as Yrjö Engeström (1987) and Michael Cole (1996). While this ensures that activity theory enjoys a rich albeit evolving philosophical grounding, it also confronts science educators with challenges when appropriating it into their classrooms. Activity theory is not a monolithic template or a well-bounded set of research techniques that one can quickly extract from a textbook and reassemble for use. Rather, it is better considered a spectrum of ideas – without achieving complete consensus among researchers – that are located within the sociocultural learning tradition. Its unfamiliarity to those trained in Western psychology may have resulted in either indifference to activity theory or its use in ways that some experts would deem as unorthodox if not erroneous. While this state of affairs is understandably confusing for educators, activity theory can offer those following Vygotsky's method of research a number of guidelines for organizing science teaching–learning that are respectful of how people learn and collaborate in tandem with cultural artifacts/tools. Together with its potential for addressing long-standing theoretical and practical dilemmas in science education research, this framework has already found resonance among those from the Learning Sciences, computer sciences, and organizational and workplace learning communities.

Within the field of science education, one has to realize that the sociocultural tradition in learning has only gained acceptance over the last 15–20 years. Placing issues of language, social interactions, and culture and history in the foreground, advocates here downplay the emphasis on achieving and assessing visible outcomes of learning where intelligence is believed to be housed within the mind. This sea change regarding the origins and development of learning as processual or transactive during activity rather than solely biological was sparked by the appearance of Vygotsky's writings in English. Activity theory can thus be said to be the most sophisticated and interdisciplinary elaboration of Vygotskian thought for education currently, which itself draws upon dialectical-materialist underpinnings in Marxism. Remembering its long intellectual heritage enables one to quickly appreciate its ontological and epistemological assumptions as well as generate applications of activity theory that are more faithful to its practice-oriented, transformatory stance. Two ideas in dialectical materialism are acknowledged as salient in activity theory:

(A) **The reciprocal relationship between acting in the world and being transformed psychologically and sociologically by this very process**.

Being within, relating to, and acting on the material world, that is, when pursuing the conditions for life, human agents are simultaneously transformed at the level of the individual (the creation of consciousness [i.e., learning], personality) and at the level of the collective (the beginning of division of labor in society). On the one hand, it affirms that there is no escape from a materialist account of learning; without the prior concrete world of experience, there would be no knowledge to grasp or exhibit. As some have put it, there is no knowledge without praxis. The Cartesian rift between mind and body (and other dualisms) is thus healed through an activity theoretic perspective. On the other hand, there is another dialectical relationship; through their labor individuals serve both individual and collective needs; indeed labor creates the very conditions for society to function just as social institutions open up opportunities for individuals to contribute and sustain themselves in diverse ways. Unlike how other creatures usually interact with nature in a direct, stimulus–response manner, humankind manages or mediates these relationships of self and others through created and ever-changing tools and practices to satisfy human needs. It is argued that all higher psychological functions such as motivation, identity, and sensemaking are irrefutably mediated by interactions with others and shared artifacts (e.g., language) – learning as a sociocultural process precedes biological development as Vygotsky maintained. Individual learning therefore contributes towards expanding knowledge in/for others at the same time as established knowledge enables any newcomer to appropriate these through instruction without necessarily rediscovering this wisdom de novo.

Because not everyone contributes in the same manner in/to society, a division of labor therefore exists. The totality of these societal activities (from which activity theory properly derives its nomenclature), however, serves in part to reproduce as well as be the engine for change in the world. And because these social practices form the basis of culture that individuals can orient towards, participate in, and perhaps depart over the course of time, the adjective "cultural-historical" is properly attached to activity theory (i.e., the popular acronym "CHAT") to underscore their explanatory significance. Psychology has traditionally eschewed matters of culture and history in accounting for learning but activity theory instead conflates them as it is felt that mental processes are utterly dependent on the former. This again affirms the materialist-dialectical core of activity theory; change in any aspect of the material world or social practices and mutual changes in human functioning and cognition will ensue. Hence, when studying skilled actions, activity theorists pay careful attention to expertise occurring within a specific environment that they regard as ontologically indistinguishable although kept separate for analytical purposes by necessity. Rather than just privileging the actions of human agents, activity theorists prefer to scrutinize that particular societal activity as a whole and then interrogate these subsets of activity through various ways: what is happening or being changed there, by whom, through what means, and for what (historical) purposes. This close as well as practical approach towards understanding learning in a complex world (e.g., through interlinking levels of individual/collective) is a distinguishing feature of activity theory.

(B) **The transformation of the world should be a primary activity, not its mere contemplation**.

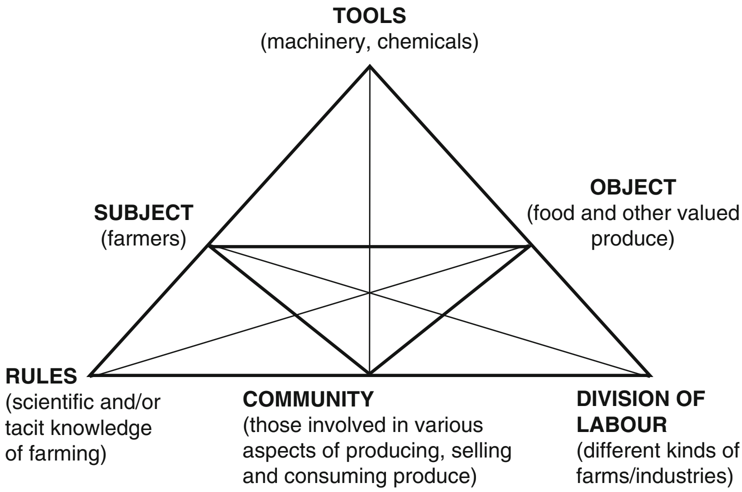
This is an extension of the former point; it is not sufficient to merely describe or philosophize about the world at the level of ideas. Instead, one has to participate with others (e.g., to describe, critique, explain, expose power) to author one's context in a life-affirming, creative, and humane sense (Roth 2010). The material world will pose all sorts of resistance to our desires (we cannot fly like birds), but this does not hold true for social phenomenon, which is amenable to human intervention/change that gave rise to it in the first place. True to its Marxist roots, activity theory is distinguished from other theories of learning in its problem-solving, expansive, and improvement-seeking nature that have been used to critique many situations and processes both in and out of school (Langemeyer and Nissen 2011). This has provided activity theory with intrinsic appeal as both a theory of instruction and a model of learning, not only for those concerned with social justice and equity agendas. A hypothetical example might serve to tie the two aforementioned key ideas in dialectical materialism: Annotated lesson plans have recently been recommended as an ideal vehicle for building a shared knowledge base for school improvement. When a teacher is motivated to submit something towards the pool of lesson plans (i.e., a knowledge product), not only does her school department benefit in enlarging the pedagogical repertoires for the collective to tap upon, but student learning (and school climate) also improves, which is the raison d'être for teachers. Identifying any obstacles together with the enablers in the overall system can provide leverage to sustain this virtuous cycle of innovative activity. Knowledge (better seen as a verb or process) in the activity system of schooling thus increases as the lesson plans are continuously revised by individual teachers engaging with different classroom/school settings and subject areas. Better yet, when students are jointly engaged in learning with teachers such as during aspects of Assessment for Learning, the joint transformation of their lifeworlds in the zone of proximal development is made manifest – does it really matter who is doing the teaching–learning now when everyone benefits?

How Can We Describe and Use Activity Theory?

Research in activity theory has fallen into two main thrusts: (1) a method and a methodology to research human psychology during engagement in everyday activities and (2) a practical intervention method for redesigning work conditions in organizations including that of schools. There are finer distinctions and a specialized vocabulary available too; the object (that part of the world to be changed) of activity is that which motivates participation in the activity system to produce an outcome. It makes no sense to speak of activity without an object for people would not undertake any actions or efforts to change the object in the first instance; they are mutually constitutive. While these actions that serve the object(s) are conscious behaviors, there is another lower level of activity that can be described – operations – which are unconscious processes (without any connotations of psychoanalysis). These three important hierarchical levels – activity, actions, and operations – are dialectically linked, just as an object is linked in a similar way to its subject (i.e., human agents). A classic example here was provided by Vygotsky's student A. N. Leontiev who spoke about the primeval collective hunt; hunters and beaters are united by a common object (to obtain food) even as they perform different and distributed actions during activity.

A more recent but highly influential heuristic known as the activity triangle has similarly proven to be an easy entry point into activity theory as seen in Fig. 1 below. Building on the fundamental concept of mediation, the subject focuses on the object using certain tools (both real and symbolic). This part of the activity system is characterized by production, whereas during consumption, exchange, and distribution, other moments/elements are brought to bear such as the rules, community, and the division of labor. Important to note is that they are again all dialectically linked; while we can focus on a single moment in the activity system, one should recall that the others are always residing in the background.

The activity triangle has achieved an iconic status although approaching activity theory this way is not without some pitfalls. For example, it tends to emphasize the synchronic rather than diachronic aspects of activity just as it has tempted some to be indiscriminate in identifying the various moments in an activity system that exist in a parts–whole relationship. These problems are partly due to the subtlety in defining "activity"; the English language is unable to differentiate the German/Russian understanding of societal activity or work (*Tätigkeit*/*deyatel' nost*) from mere effort, being engaged or busy, which is known as *Aktivität*/*aktivnost*. Hence, educators are



Activity Theory and Science Learning, Fig. 1 A depiction of an activity system – the fundamental unit of analysis – using agriculture as an exemplar. Farmers (subject) plant crops using machinery and chemicals (tools) to produce food and other valued produce (object). This process follows scientific and/or tacit knowledge of farming (rules) and articulates with those involved in production/exchange/consumption practices such as salespersons, irrigation experts, and restaurateurs, etc. (community). No single farmer can/might produce everything and is thus reliant on others for equipment, building materials, seeds, and so forth (division of labor)

frequently puzzled over the most appropriate level of analytical focus – the national system (i.e., schooling), the school/district, or the classroom/groups of students – because all three "activity systems" are amply represented in the literature, sometimes even within a single manuscript.

Besides the three hierarchical levels of activity and the different moments in an activity system, another fruitful concept is the idea of contradictions. These are frequently described as inner contradictions and are not to be confused with issues, conflicts, or problems of a superficial nature. Contradictions per se do *not* cause change; instead, they act as both resources and products of human agency during transformations of activity systems (i.e., when the object is changed). These dilemmas that are cultural-historical in origin exist at the collective/societal level and appear in four kinds. For instance, schools undergoing STEM reforms might encounter a lack of resources (a primary contradiction), learning mismatches between learners and teachers (secondary contradiction), unrealistic policy mandates coming from external authorities (tertiary contradiction), and possibly graduating students ill-prepared for science-related careers (quaternary contradiction). Presently, one reads about third generation (at least two interacting activity systems, tensions, dialogue, etc.) and fourth generation activity theory (inclusion of emotions, identity, ethics) although there is no firm consensus on their characteristics. What perhaps can be agreed is that activity theory tries to explain how sensemaking and development occur at the intersection of people acting in and on their sociomaterial environments.

Activity Theory and Science Education

In general, activity theory has been commended for its ability to handle issues of contexts, complexity, power and politics, identity and emotions, and the rapidity of educational change among others. Yet, the inroads into science education have been patchy without any person, group, or research program who can be consistently associated with this framework save for a select few such as Wolff-Michael Roth (2010). Science educators would find interest in some of the advantages of using activity theory in the discipline that are summarized below (see Roth et al. 2009).

1. To understand tool mediation in teaching and learning

   Most studies in this category have examined the use of computers and software as mediators of science learning, including the role of contradictions in the activity system. The use of psychological/thinking tools such as scientific representations has also been an area of interest. And treating science as practice in the new STEM standards in the United States finds much alignment with understanding activity as equivalent to the production, consumption, and exchange of knowledge.
2. To make visible normally invisible structures, processes, relations, and configurations

   It is the intent of educators here to provide accounts of learning that are more inclusive, to understand how schooling in society mediates individual learning. Urban science education or those initiatives that advocate science for all or with science–technology–society emphases immediately come to mind. Important but less invoked themes of race, class, and gender that play over different timescales for learners are now salient. This is the strength of activity theory when it draws culture and history into our explanations of learning.
3. To investigate issues concerning a larger system or across systems

   Even though the focus of analysis has often been the single activity system, activity theory allows researchers to zoom in and out, to make linkages between nested and overlapping activity systems (i.e., boundary objects) and give greater breadth and depth to analyses. For example, science teachers are impacted by district and societal demands and the forces of globalization even though classrooms might seem like rather isolated activity systems to many.
4. To rethink and empower science learning

   Squarely within its transformative stance, past research in this category has shifted attributing (dis)ability in purely personal terms to incorporate the sociocultural dimensions as well. Research in science education here has studied informal learning environments (e.g., environmental groups) where deep motivation and surprising levels of science expertise are displayed among students that have been written off by formal institutions.
5. To create structures and collaborations to facilitate change

   Notable here is the vast amount of work done on coteaching and cogenerative dialogs in urban science education where activity theory is used as a theory for praxis and theory of praxis. Stakeholders in environmental or workplace disputes have also been brought together using this framework to good effect because it allows for multi-voicedness in uncovering the contradictions and the heterogeneous forms the object of activity might assume.

Ongoing Difficulties with Activity Theory

One persistent dispute concerns the unit of analysis in activity theory. If we assume that activities are properly those that sustain human society, then the unit of analysis that Vygotsky championed tends towards larger, more encompassing categories such as schooling, agriculture, law, and so on. It is definitely not at the level of the individual which classical psychology has favored. Be that as it may, this has not prevented the examination of classrooms or curricula programs using activity theory to unpack the systemic contradictions there or to pinpoint specific individuals as the subject of activity. Similarly, identifying the elements or moments within the activity triangle has been seen as problematic because these are believed to be dialectical in nature thereby impossible to analyze or comprehend as stand-alone entities. Again, such a purist stance has not been consistently applied; individual elements within the triangle have been the topic of past research. In short, activity theory has philosophical underpinnings that are not easily understood (e.g., privileging knowledge as process), and thus it sometimes seems too encompassing to the point of being vague as well as too specific on other occasions with claims made that are unsupportable by the data. However, it is now increasingly accepted that micro-level phenomenon feed and support macro-level events which themselves offer affordances for the emergence of new or existing structures – both levels are analytically productive as what Vygotsky had proposed although declaring one's theoretical commitments here is needed.

Contradictions have also long been irresistible as an explanatory variable when accounting for problems and resistance to change in activity theoretic research. Yet, fidelity to these being an inner, systemic contradiction which the use and exchange value of all objects exemplify is not often adhered. The final candidate for why activity theory is so frequently misunderstood is most likely its inherent dialectical structure; learning changes from being largely attributable to individual qualities or accomplishments to being a social, collective venture. A dialectical perspective likewise suggests a needed corrective against a form of smugness in sociocultural research – our interpretations of the social world are but works in progress, by-products of a particular age and place and of fallible human beings. Certainly, this lack of closure and certitude in taking a dialectical stance will be frustrating to many.

Overall Assessment of Activity Theory in Science Learning

What are science educators to make of activity theory? It has been claimed to be able to overcome dichotomies that have plagued education such as individual/collective, body/mind, intra-/inter-psychological, and so forth. While these goals are still being worked out, at the very minimum it sensitizes us to view learning as an ongoing orchestration of people and cultural artifacts in practices (activity systems) where the past and the present are intertwined. It also inspires us to see the potential for human(e) development when societal contradictions are surfaced, critiqued, and overcome. This is an exciting but extremely difficult endeavor; human learning is multidimensional and complex, which science educators have overwhelmingly theorized at the level of the individual learner. Activity theorists will therefore continue to plod on in their research long after where Vygotsky had left off.

Cross-References

▶ Assessment Framework
▶ Communities of Practice
▶ Dialogic Teaching and Learning
▶ Emotion and the Teaching and Learning of Science
▶ Heterogeneity of Thinking and Speaking
▶ Socio-Cultural Perspectives on Learning Science

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Adaptive Assessment

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Adaptive Testing

Adaptive assessment can be defined as any type of assessment that is tailored specifically to each examinee, based on their performance on previous items on the assessment. Most adaptive assessments are based on the theories and advances of Item Response Theory (IRT). More specifically, in IRT the examinee ability estimates, as well as item characteristics such as the item difficulty, are placed on the same continuum. This allows for the administration of items that are matched to the estimated ability level (θ), of each examinee, at each point of the assessment. Therefore, adaptive assessments allow for the administration of items that are targeted to the ability level (or trait level) of each examinee, which enables the estimation of more accurate examinee ability estimates. For example, if an examinee responds correctly to item 1, their estimated ability will increase, so the second item that will be administered will be of higher difficulty than the first item. If the examinee responds incorrectly to item 2, the examinee's estimated ability will drop slightly, so the third item that will be administered will have a level of difficulty in between the difficulty levels of items 1 and 2. By administering more items that are specifically targeted to each examinee's ability, a more accurate ability estimate is achieved.

Adaptive assessments come in contrast to linear, nonadaptive assessments where all examinees respond to the same or equivalent forms of a test in a predetermined order. One problem with nonadaptive assessments is that the majority of the items administered are targeted to examinees in the middle of the ability continuum. Therefore, linear tests typically include a large number of items of average difficulty and few items of lower and of higher difficulty. This creates problems for the accurate estimation of examinees at the extremes of the ability continuum, as low ability examinees will find the items at the middle of the ability continuum too difficult, whereas high ability examinees will find such items too easy. Consequently, nonadaptive assessments tend to provide little information for high-achieving and low-achieving examinees, the ability estimates of whom therefore include large amounts of measurement error.

Some of the advantages of adaptive assessments are those of increased measurement accuracy for examinees at all ranges of the ability continuum and item efficiency since fewer items are needed to reach the same level of accuracy as with linear tests. Additional advantages of adaptive assessments when they are administered electronically are those of immediate scoring and reporting and more frequent test administrations.

Some disadvantages of adaptive assessments include (a) the considerable initial costs of creating and calibrating large item pools that are needed for such assessments, (b) the inability of the examinees to go back and change their answers on most adaptive assessments which can create anxiety and frustration to some examinees, as well as (c) the security issues related to the compromise of the item pool due to the overexposure of some items.

Adaptive assessments can take various forms, based on their degree of adaptivity. Fully adaptive assessments are those where every item is matched to the examinee ability estimate with the only goal of increasing the amount of information on each examinee's ability. Other types of adaptive assessments administer groups of items together, as a testlet, and are called multistage adaptive tests. In other cases, due to various content constraints and problems with the overexposure of certain items, the assessments are called Barely Adaptive Assessments. For most types of adaptive assessments, due to the extensive computations that are required, they are typically administered on a computer and are frequently called Computerized Adaptive Tests (CAT).

Cross-References

▶ Assessment: An Overview
▶ Computer-Based Assessment
▶ Test

Advance Organizer

▶ Meaningful Learning

Affect in Learning Science

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Keywords

Affect; Content; Learning; Pedagogy

Introduction

In the current era of education where there is so much emphasis on cognitive educational outcomes and accountability, it can be difficult to recognize the importance of affect in learning science. Today, much of the public debate about and rationale for education sees the very basis of that education being best captured by accounts of instructional efficiencies, curriculum statements, lesson plans, and public records of pupils' performance. This is at best only a partial picture, and in such an era, we need to be vigilante in reminding ourselves of this. What is abundantly clear from research and practice is that affect has considerable influence over what happens in the classroom. Some emotions (such as joy, happiness, pleasure, delight, thrill, zeal, and gladness) act to potentially enhance learning and optimize student enjoyment and achievement, while other emotions (such as sorrow, boredom, sadness, distress, regret, gloom, misery, and grief) can close down concentration, deaden curiosity, and insight and in so doing can suppress learning. The affective and emotional encounters and relationships that we develop within pedagogies and with knowledge are profoundly and deeply important. Indeed, some would go as far as to say that they actually make science education possible (Alsop 2005).

Such an assertion is not really controversial. After all, there is overwhelming evidence from a diversity of academic fields and professional practices that teaching and learning are complex, both individually and particularly in their interactions. The focus here is on the mutually constitutive nature of cognition and affect. This may seem a small point; however, it is a shift in perspective with far-reaching consequences. In recognizing the importance of affect in knowing and knowledge, we start to dispel the view that science and science education is, can be, or ought to be based on reason alone. There is a long associated history, of course, in which affect is framed as mainly undesirable, as a potential obstacle to enlightened, objective thought (especially in science). In departing from this history and holding onto the importance of affect, we open up profound questions of objectivity and subjectivities, questions that more often than not accompany popular Western narratives of mind and body duality. There are legitimate arguments that such a departure leads one to a history of science that is more consistent with the practices of sciences than history often seeks to represent.

Affect has become represented by so many diverse theories and methodologies: Darwinism, Jamesian, cognitive and socio-constructive, phenomenological, neurological, psychoanalytical, and many other perspectives as well. These each bring languages, analytical categories, modes, and methods of explorations. In the history of science education, we have been drawn to a particular personal psychological perspective and have placed sustained attention on explorations of the construct of attitudes toward science. This significant and thoughtful body of work is the subject of another entry; so it is mentioned only in passing here.

Affect in Science Education

Studies of attitudes toward science have now been joined by a growing number of studies that adopt more situated perspectives in which affect is studied within particular contexts and settings. Such studies accentuate the situated nature of affect, stressing that emotions are always grounded in personal, social and cultural contexts. Of course, studies of attitudes are themselves set within particular contexts and times, and they often reference these within their methods. Today, attention is more commonly placed on studying learning embedded within identified and identifiable science education environments, such as school classrooms and laboratories. Studies of affect in science education (a term that is used here to denote these studies) are theoretically wide ranging and empirically diverse. Some researchers, for instance, attend to particular motivational constructs including self-efficacy, interest, task value, and achievement goals. These constructs have established definitions and lineage within particular educational learning theories. They have become firmly associated with enhanced learning outcomes. In particular educational settings, researchers explore the mediatory and moderating effects of such constructs with an overarching goal of better understanding how and why some instructional practices and approaches might be more efficacious than others. Here, for instance, emphasis could be placed on personal and environmental interactions as represented by interactions between intrinsic and extrinsic motivations (see Bonney et al. 2005).

Other researchers focus on specific instructional practices and processes. In these cases, affect is evoked as a vital consideration in understanding the relative advantages (or disadvantages) of some pedagogies – such as "hands-on" laboratory or practical work, animal dissections, inquiry-based learning, drama and role play, computer-based learning, and science field trips as well as many out-of-school activities. In particular instructional contexts, studies of pupils' emotions, and conceptual understandings employ a diversity of methods but are unified in stressing the importance of positive affect for deeper, more meaningful, and longer-lasting learning. Studies deploy a wide range of different measurements as a means to comment on the effectiveness (or otherwise) of instructional practices and innovations. Studies of free-choice learning and learning within informal contexts – to give very high profile examples – consistently highlight the importance of affect for learning. Indeed, affective considerations such as "interest," "curiosity," and "fun" are now widely assumed as an essential part of lifelong learning encounters with science.

There is a literature in science education in which affect is conceived more as an outcome rather than, or as well as, a process. In such cases, the goal of a learning encounter might be evaluated predominately in affective terms (such as building a positive relationship with science). Learning encounters with science can be seen in emotional developmental terms, using constructs such as Emotional Intelligence (EI), Emotional Quotient (EQ), or emotional well-being. EI and EQ are both associated with best selling popular texts, and there are a series of widely available standardized EI and EQ tests. Although these constructs remain controversial, in some educational jurisdictions, they can be appealing (particularly within associated discussions of character education and civic education).

Perrier and Nsengiyumva (2003) study of affect has a distinctive outcome focus of therapeutically reclaiming a sense of self as an "affective being." Set within the context of post-genocide Rwanda and extreme trauma, these pedagogues turn to inquiry-based science as a means to open up channels of communication, play, and joy. The predictability and safety of gathering biology and physics data offer a platform (they persuasively demonstrate) to restore and build learner's self-actualization and relationships with others. As the authors' note of their practice, "the most important goal, indeed, is not the quality of the scientific message or the pedagogy: the most important is whether the activities contribute to an actualization of the being" (p. 1123). Although this study was conducted nearly a decade ago, this account remains a powerful example of the potentially far-reaching emotional effects of science education.

Affect of Science Education

In the examples above, emphasis has been placed mainly on the socio-psychological; the focus has been on individuals within particular educational contexts and practices. There are a modest number of studies in which affect is framed more as a sociocultural or poststructural construction with particular social, cultural, and political origins. With this orientation, affect is represented as constitutive with particular cultures and social practices (including language, institutions, social relationships, behaviors, and histories). Research attention is drawn to analyzing these co-constructed educational cultural practices with their associated emotionalities.

Zembylas (2004, p. 301) in a 3-year ethnographic study of an elementary classroom, for example, draws attention to how a teacher's performance of emotional labor is an important aspect of science teaching. Teachers' emotional labor and their emotional metaphors function, in part, in creating inspiring cultures for teaching and learning. The teacher is willing to embrace "suffering" in the form of emotional labor because of seemingly "gratifying" emotional rewards. This study highlights teachers' agency in creating and maintaining socio-emotional cultures.

Orlander and Wichram (2011) study exposes some deep rifts between learners' lived emotional experiences and some of the sociocultural academic traditions of school-based science education. The focus here is adolescents' reactions to calf-eye dissections and sex education. The authors persuasively cast this as an instance in which learners' bodily reactions are central to meaning making in science. It also highlights the emotionally lively nature of some aspects of science education and raises questions of what emotionality is desirable or indeed, undesirable within science education practices.

Cultural and poststructural studies of affect raise significant socio-political questions concerning the emotional rules governing science classroom behavior and underpinning power relations that these rules support. For some time, feminist and postcolonial scholars have drawn attention to the politics of affect, exposing the legacies of Western patriarchal thought and institutional practices. Different authors theorize the political motivations that reinforce the seemingly undesirable nature of some emotions and the worldviews that this presupposes and actively supports. This raises a number of questions for science education, including whose emotionality gets to count in our practices? How? Why? What are the shorter-term and longer-term implications of more dominant emotional traditions for different groups of learners? Are practices in science education failing students because of the particular emotional (or emotion less) forms of knowing that are stressed in teaching? These questions are presently largely under-researched and call for much greater attention in the future.

Affect in Learning Science

As with all attempts to describe learning and education, there are associated theoretical and methodological conundrums. Our narratives of learning are at best partial and serve to illuminate particular aspects whilst leaving others underdeveloped. We make our way in the world through telling stories and these stories also make our worlds. Our primary story in science education is cognition, and we record and rightly celebrate the conceptual performances of learners. Yet there is a clear evidence base that affect and cognition are inseparable and mutually constitutive.

This entry has drawn attention to three broadly different orientations to the study of affect and learning science: attitudes toward science, affect in science education, and affect of science education. These orientations are not offered here as distinctive or categorical, but as illustrative and carry with them an invitation to explore how they might, or might not, be connected. While pupils' attitudes toward science have been widely documented (often and for many decades presenting worrying trends of decline) there is an open question as to how to best respond. Different authors, quite understandably, offer a wide variety of suggestions and these often make reference to changes in teaching and learning practices. As such, they assume a connection at some level between attitudes and situated experiences. However, much research suggests that individual dispositions and situated experience are very different. Attitudes can develop more slowly; perhaps over a longer period of time, while lived emotional experiences can be short lived, episodic, transitory and more immediate. In a recent study, for instance, Abraham (2009) records an increase in short-term engagement during practical lessons but this does not translate into longer-term changes in students' interest. One of his recommendations is that researchers need to develop much more realistic understandings of the potential affective benefits of practical work. Indeed, much evidence now suggests that the construct attitudes toward science and more situated studies of affect in science education are not as closely related as is often assumed. For instance, much research paints such a gloomy picture of students' declining attitudes to science and this is a source of legitimate concern. However, this research cannot be simply extrapolated to conclude that students are regularly having problematic emotional experiences in science lessons. Most science teachers, I am sure, spend considerable time seeking to make their lessons emotionally engaging and enticing.

Similar arguments can be made concerning sociocultural studies of affect (affect of science education). While the emotional natures of our practices remain largely under-researched, these natures raise a number of questions of how they might (or might not) influence learner's situated experiences and their general dispositions and attitudes toward science. It remains an open question, for instance, as to how ways of feeling that are legitimized and de-legitimized by classroom practices impact (or not) students' lived classroom experiences. Orlander and Wickram (2011) previously mentioned study serves to demonstrate that dominant cultural traditions can be quite different to pupils' actual educational experiences. The relationship between what teachers intend students to learn and what they do learn is both dynamic and complex. Exploration of the nature and consequence of possible connections between attitudes toward science, affect in science education, and affect of science education requires greater attention in the future.

Studies of affect also present their own methodological conundrums. The ephemeral, fleeting and episodic nature of situated affect makes it challenging to quantify. Perhaps this is one reason why it is often absent from high profile discussions of school and pupil performance. It now seems like a cliché to say that the ways in which we measure learning influences how learning is both publically and privately conceived and valued. In science education, we have clearly been drawn more to some approaches in the study of affect rather than others. There is an open question of why personal psychological studies have been so appealing and seem so influential in policy and curriculum reforms. The politics of why and how we speak for science education is important.

There has been a sustained interest in a "theory of content" in science education. This is based largely on an assumption that particular content might be best taught and learned in particular ways and in particular social and environmental contexts and settings. Few would disagree that some science content is more provocative and once encountered can arouse intense reactions and equate to particular political allegiances. Other content can, of course, be much more anodyne, dry, and mundane, and this poses its own set of educational dilemmas. Over the past few decades, increasing attention has been placed on socio-scientific issues that are themselves now readily associated with heightened emotions (sometimes grief and loss with apocalyptic dimensions). Global warming and climate change is one such example. Other examples include nanotechnologies, genetically modified foods, and nuclear power and weaponry. Encountering science and technology in these areas raises axiomatic questions of affect and learning. To use a distinction drawn by Bruno Latour, encountering "matters of concern" is likely to be very different than encountering "matters of fact" – a distinction that raises some important pedagogical questions for science education. Traditionally, we have tended to associate difficult knowledge with conceptual demands rather than emotional demands. The emotive power of content still remains largely unexplored. More recently, Maria Puig de la Bellacasa has encouraged us to move beyond facts and concerns to reflect on "matters of care" in techno-science and ask: "Who cares?" "Why ought we care?" "How ought we care?" Reactions to climate change, for instance, raise questions of the importance of understanding the science involved but also, perhaps even more importantly, recognizing why, how, where, and with whom we should, or might, care. Although "pedagogies of care" have been a topic of sustained attention in education, they have yet to develop as a major theme of interest in science education and as such offer an intriguing topic for future research.

Recognizing the constitutive nature of cognition and affect (in contrast to more dualistic orientations) raises profound questions central to any considerations of science teaching and learning. As science educators, our pedagogies are at their heart an invitation to invite others into our worlds and experience a subject that has occupied our minds and emotions for such a long time. This invitation carries with it an open prospect of encountering the wonderment, delight, hopes, challenges, and possibilities of seeing the world and ourselves in different ways. Studies of affect hold the potential to simulate a new body of research with fresh insights into the teaching and learning of science. This can have far-reaching implications for practice and this seems even more pressing in an era of truly global concerns.

Cross-References

- ▶ Attitudes to Science and to Learning Science
- ▶ Attitudes Toward Science, Assessment of
- ▶ Emotion and the Teaching and Learning of Science
- ▶ Informal Science Education
- ▶ Interests in Science
- ▶ Learning Science in Informal Contexts
- ▶ Situated Learning
- ▶ Socioscientific Issues

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After School Science

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Keywords

Afterschool; Diversity/equity; Hands-on learning; Informal science education; STEM education

Introduction

Nations all over the world are recognizing the importance of preparing their students to be literate and proficient in science, technology, engineering, and mathematics (STEM) fields so their citizens can navigate the modern world and participate productively in the workforce. For students in kindergarten through high school, the formal school day and classroom teachers are at the forefront of the effort not only to increase the number of children and youth who have access to STEM learning opportunities but to do so in an equitable manner that will reach and equip a diverse group representative of the nation's population. But because children spend less than 20 % of their waking hours in school, out of school-time experiences such as afterschool programs – and the institutions and people who provide them – need to be essential partners in this effort. Both the additional time offered by afterschool programs and the opportunity are needed to diversify the ways that students experience STEM learning.

"Afterschool" is defined here as programs which provide an array of safe, supervised, and structured activities for children and youth that are intentionally designed to encourage learning and social development outside of the typical school day. Programs generally operate during the hours immediately following school dismissal; however, they also include activities that occur before school, on weekends, over school breaks, and during the summer. They may be located at a school or off-site, but the programs that show more impact on the participants are usually aligned with the school day (Afterschool Alliance 2011). A common element across these programs is an engaging, hands-on learning approach and less formal environment that aims to feel different from school. Afterschool programs are different from some of the other informal science education (ISE) environments in that they are usually much more structured and sit at the junction of the school day and a truly free-choice learning environment.

In the United States, afterschool programs present a significant potential for young people to engage in STEM education programs – 8.5 million children participate in afterschool programs and structured, comprehensive afterschool programs provide an average of 14.5 hours of programming per week for the participants. Children from populations traditionally underrepresented in STEM fields are more likely to participate than others (Afterschool Alliance 2009) – 24 % of African-American, 21 % of Hispanic, and 16 % of Native American children attend afterschool programs, compared to the national average of 15 %. Girls attend afterschool programs in equal numbers to boys. The afterschool setting thus presents an opportunity to reach the very populations we need to bring into the STEM pipeline through experiences that supplement and complement the school day.

Why STEM in Afterschool?

Afterschool programs have traditionally been very strong on targeting and delivering youth development outcomes. Public support for this setting has also been traditionally based on keeping children and youth safe and providing them with enriching experiences that contribute to the development of the whole child. However, modern afterschool programs do much more than keep kids safe and are strong learning environments that provide a wide array of engaging activities. Many of them have embraced STEM programming and pride themselves on providing engaging hands-on learning opportunities that complement the school day and get young people excited and knowledgeable about STEM topics and careers.

National youth organizations in the United States such as 4-H, Girls Inc., and Girl Scouts and a few other strong state and local afterschool providers have been offering STEM education programs for many decades. However, over just the past 5 years, the general afterschool field has come to enthusiastically embrace STEM programming and is deepening its commitment to offering STEM learning opportunities. Afterschool programs are strategic partners to engage in STEM education – they provide an environment that is free of many of the constraints of the school day and is structured yet flexible. Children and youth can engage in STEM learning and projects in this setting without fear of academic failure. Afterschool programs are characterized by a focus on project-based learning, relevance to real life, and exposure to STEM career options. Thus young people in these programs can meet and interact with adults working in STEM fields; be encouraged to appreciate the relevance of STEM topics and fields to their daily lives and global problems through hands-on projects; and come to understand that persistence in the face of failure is crucial for being an effective STEM professional. It is also a setting where technology and engineering education can occur as they are often not included in school curricula.

Among students who are fortunate enough to have access to afterschool enrichment opportunities, the benefits of afterschool programs in general are well documented, showing positive impacts on both academic and behavioral development. A review of evaluations of afterschool programs in 2011 showed that attending high-quality STEM afterschool programs yields STEM-specific benefits that can be organized under three broad categories: improved attitudes toward STEM fields and careers, increased STEM knowledge and skills, and higher likelihood of graduating high school and pursuing a STEM career.

Supporting STEM in Afterschool

The US Department of Education's 21st Century Community Learning Centers program is the largest exclusive federal funding stream for afterschool programs (at approximately $1B as of 2013), but many other federal agencies also allocate small pots of funds for supporting various aspects of afterschool programming. While only a small portion of these public monies are applied toward afterschool STEM programming, corporate and philanthropic foundations have recognized the potential of this space for STEM education and have begun investing in it as well.

To enable growth and support for STEM in afterschool, infrastructure is being assembled at a rapid pace. In addition to supports and technical assistance that go along with federal funding streams, system-level intermediaries funded by private philanthropic foundations are working to increase the quality and availability of afterschool programs and STEM learning opportunities within such programs.

Statewide Afterschool Networks operating in 42 states (as of 2013) are increasingly becoming the brokers to advocate for and coordinate afterschool STEM learning efforts in their states. Similarly, *Every Hour Counts* is a partnership of intermediary organizations dedicated to increasing the availability of high-quality afterschool programs by building citywide afterschool systems. Both these networks follow a model of advocating for policy changes at the state and local levels while working to build capacity at the practitioner level.

To aid with the capacity building and professional development needs, strategic partnerships are being formed to bridge the learning that happens within the traditional school day and in afterschool programs. Examples of systemic partnerships include those with school districts, science centers and museums, federal science agencies, and businesses and corporations. This type of alignment and reinforcement of learning will be especially critical as the nation moves toward adoption of a common set of national standards (the Next Generation Science Standards), which will require STEM education to go beyond content knowledge and embrace contextualized modes of learning.

Challenges

However, several challenges remain. Although afterschool programs are increasingly being recognized as important partners in STEM education, much of the dialogue about STEM education improvement centers around what traditional schools can do. The education reforms that are unfolding also mainly target the school day, and hence most public policy initiatives and public dollars target formal schooling as well. As children and youth spend less than 20% of their waking hours in school, it is critical that there is movement away from a model of placing the entire burden on schools and toward a model of a learning "ecosystem" that includes all relevant partners and has appropriate funding streams attached to it.

The range of STEM offerings in afterschool programs varies from one-off science activities to yearlong projects. Consequently the range of reported outcomes for afterschool STEM programs and the language used to describe them also vary greatly. There is a need to define an ISE outcome framework for afterschool that takes advantage of its strengths and clearly defines how it is responding to the national need around STEM education. A challenge for the field is to document and demonstrate the ways in which children's deepening STEM learning and engagement develops and is made possible (and possibly is more inclusive, including of children who do not succeed in school science) *because* of the strong youth development contexts in which the teaching and learning take place. That is, rather than choosing between youth development and STEM learning, it is imperative that the field identify ways of showing how they interrelate and indeed advance one another in the context of the broad reach and audience of the afterschool student population.

There have been efforts to define meaningful outcomes for ISE: the National Science Foundation released a *Framework for Evaluating Impacts of Informal Science Education Projects* in 2008 that defined impact categories (Friedman 2008); the National Research Council's 2009 report, *Learning Science in Informal Environments*, described six strands of science learning in informal environments (National Research Council 2009). Most recently, the Afterschool Alliance conducted a Delphi study (Afterschool Alliance 2013) that asked expert practitioners, policymakers, and funders to define an appropriate set of outcomes and indicators of learning for afterschool STEM. A challenge is how to take these studies and design assessments that do not change the social and cultural tenor of the afterschool space but reveal the ways in which the skills students are developing go hand in hand with the kinds of understandings traditionally associated with schools such as conceptual knowledge.

Afterschool programs have emerged as strong partners in STEM education improvement efforts. Policy initiatives and appropriate resource allocation would allow them to go the next step and become an essential part of the STEM learning ecology.

Cross-References

- ▶ Affect in Learning Science
- ▶ Informal Science Education
- ▶ Learning in Play-Based Environments
- ▶ Learning Science in Informal Contexts

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Agency and Knowledge

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An Agentive and Social Conception of Knowledge

What is the meaning of knowledge? We think that any educational endeavor rests on a conception of what knowledge is. This conception may be explicit or tacit, but we argue that it shapes the way educational processes unfold and the conception in turn is shaped by these educational processes.

In this short entry, we propose an agentive conception of knowledge. What does it mean? We consider knowledge as a power of acting. In that conception, learning a piece of knowledge means becoming able to act in a specific new way. This definition does not imply any normative conception of knowledge. For example, a person who learns a science formula by rote and without understanding has gained a power of action. If someone asks her to recite this formula, she will be able to do it and she will be able to do something she was unable to do before she learned by rote. One may argue that that is a poor conception of science education, in that the learned capacity is not very strong. But it suffices to find an educative situation, in a given institution, in which "reciting" is the right thing to do, to convince oneself that, in this setting, the person who recites the formula accurately fulfills the local educational obligations. Of course, it will be possible to find educational settings in which knowing a formula only by rote will not be sufficient. One can even think of educational settings in which rote learning will not be necessary. But we claim that in each case, knowledge, as a power of action, is shaped by the institutional setting in which it is used.

This leads us to a definition of knowledge. Knowledge is a power of acting in a specific situation, within a given institution. This conception of knowledge is both agentive and social. It is agentive, in that it sees that knowledge through the possibilities of acting it enables human beings to undertake. It is social, in that it relates these possibilities of acting to the way the social structure in which knowledge is acquired considers them.

Transmission of Knowledge in Joint Action Theory in Didactics

Conceiving knowledge as a power of acting in a specific situation, within a given institution, gives us an ontology of knowledge, both social and agentive. But such a definition has to be worked out in order to be productive. In the Joint Action Theory in Didactics, the transmission of knowledge is conceived of as a knowledge building, which is viewed in a specific dialectic between two concepts of the theory, the contract and the milieu.

The relation between the teacher and the student is considered as a transaction in which the object is based on knowledge. In this transaction the teacher's intention is to teach knowledge and the student's intention is to learn knowledge, and a problem is at play. Here "problem" corresponds to what is at stake in the transaction and thus is not limited to its usual meaning.

The didactic contract can be seen as the previous knowledge system against the background of which the teacher and the student deal with the problem at play. This knowledge system has been developed in the prior joint actions between the teacher and the student. It is both epistemic (e.g., the way of resolving a given problem or a particular concept as it has been figured out in the didactic joint action) and transactional (grounded on a system of reciprocal expectations between the teacher and the student). The contract then can be seen as a system of rules structuring the didactic action and, more generally, as the strategic systems used by the teacher and the student to deal with the problem at play in the transaction.

The didactic milieu (Sensevy 2012) is the actual material and symbolic structure of the problem at play, which the teacher and the student have to deal with in order to solve this problem. At the outset of the interaction, most of time, the milieu is not identical for the teacher and the student, depending on their understanding of the problem. The milieu can be described as the set of symbolic forms that the didactic experience transforms in an epistemic system, through the didactic contract.

In this perspective, what we call didactic equilibration refers to the way contract and milieu are related in the didactic activity. One can delineate two main patterns of didactic equilibration. According to the first pattern, the milieu is used by the teacher mainly as a way of reenacting a piece of knowledge already encountered by the student. We termed this structure a contract-driven equilibration. According to the second pattern, the contract is used by the teacher as a way of organizing the student's inquiry in the milieu so that he/she is able to solve the problem on his/her own. We term this structure a milieu-driven equilibration.

This theoretical conception enables us to come back to the issue of agency and knowledge. We assert that didactic activity has to be carried out in institutional settings in which the power of acting that the knowledge bestows is acquired through an equilibration form in which the conceptual priority is given to a milieu-driven equilibration. In that, the student's power of acting is strongly related to the teacher's capacity to enable the student to use accurately the didactic contract meanings and to accept to work in a certain kind of epistemic uncertainty to explore the milieu. The result of this equilibration work will be the growing of the student's epistemic agency.

Let us give a short example of such an epistemic agency.

An Example in Mechanics

The chosen example (Tiberghien et al. 2009) comes from a mechanics teaching sequence at high school level (grade 11) after the introduction of the inertia principle and Newton's first and second laws. One of the activities to carry out in small groups (two students) proposed the situation where a student, standing up on the ground, pushes horizontally on a vertical wall. The question was "By using the laws of mechanics, say if the forces that are exerted on the student compensate for each other or if they do not compensate for each other. Indicate the law(s) to which you refer to answer." To solve this problem the students had to make the experience, and they have an available text, given by the teacher during a previous session, with the laws of mechanics.

The two students working in group who were observed and videotaped showed two ways of seeing the situation and solving the problem; they instantaneously disagree and gave different arguments (A, the first student; L, the second student; T, the teacher):

1. A: no.
2. L: yes.
1. A: no because you do not feel the force of the ground but you feel the force of the wall.
2. L: but look at me I am going to tell you something it is [L is looking for something in his file].
3. A: no you do not feel the force no.
1. L takes the sheet and read the Inertial principle. [. . .] L calls T and T arrives.
1. L (to T): in the inertia principle, there is a condition that says that if the velocity of the inertia center is null, then (. . .) the forces compensate for each other.
   T leaves the group [. . .]
2. L: in fact you are like that there is there is/last year we saw the inertia principle it was er the forces they compensate for each other either the object it did not move like here the forces compensate for each other or there is a uniform rectilinear motion then that is if the vector is constant that is in the same direction same length [. . .] (L reads and shows the statement with his finger) if the velocity of the inertia center of a system is a constant vector, then the sum of the forces exerted on the system is null; here the constant vector is null.
3. A: but it means that in fact all the forces there remains the force of the Earth only.
4. L: no even not/all the forces they canceled.
5. A: pouff wait I have to read the summary again (10s) indeed but I am not sure; I wonder if there is not a force that does not get canceled.

For the two students, the contract-milieu relations are not the same when solving the problem.

Student L looks for the text of the principles and uses it; his strategy starts by raising a physics principle; he then checks it with the teacher if he can apply it. Then, the starting point (the problem statement, the studied situation of pushing a wall that he experiences, etc.) of his inquiry strategy is elements of the milieu and his strategy development is based on the contract (text of the laws, calling the teacher, etc.). In this case the use of contract (as the knowledge system developed in the prior joint action between the teacher and the student) is motivated by the milieu that orients the contract. In other terms, the didactic equilibration process is milieu driven.

Student A uses his perception and puts in question the physics principle. His relationship with physics knowledge leads him to use his own perception as a solution more certain than a physics principle. Consequently he does not use the available elements of milieu. His strategy development is directly associated to what he personally knows, as a previous system of knowledge which would enable him to answer the question. In this case it is the contract that orients his activity. The didactic equilibration process is contract driven.

Concluding Remarks

This example enables us to underline a critical point. In our mind, epistemic agency is not a "here and now" achievement. Even though it can be acknowledged in a specific problem solving, this performance depends on a long-duration inquiry process, in which students are enabled to acquire a scientific thought style (Fleck 1981; Sensevy et al. 2008), that one may consider as an epistemic activity in which the current system of knowledge (the contract) has always to be redesigned by the elements of the problem at stake (the milieu). This long-time process needs a specific methodology to be documented (Tiberghien and Sensevy 2012).

Cross-References

- ▶ Communities of Practice
- ▶ Didactical Contract and the Teaching and Learning of Science
- ▶ Epistemic Goals
- ▶ Epistemology
- ▶ Milieu

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Alienation

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Characteristics

Alienation is as a sociopsychological construct broadly defined as the state of being/feeling disengaged, disempowered, and isolated from people and/or the local contexts where one is embedded (Lukes 1978; Calabrese 1987). Its symptoms are both individual and collective and are manifested in unique ways by those who have been positioned, or position themselves as, the Other. To be the Other is to be outside of an established norm, and being outside of an established norm results in the development of a bevy of emotions which result in “the distancing of people from experiencing a crystallized totality both in the social world and in the self” (Kalekin-Fishman 1998, p. 6).

In science education, where teaching is often focused on the meeting of arbitrary benchmarks of science skills, and learning is assessed based on the ability of the student to memorize information, alienation is one of the chief means through which a large number of youth underachieve in science. This is the case because school science lends itself to the creation of spaces where there are constant clashes between science, school science, and the ways of knowing and being of students in classrooms. In urban science education, where socioeconomically deprived urban youth of color populate classrooms, alienation from science is a pervasive issue. In these classrooms, alienation is closely correlated to Durkheim’s term anomie, which he describes as a mismatch between individual/group norms and larger societal norms (Durkheim 1915).

In urban classrooms, larger societal norms reflect a White, middle-class experience (Bourdieu and Passeron 1977) that is markedly different from the experiences of urban youth. In urban science classrooms, “the dominant cultural ideals of mainstream White society and Eurocentric science. . .are incommensurable with the beliefs and values of African American students” (Seiler 2001). This incommensurability is exacerbated by the physical structures of school and science such as textbooks, scripted curriculum, and laboratories that do not reflect the culture of students. When textbooks do not have images of Black and Brown scientists, curriculum does not create a space for students to express their inherent need to question, and cultural dispositions that align to orality, impromptu expression, verve, and movement are not considered in the teaching of science, youth of color are alienated from the discipline just by entering into the classroom (Emdin 2010).

While the larger structures of traditional science classroom alienate urban youth just because they happen to be in those physical spaces, alienation is even more deeply expressed because of the constant efforts to extract/invalidate urban youth culture in teaching and assessments. For example, when students are given academic grades in science based partly on "good" behavior or "academic potential," they may be inadvertently judged based on the extent to which their expressions of culture are aligned to a Eurocentric ideal or the extent to which they are able to hide this culture. This process equates to an attempt to wipe out of the customs and the understandings of a population to the extent that consciousness of oneself within a context (in this case the science classroom) is a negating activity. In other words, they are commended or viewed as more scientific for not being themselves or for being closest to what is perceived to be a White male scientist ideal (Emdin 2011).

Finally, one cannot understand alienation without having some understanding of affiliation. Affiliation, which is the state of being connected to, or feeling the connections between, self and others, is a significant component of making youth feel like a part of the science classroom. It is also one of the major ways of being within communities who are not well represented in science. For these populations, there is strength in acknowledging their unique culture, and feelings of contentment, satisfaction, belonging, and togetherness are developed as they communicate with each other. Each of the emotions generated through affiliation stand in contrast to powerlessness, meaninglessness, normlessness, cultural estrangement, self-estrangement, and social isolation that Seeman (1959) suggests are the result of alienation. If youth develop these emotions within science classrooms, they will not see themselves as scientists.

Cross-References

▶ Acculturation
▶ Cultural Influences on Science Education
▶ Culture and Science Learning
▶ Emotion and the Teaching and Learning of Science
▶ Indigenous and Minority Teacher Education

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Alignment

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Keywords

Achieve methodology; Surveys of enacted curriculum methodology; Webb methodology

Alignment of Assessment

There are research studies which look into the alignment of assessment and instruction and assessment and content standards. These alignment studies provide data to guide decisions on assessment, standards, and instruction. Based on the findings of these alignment studies, decisions for changes can be made on course level, e.g., related to course content, course objectives, and assessment tasks. The data may also inform educators to make decisions to align instruction or the curriculum for targeted learning outcomes.

Different methods are employed to study alignment including Webb methodology, Achieve methodology, and Surveys of Enacted Curriculum (SEC) methodology. These methods have all been adopted in the United States. Webb methodology was developed by Webb in 1997 when he compared alignment with content focus, articulation across grades and ages, equity and fairness, pedagogical applications, and systems applicability. Achieve methodology involves both qualitative and quantitative comparisons of assessment with standards. The SEC alignment methodology allows comparisons across schools, districts, or states.

Other methods to study alignment include eliciting assessment beliefs, observing assessment practices, and reflecting on assessment events. Having gathered these data, the researcher may subsequently compare the data collected relating to assessment with data relating to instruction or classroom teaching. There are studies which investigate alignment for vulnerable populations including students with disabilities, preschool children, individual students, and classroom teachers.

Cross-References

► Assessment Framework
► Assessment to Inform Science Education
► Assessment: An Overview

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Alternative Assessment

► Authentic Assessment

Alternative Conceptions and Intuitions

► Alternative Conceptions and Intuitive Rules
► Alternative Conceptions/Frameworks/Misconceptions
► Alternative Conceptions and P-Prims
► Constructivism

Alternative Conceptions and Intuitive Rules

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Keywords

Conceptual change

A major thrust in science education research has been the study of students' conceptions and reasoning. Many have pointed out the persistence of misconceptions, naïve conceptions, alternative conceptions, intuitive conceptions, and preconceptions. Studies have covered a wide range of subject areas in physics, in chemistry, and in biology (Thijs and van den Berg 1995).

In view of the large volume of documented instances of alternative conceptions and reasoning, a theoretical framework with explanatory and predictive power seemed to be in order. While most of the previously mentioned studies adapted a content-oriented perspective of alternative conceptions, another approach is suggested by the intuitive rules theory. The intuitive rules theory takes a task-oriented standpoint, addressing the impact of specific task characteristics on learners' responses to scientific tasks (Stavy and Tirosh 2000). The main claim of this theory is that students tend to provide similar, intuitive responses to various scientific and daily tasks that share some external features. The intuitive rules theory offers four major intuitive rules. Two of these rules (*more A–more B*; and *same A–same B*) are identified in students' reactions to comparison tasks, and two (*Everything can be divided* and *Everything comes to an end*) are manifested in students' responses to processes of successive division. Here we refer briefly to the two comparison rules, whose impact can be seen in students' responses to a wide variety of situations.

Responses of the type *more A–more B* are observed in many comparison tasks, including classic Piagetian conservation tasks (e.g., conservation of weight, volume, matter), tasks related to intensive quantities (density, temperature, concentration), and other tasks (e.g., free fall). In all these tasks, relationships between two objects (or two systems) that differ in a salient quantity A are described ($A_1 > A_2$). The student is then asked to compare the two objects (or systems) with respect to another quantity, B ($B_1 = B_2$ or $B_1 < B_2$). It was observed that a substantial number of students responded incorrectly according to the rule *more A* (the salient quantity)–*more B* (the quantity in question), claiming that $B_1 > B_2$. We suggest that students' responses are determined by the specific, external characteristics of the task, which activate the intuitive rule *more A–More B*. This tendency is evident in a wide range of ages. For instance, even university students tend to incorrectly predict that a heavy box will hit the ground before a light one. This response is in line with the intuitive rule *more A* (heavier)–*more B* (faster).

Responses of the type "*same A–same B*" are observed in many comparison tasks. In all of them the two objects or systems to be compared are equal in respect to one quantity A ($A_1 = A_1$) and this equality is salient. Yet, these objects or systems differ in another quantity B (B_1 is not equal to B_2). A common incorrect response to these tasks, regardless of the content domain, is $B_1 = B_1$ because $A_1 = A_1$. Megged (in Stavy and Tirosh 2000), for instance, found that when middle school students were presented with two vials containing equal amounts of water and one of these vials was heated, the students tended to incorrectly claim that *same A* (water)–*same B* (volume of water).

The intuitive rules, which account for many incorrect responses to science tasks, have a predictive power. That is, one could predict how a student will respond to a given task on the basis of external, specific features of the task and a small number of intuitive rules. Moreover, the rules seem to be universal to affect students' responses regardless of culture.

Various instructional methods have been employed in science education for overcoming intuitive interference including teaching by analogy, conflict teaching, calling attention to relevant variables, raising students' awareness of the role of intuition in their thinking processes, and experiencing practical activities. Recently, cognitive psychology (e.g., reaction time) and neuroscience methodologies (e.g., fMRI) are employed to study the reasoning mechanisms related to intuitive rules (Stavy et al. 2006). The insight to be gained from employing these methods could lead to a deeper understanding of students' difficulties and their reasoning processes and eventually to improve science education.

Cross-References

▶ Alternative Conceptions and P-Prims
▶ Alternative Conceptions/Frameworks/Misconceptions

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Alternative Conceptions and P-Prims

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Keywords

Conceptual change

Setting the Scene

The discovery of students' alternative conceptions constitutes one of the major landmarks of science education. No longer is it sufficient to study only "effective methods," or general learning processes. Instead, the field came to understand that students had particular and resilient ideas about various scientific domains, which strongly affect learning.

Few doubt this constructivist presumption today. However, there is still much debate about how to construe these phenomena. As a result, there is also debate concerning how one should best pursue good instruction in the light of alternative conceptions. P-prims theory offers a carefully articulated and systematic approach to understanding the nature of students' naïve ideas, their origins, and their role in coming to understand science concepts deeply.

P-prims theory is part of a broader approach, called "Knowledge in Pieces" (KiP), to understanding the nature of students' intuitive ideas and their role in learning. P-prims theory deals with intuitive preconceptions per se, and other parts of KiP (e.g., the "coordination class" model) deal with the nature of expert concepts. Kindred approaches to KiP include Minstell's "facets" and Linn's "knowledge integration." Here, I use "the theory theory" and the basic idea of "misconceptions" to represent competing perspectives.

The Basic Idea

P-prims theory aims to explain student alternative conceptions as stemming from bits of intuitive knowledge that contribute to our intuitive "sense of mechanism," that is, what kinds of occurrences are natural and to be expected. P-prims express regularities, like scientific principles, except that there are many more p-prims than scientific principles, and there are other significant differences, described below.

"P-prim" stands for "phenomenological primitive." "Phenomenological" means that p-prims are usually evident in our everyday experience. One just sees situations in terms of them. As a consequence, what happens in a situation is regarded as natural if a p-prim applies, or surprising otherwise. "Phenomenological" also suggests that p-prims are encoded in ways other than in words, as images or kinesthetic schemes. "Primitive" means to imply that people cannot, in general, analyze or justify their p-prims. Part of this follows from the fact that they are not encoded in language. In contrast, the words "force equals mass times acceleration" provides a clear top-level analysis of Newton's laws, but the same cannot be done for p-prims (except by us, as analysts). Similarly, while Newton's laws can be argued for, explained, and even supported by empirical results, one cannot do those things for p-prims. P-prims are simply evoked by situations either directly or as a result of deliberately attending to other aspects of a surprising situation that might render it more comprehensible than our first impressions.

I will not discuss other aspects of p-prims theory, such as (1) how we describe a p-prim's contextuality – when it applies and when it does not – and (2) how they develop, as a result of sorting experience toward deeper principles.

P-prims theory maintains that there are hundreds or thousands of p-prims. That is, our personal search for ultimate explanation of the world does not result in only a few general principles. No p-prims are as deep and complicated as Newton's laws. So, we simply must have many of them to "cover" the array of experiences that we have.

In contrast to p-prims, the "theory theory" view maintains that intuitive knowledge comes down to just a few core principles. Some advocates of the theory theory even describe intuitive theories as "remarkably articulate," suggesting a close connection to language, which is explicitly denied by p-prims theory. The theory theory also contends that intuitive principles, in addition to being few, are substantially coherent. That is, they are embedded in a rich web of relations that mutually constrain all the pieces. P-prims theory maintains that p-prims, for the most part, have independent developmental histories and remain, at best, loosely interconnected.

Examples

Since there are many p-prims, there is no definitive list of them. However, we illustrate with some informative examples.

Ohm's P-Prim. Ohm's p-prim is one of the most powerful and important p-prims. It specifies that many causal situations can be understood as an "agent" acting against some kind of "resistance" to achieve some particular "result." People are prototypical agents that exert effort toward particular results. We "work harder" (e.g., push harder) in order to obtain greater result (which may be that an object moves either faster or farther). Various intervening "resistances," such as friction or the object's size, can moderate our efforts. Ohm's p-prim applies to intellectual effort, such as working harder to achieve a higher grade in school. In inanimate situations, agency may be attributed to elements of situations that have the capacity to make things happen. A rapidly moving object, for example, may be construed as an agent, or a battery might exert a kind of "effort" called "voltage."

In contrast to the misconceptions perspective, p-prims recognize the ecological validity of intuitive ideas. It is not strange that we have ideas that fit particular situations (throwing harder to have a ball travel faster). Such ideas are "entrenched" because they are excellent ideas. They simply work well for many situations in the real world. However, p-prims are not yet the complex, general, and articulated ideas of professional science.

P-prims research has found many reuses of intuitive ideas in learning science. Ohm's law in electricity is comprehensible to novices precisely because it is an obvious situation that is governed by Ohm's p-prim. Similarly, although Ohm's p-prim contradicts $F = ma$ in some situations, in other situations (e.g., those involving small objects moving through a viscous fluid, which involves Stokes' law friction) Ohm's p-prim is entirely consistent with Newton, and it is likely to be used for rapid reasoning, then, even by experts. The problem with Ohm's p-prim is not its incorrectness, but its vague contextuality. Students are prone to apply Ohm's p-prim where it should not apply, and they do not know that deeper principles can often replace and improve Ohm's p-prim even in circumstances where it does apply.

The fact of productive engagement of p-prims in learning science cannot be overemphasized. Misconceptions views uniformly characterize intuitive ideas as false and in need of replacement. Similarly, theory theory views uniformly describe naïve theories as in need of replacement. As a consequence, misconceptions and theory theory views are effectively "blank slate" theories of learning or, worse, views holding that the slate must be wiped clean before real scientific ideas can be developed. In contrast, p-prims theory sees many productive roles for p-prims, achieved through modifying them, adjusting their contextuality, combining them, and reorganizing them.

Abstract Balance and *Equilibration.* Balance is a powerful intuitive principle. When people view a balance scale, its behavior is intuitively comprehensible as a system that has a natural "balanced" position. According to the abstract balance p-prim, a balanced system can be disturbed and put "out of balance." If the disturbance is then removed, the system just returns to its natural state; it *equilibrates*. This conceptualization is a misconception to the extent that Newtonian mechanics requires a force or torque to drive equilibration; intuitively, return to balance just happens and needs no other explanation.

No putative naïve theories of physics recognize either abstract balance or other important balancing p-prims. Such ideas have been found particularly helpful, not surprisingly, in understanding thermal phenomena such as temperature equilibration. It is conjectured that balancing p-prims also help with understanding conservation laws, such as conservation of energy.

Carrying. One can easily imagine very young children recognizing that carried things just "go with" their carrier. A baby goes with the carrying parent. A toy in a child's red wagon just goes along wherever the wagon goes. A true physics explanation of these situations is simply too complicated for children, or even for most college students. So, the carrying p-prim is about as good an understanding of these situations as early physics learners can achieve.

Dropped Objects Fall. As with carrying, it is hard to imagine even very young children not noticing that when one drops an object, it falls (straight down). This p-prim, like others, fails as science because of contextuality. People do not notice that the "straight down" aspect only happens when the dropper is not moving. Yet, dropping from rest is so much more important and frequent in a young child's world that it should not be surprising that separate principles are not developed for moving drops.

Channeling, *Blocking*. The channeling p-prim recognizes that trains just follow their tracks and balls just follow along in a tube in which they move. Like equilibration of a balance scale, forces are not needed. Blocking is the very important phenomenon, observed every day, that sturdy objects simply support things put on them; they block falling. These situations are, again, somewhat complicated to analyze from a Newtonian point of view, so students often appeal to the relevant p-prims when asked about blocking or channeling situations.

Competitive Advantage

P-prims as a theory of intuitive knowledge have a number of advantages, compared to competitors. Here are a few:

Strong constructivism. Tracking the positive value of p-prims in learning science (Ohm's p-prim works for electrical circuits; balancing p-prims evolve into understanding conservation laws) distinguishes this view from the uniformly negative view of intuitive ideas in the misconceptions or theory theory views. So learning, when it happens, is easier to account for with p-prims.

Coverage. The theory view selects, without good rationale, the effects of certain p-prims (or combinations of p-prims) *in certain situations* (*not* where they work well) to "knight" as part of a "core theory," and it ignores many other p-prims. This is particularly problematic when naïvely less important p-prims grow substantially in importance when they enter into learning real science.

Tracking Learning at Fine Grain Sizes. The task of understanding how learning happens in sequences of student thinking is much easier to handle in p-prims theory. The theory theory marks one end of a wide spectrum as "the naïve theory," and the other as "the normative theory," but what happens in between requires more detail. P-prims' growing or fading in importance or combining with other ideas can track learning much more precisely. Recent p-prims work has been particularly rich in tracking moment-by-moment learning.

Implications for Learning and Instruction

Here is a short list of implications of p-prims theory concerning instruction, and some opportunities it may afford with future work:

Pools of Productive Resources. As we learn more about the p-prims students have, we come to understand better a pool of very helpful resources for instruction. Misconceptions or naïve theories that are "just wrong" cannot help us in this way.

A Fine-Grained Approach to Instructional Design. The latest p-prims work shows in detail how moment-by-moment learning can happen. As such, it is a lens that can be used to understand and refine instructional sequences.

Deep Learning Just Takes Time. The change from the naïve state to scientific understanding is unequivocally complicated when viewed at the grain size of p-prims. Recognizing this, many instructional approaches may simply be grandly overoptimistic. Experiments that try to squeeze down known-to-be-effective instruction to shorter interventions suggest that this may be impossible.

Learning in Many Contexts. P-prims are highly contextualized. It is almost certain that one cannot learn scientific ideas without sampling a wide range of contexts that employ the same scientific ideas, but are construed very differently from an intuitive point of view – and conversely!

Handling Diversity. The set of p-prims students may have and levels of confidence concerning particular ones may vary a lot from student to student. Recent p-prims-based work has allowed us to see these differences and to understand why they can lead to success or failure of instructional treatments.

Coaching Students Metaconceptually. A significant part of understanding the *nature of science* might well be understanding the distinctive properties of students' own intuitive knowledge and how it changes to become genuine science. It may be that this is far more important to students' learning than understanding "what scientists do."

Cross-References

- ▶ Alternative Conceptions and Intuitive Rules
- ▶ Alternative Conceptions/Frameworks/Misconceptions
- ▶ Computers as Learning Partners: Knowledge Integration
- ▶ Conceptual Change in Learning
- ▶ Constructivism
- ▶ Prior Knowledge

Further Reading

A full account of p-prims theory:

diSessa AA (1993) Toward an epistemology of physics. Cogn Instr 10(2–3):105–225

Contrasting p-prims with theory theories:

diSessa AA (2013) A bird's eye view of "pieces" vs. "coherence" controversy. In: Vosniadou S (ed) International handbook of research on conceptual change, 2nd edn. Routledge, New York, pp 31–48

Tracking moment-by-moment learning with p-prims:

diSessa AA (2014) The construction of causal schemes: learning mechanisms at the knowledge level. Cogn Sci (in press)

A p-prims account of learning through analogies; individual differences:

Kapon S, diSessa AA (2012) Reasoning through instructional analogies. Cogn Instr 30(3):261–310

A Knowledge in Pieces analysis of "misconceptions":

Smith JP, diSessa AA, Roschelle J (1993) Misconceptions reconceived: a constructivist analysis of knowledge in transition. J Learn Sci 3(2):115–163

Alternative Conceptions/Frameworks/Misconceptions

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Keywords

Alternative conceptions; Alternative conceptions movement; Alternative conceptual frameworks; Alternative frameworks; Implicit knowledge elements; Intuitive theories; Knowledge in pieces; Misconceptions; Personal constructivism; P-prims; Preconceptions; Cognition; Conceptual change

There are a great many studies into learners' ideas in science topics, focusing on learners at different levels of the education system (Duit 2009; Taber 2009). These studies reveal that learners often present ideas relating to science topics which are at odds with the target knowledge set out in the curriculum. These ideas have been described using a wide range of terms, including misconceptions, preconceptions, alternative conceptions, alternative frameworks, alternative conceptual frameworks, intuitive theories, and mini-theories. Sometimes particular authors distinguish between meanings for some of these terms, but usage varies across the literature so often the different labels are, in effect, broad synonyms (Taber 2014).

Interest in students' ideas came to prominence in science education in the 1980s when a considerable research program (sometimes labeled the "Alternative Conceptions Movement") developed around eliciting such ideas. The theoretical perspective that informed much of this work was personal constructivism, which considered knowledge to be developed iteratively within the minds of individual learners (Driver 1989; Gilbert and Watts 1983). Teachers were seen as being able to support and scaffold learning, but learning itself was considered an act of personal construction of knowledge. From this perspective, the notion (inherent in much discourse around teaching) that knowledge could somehow be "transferred" or copied from teachers and textbooks to learners in a straightforward way is untenable. The learners' prior knowledge and beliefs were recognized as providing the conceptual resources for interpreting teaching, and studies showed that students commonly held informal ideas about science concepts and topics that were inconsistent with the target knowledge set out in the curriculum.

The constructivist perspective was influenced by a range of thinkers including Jean Piaget, George Kelly, David Ausubel, Jerome Bruner, and Lev Vygotsky. The personal constructivist perspective and the research programs it informed have been significantly criticized from various standpoints, although robust defenses against these different criticisms have also been offered, and the constructivist perspective continues to be widely adopted in science education (Taber 2009). However, it has become clear that it is important to distinguish between constructivism as a theory of learning (which is widely accepted) and constructivism as a wider epistemological stance (which is sometimes characterized as inconsistent with the epistemology of science). Those adopting a personal constructivist perspective have had to acknowledge an increasing focus on the importance of cultural and social influences on learning, with some commentators seeing social constructivist perspectives as contrary to (rather than complementary with or able to be accommodated within) personal constructivism.

The initial motivation for research in this area was the claim that students commonly held alternative ideas inconsistent with the science to be learned that were tenacious and which would impede the learning of canonical scientific concepts. It was widely argued that it was important to diagnose learners' alternative conceptions in a topic before teaching and then to explicitly challenge them. Ideally learners would be presented with activities, demonstrations, and opportunities for dialogue that would allow them to recognize the superiority of the scientific concepts and models presented in the classroom to their own alternative conceptions. All aspects of this argument have been subject to criticism and counter claims. In particular, there have been debates about the key issues of the nature of learners' ideas about scientific topics and the significance of alternative conceptions for subsequent learning.

Some initial characterizations of learners' alternative conceptions were that these were of the form of personal theories to which learners were strongly committed. However, critics argued that learners' ideas were more akin to "fragments" of knowledge, often of very limited ranges of application, and readily disregarded. Some argued that giving attention to "alternative conceptions" in teaching would seem to give them more status and was likely to reinforce rather than challenge them, whereas such ideas were otherwise likely to be readily abandoned when scientific knowledge was authoritatively and persuasively presented in teaching. The empirical evidence suggests that neither view is generally correct. The range of results reported in diverse studies suggests that learners' ideas about scientific topics are actually quite diverse in nature, as might be expected when considered as knowledge "under development" (Taber 2009, 2014).

Some ideas have been found to be widely applied across broad ranges of application and to be retained despite teaching designed to explicitly challenge them. Two examples would be the idea that a moving object must be subject to a force (sometimes referred to as the impetus framework or F-v thinking), and the idea that chemical reactions occur so that atoms can fill up their outer electron shells (the octet alternative conceptual framework). These ideas seem to become well established, to be linked to explicit principles (and so can be seen to form the core of a framework of related conceptions), to be applied consistently and across diverse contexts, and to be largely retained despite teaching of the scientific models. These ideas have been reported across many different educational contexts.

However, not all of the reported alternative conceptions have these features, and some of the ideas reported in studies are more labile (as learners are not strongly committed to them) and do indeed seem to be better characterized as knowledge fragments. Clearly such characterizations are important in considering potential implications for teaching. Where students hold fanciful and weakly committed ideas about science topics, then these are likely to have limited influence on learning of target knowledge, and there is limited value in spending time devising teaching strategies that take them into account. However, it is known that an idea like the impetus framework is highly intuitive to many learners and often tends to be retained after school and even college instruction. Research also suggests that even when students learn to answer regular classroom exercises correctly from the scientific model, they may still apply their alternative intuitive ideas when facing a problem that cannot be solved by standard algorithmic approaches, or when asked a question set in an everyday context, or when facing real-life problems beyond the classroom.

Moreover, even apparently persuasive demonstrations that seem to convince students that their alternative conceptions are wrong may only dominate their thinking over short periods before they revert to their longer-established ways of thinking. For example, students who initially assume that current must decrease at each lamp in a series circuit are often found to change their minds once they have seen their predictions of lamp brightness and ammeter readings are wrong. However, after some weeks have passed the students are likely to revert to their original view and may actually "recall" the demonstration as having shown that lamp brightness or ammeter readings did indeed diminish around the circuit.

An important theme for research concerns the origins of students' alternative conceptions. A number of possibilities have been suggested, although in reality there will be interactions between these and many alternative conceptions cannot be understood to have a single distinct origin. One potential influence is genetic, in that our genetic inheritance provides the framework within which we can develop. Although it seems unlikely that specific ideas are coded in our genes, it does seem that we have genetically directed predispositions to perceive the world in particular ways. One well-known example is the ability of neonates to recognize faces (i.e., the general pattern of a face, not specific faces) suggesting this ability is innate. The ability to identify a face in what William James referred to as the "great blooming, buzzing confusion" a newborn baby experiences clearly has value but leads to people readily recognizing faces in all kinds of inappropriate places – so a vague resemblance to faces in images of the surfaces of the moon and mars is taken by some as evidence that aliens have deliberately sculptured faces there.

The importance of the cognitive apparatus responsible for recognizing familiar patterns in perception has been emphasized in an approach to thinking about students' ideas referred to as knowledge in pieces (Hammer 1996). In this approach (championed by Andrea diSessa and David Hammer among others), the importance of implicit knowledge elements not open to direct introspection is emphasized as the basis for intuitive understanding of the world. Certain patterns recognized as recurring in experience become so familiar that we come to see them as natural and part of how the world works. These implicit knowledge elements (sometimes called p-prims or phenomenological primitives) act as basic cognitive resources that are recruited to make sense of diverse phenomena. This processing is preconscious, so the individual is not aware of the p-prim, just the outcome of its application.

The knowledge in pieces perspective emphasizes how many ideas elicited from students which might be labeled as alternative conceptions may not be established ideas, but rather could be constructions undertaken in response to a researcher's questions offering a new (and perhaps transient) nexus drawing upon the more stable underlying knowledge elements. An example might be a research participant explaining the seasons in terms of the earth's distance from the sun, drawing upon a more general intuition that effects are greater closer to the source. However, even if many elicited conceptions begin in this way, once such conceptions are made explicit (e.g., verbalized or built into a mental image or simulation), they may often become incorporated into the individual's explicit knowledge base, i.e., coming to believe that summer is the time when the earth is closer to the sun in its orbit. The common alternative conception that objects will only continue to move when acted upon by a force does not match scientific understanding, but actually fits most people's experience of moving objects. Given its constant reinforcement in everyday life, it is not surprising that this has been found to be an especially tenacious alternative conception.

Although many of our formal conceptions of the world may begin as applications of intuitive knowledge elements (what Vygotsky called spontaneous conceptions), a key feature of human learning is the role of culture, and in particular language, that allows us to learn vicariously from the experiences of others. For such learning to be more than rote learning, it needs to be interpreted in terms of our existing stock of conceptual resources – with the inherent risk of misinterpretation. Nonetheless, formal learning of "academic" concepts allows us to learn vastly more than is possible if we relied on our spontaneous concepts alone. Unfortunately, many of the ideas with currency in popular discourse are themselves inconsistent with scientific concepts, and so "folk theories" may act as sources of individuals' alternative conceptions.

Language is the key mediator of meaning between individuals, although inevitably communication is imperfect. Sometimes language has been considered to influence the development of alternative conceptions such as when a technical term has associations from everyday life that do not match the scientific meaning (e.g., particles, electron spin), or when it is used metaphorically (plant "food") or is misleading (e.g., neutralization of an acid with a base does not always lead to a neutral product as students may assume is implied by the term).

Teaching may itself be the source of students' alternative conceptions. This may be either because students do not realize when such teaching devices as analogy, models, metaphors, and anthropomorphisms are being used to help make the unfamiliar familiar and so take these representations too literally or because alternative conceptions are taught. The common alternative conception about chemical reactions being driven by atoms seeking to fill their shells is clearly not based on students' direct experiences of atoms and therefore seems to be based on the interpretation of teaching which either presents inadequate models or offers ambiguous descriptions that students then misinterpret in terms of their intuitions of the world. Research has shown that some alternative conceptions in this particular topic area are found widely among trainee school teachers suggesting that some alternative conceptions are being directly taught to new generations of learners by their teachers.

Research to understand the nature and characteristics of students' conceptions continues because understanding the precise nature and status of different types of reported conceptions is important in understanding how conceptual change may be best brought about, e.g., by directly challenging student conceptions, by ignoring them and simply teaching the canonical ideas, or by seeing learners' conceptions as useful (or necessary) starting points that need to be modified over time through a multistage conceptual trajectory. Each of these approaches is likely to be most sensible in some cases and counterproductive in others. Research into implicit knowledge elements such as p-prims may even lead to strategies to recruit the most helpful intuitions in learning particular concepts. So where much early research on alternative conceptions was concerned with cataloguing the range of ideas presented by learners, current research in this area is closely linked to models of conceptual change and designing appropriate strategies for teaching different curriculum topics.

Cross-References

- ▶ Alternative Conceptions and Intuitive Rules
- ▶ Alternative Conceptions and P-Prims
- ▶ Ausubelian Theory of Learning
- ▶ Conceptual Change in Learning
- ▶ Constructivism
- ▶ Metaphors for Learning
- ▶ Piagetian Theory
- ▶ Prior Knowledge
- ▶ Scaffolding Learning
- ▶ Socio-Cultural Perspectives on Learning Science

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A

Analogies in Science

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Keywords

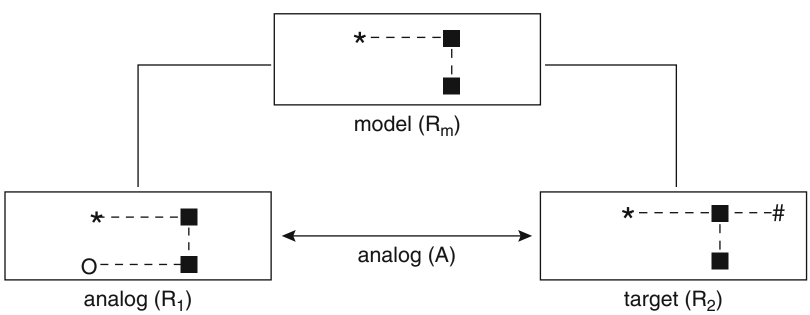
Analog; Analogies; Scientists; Target

Analogies help scientists and everyday people make sense of the natural phenomena that surround them. We have an everyday object, event, or story that is well understood – this is called an analog, and a science concept to which it is compared called the target. Links – called mappings – are then made between the analog and the target. Mappings can be positive, ways in which the target is like the analog; negative, ways in which the target is not like the analog; and neutral, when it is not clear whether the target is or is not like the analog.

A visualization of mapping by Duit (1991) shows there may be identical features in parts of the analog (R1) and target (R2); the model (Rm) then represents similarity – with analogy (A) representing the relation between analog and target (Fig. 1).

To illustrate, we might compare a model of the atom with the solar system and map shared and unshared attributes: the sun and nucleus, the electrons and planets, and the sun is large – the nucleus is small, electrons travel much faster than planets.

The use of analogy works because it makes the unfamiliar (i.e., what we are trying to explain/



Analogies in Science, Fig. 1 Duit's model for analogical transfer by mapping (This material is reproduced from Duit, R., 1991, Science Education, 75(6): p. 650, with permission of John Wiley & Sons, Inc) teach) familiar by drawing on what the student already knows. We do need to make sure the analogy is interesting and familiar, and both the shared and unshared attributes need to be discussed. We also must point out where the analogy breaks down, lest students think the analog and target have things in common that they do not.

Cross-References

- ▶ Analogies, Metaphors, and Models
- ▶ Analogies, Role in Science Learning
- ▶ Analogies: Uses in Teaching
- ▶ Representations in Science

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Analogies, Metaphors, and Models

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Keywords

Analog; Analogies; Metaphors; Models

It can be argued that all language is itself a metaphor, the "conduit metaphor" (Reddy 1979), such that meanings are contained in words and linguistic expressions are containers which are sent to somebody. A range of types of "containers" can be used. While a simile is merely a decorative addition to a statement, e.g., "as dead as a doornail," a metaphor is an attempt to understand something about which little is understood (the "primary subject") by considering it to be the same as something that is much better known (the "secondary subject"), e.g., "the sun (primary subject) is a furnace (secondary subject)." In so doing, the understanding of the secondary subject is also altered by an interaction of meaning: in this case it becomes possible to think of the furnace as life-giving.

The very readable book *Metaphors We Live By* (Lakoff and Johnson 1981) argues that metaphors are central to thinking and hence to communication, for they are the tools with which we conceive of, and hence experience, the world. They point out that metaphors can be grouped into categories, each of which is manifest with a particular resonance in a given culture. Typical categories are the "orientational," relating to positions in space relative to a person, e.g., "having full control of events is up" and "having no control is down," and the "ontological," where an abstraction is given the status of an object, e.g., "inflation is an entity." To be of any value, the characteristics of the secondary source must be known in detail. That said, a secondary source that is of great value is one that is drawn from a field of endeavor very different from that of the primary source. Metaphors do not identify exact equivalences; thus, there are attributes of a furnace that the sun does not have, e.g., a furnace uses oxygen, the sun does not. A metaphor seems promising where the secondary source has a number of important attributes that might be useful in understanding the primary source, and the relationship is explored to yield an analogy. In an analogy, the primary source is said to be like the secondary source to some extent, but not identical to it. The important issues are the identification of those attributes that are similar and the estimation of the degree of similarity.

Hesse (1966) separated the attributes of any secondary source into three types. Positive analogues are where some similarity seems likely, e.g., "the sun produces both heat and light as does a furnace"; negative analogues are where no similarity seems possible, e.g., "the thermal output of the sun cannot be controlled as can that of a furnace," while neutral analogues are attributes of the secondary source that may, or may not, be useful in understanding the primary source, e.g., "the sun may or may not consume its fuel." Neutral analogues are valuable in that they direct research attention to the attributes in question. The conceptualization of the degree of similarity between a primary and a secondary source in respect of a given positive analogue is still taking place. "Structure mapping theory" (Gentner 1983) is a useful approach using an analogy of "distance" to discuss the issue. In it, a "near" analogy is one that is readily perceived, while a "far" analogue requires more adaption of ideas before the relationship becomes apparent.

The readiness with which metaphor and analogy can be used by an individual will depend both on the width of the spectrum of domains of knowledge with which they are acquainted in any detail and on their capability to evaluate the status and degree of similarity of attributes. These capabilities are manifest in the creation and use of models.

The world as experienced, as initially encountered, is a bewildering complex of objects and events. In order to make sense, to be able to think about it, humans (and probably other species) isolate and simplify specific aspects of it: models are produced. In the broadest sense, a model is therefore a simplified representation of any object, system of objects, events involving systems, or ideas about any of these, which is initially produced for a specific purpose. Mental models are ontological entities created in the mind and are vital to all thinking (Johnson-Laird 1983). Science, being centrally concerned with producing explanations of the world as experienced, places an especial value on models, for these are used to produce the predictions which are a defining aspect of scientific methodology. The creation of all models involves the identification of metaphors and hence on the drawing of analogies; being human creations, a distinct culture has evolved around them.

It is in the nature of science that once a mental model has been created in the mind of an individual, an attempt is made to express it to others. This expression can be carried out using gestures, materials, words, visuals (e.g., in pictures, diagrams, or graphs), symbols and equations, or a combination of these (Gilbert et al. 2000). It does seem that the translation in both directions between a mental model and an associated expressed model can involve some change: perfect communication is probably impossible. Each of these modes of representation relates to a given mental model in a precise way: each has a specific code of representational capability. Attempts to comprehensively communicate any mental model may therefore require the use of several modes of representation.

A mental model is expressed into the public arena by the creator(s) as a suggestion about the nature, structure, and mechanisms of the world as experienced. This suggested model is then subjected to tests by the science community and is then either discarded, amended, or accepted as a consensus model of some value. This valuation may continue for any number of years, ranging from a few (e.g., Pauling's triple strand model for DNA) to very many (Aristotle's model for motion). Eventually, in most cases, a given model is superseded for research purposes but is retained as an historical model because of its capability to provide adequate explanations of some phenomena that are now seen to be unproblematic. Metaphors, analogies, and models play key roles in science. Examples are Harvey's metaphor of "the heart is a pump," based on extensive knowledge of water pumps in mines, and Bohr's metaphor of "the atom is a planetary system," based on the standard model of the solar system, both of which advanced thinking considerably in their respective fields when they were proposed. The central role of science education of introducing students to science ensures that the major models produced by science are taught. These are usually historical models, originally proposed in a simplified form, and, having come to rest in the school curriculum, dwell there unchallenged for many years. For models that are particularly intellectually challenging, teaching models, based on metaphors that will be more readily comprehended by students, are devised.

Finally, in addition to transmitting established models, teachers themselves develop metaphors, and hence analogies and models, of their work. For example, they may see themselves as "captains of a ship," "entertainers," "facilitators of learning," and "assessors of learning." Professional development can involve causing science teachers to reconsider the significance of their chosen metaphor(s) of teaching.

Cross-References

- ▶ Analogies in Science
- ▶ Analogies, Role in Science Learning
- ▶ Analogies: Uses in Teaching
- ▶ Scientific Language

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Analogies, Role in Science Learning

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Keywords

Analog; Analogies; Learning; Models; Representations; Target

Introduction

Science education research studies have shown that analogies, when well designed, can support students' science learning. Well-designed science analogies can help students build conceptual bridges between what they already know and what they are setting out to learn. This entry explains what analogies are, how analogies support learning, and what form analogies should take to be effective. A research-based model for designing effective analogies is described: It provides guidelines for the use of analogies in science classrooms, textbooks, software programs, and Internet sites.

Science Education and Analogies

Analogies have often played an important role in scientific discoveries, not as proof, but as inspiration. Analogies have also played an important role in explaining those discoveries. Ernest Rutherford, for example, used an analogy when describing his experiment which led to the modern model of the nuclear atom. Rutherford had bombarded a metal foil with charged particles, and some of them bounced back. Rutherford said: "It was almost as incredible as if you fired a 15-in. shell at a piece of tissue paper and it came back and hit you.... I had the idea of an atom with a minute massive center, carrying a charge."

Science teachers, like scientists, frequently use analogies to explain concepts to students. The analogies serve as initial models, or simple representations, of science concepts. The teachers frequently preface their explanations with expressions, such as, "It's just like," "Just as," "Similarly," and "Likewise." These expressions are all ways of saying to students, "Let me give you an analogy." The students use these analogies to support their learning, and they often construct their own analogies. Constructing their own analogies helps students to take an active role in their learning.

Analogies are double-edged swords: They can foster understanding, but they can also lead to misconceptions. Effective analogy use fosters understanding and avoids misconceptions (Duit et al. 2001). In order to use analogies effectively, it is important to understand what analogies are, how they can support learning, and what kind of analogies are particularly effective.

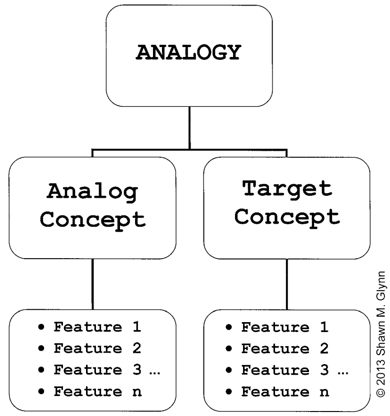
Analogy Defined

An analogy is a comparison of the similarities of two concepts. The more familiar concept is called the analog and the less familiar one the target. Both the analog and the target have features (also called attributes). If the analog and the target share similar features, an analogy can be drawn between them. A systematic comparison, verbally or visually, between the features of the analog and target is called a mapping. A conceptual representation of an analogy, with its constituent parts, appears in Fig. 1.

Analogical reasoning can occur between conceptual domains and within a conceptual domain. Between the domains of physics and biology, for example, an analogy can be drawn between a camera (with its lens, aperture, and microchip sensor) and the human eye (with its lens, pupil, and retina). Within the domain of physics, for example, an analogy can be drawn between a water system (with its pipes, pump, and pressure) and an electric circuit (with its wires, battery, and voltage).

How Analogies Support Science Learning

The analogies used in classrooms, textbooks, software programs, and Internet sites should be designed to promote elaboration, the cognitive process of constructing relations between what is already known and what is new. Elaboration can be activated by questions, objectives, personal examples, and other strategies, but analogies seem to be particularly appropriate because they can provide the rich, familiar contexts that successful elaboration requires. Elaboration is essential to ensure that students' science learning is meaningful rather than rote.



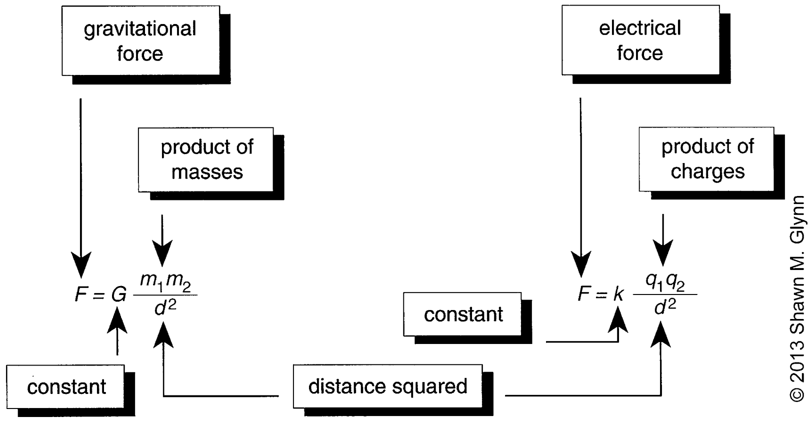
Analogies, Role in Science Learning, Fig. 1 A conceptual representation of an analogy

In a constructivist learning framework, students learn progressions of increasingly sophisticated mental models of science concepts. Often, these concepts represent complex, hard-to-visualize systems with interacting parts: An atom, a cell, photosynthesis, an electric circuit, and an ecosystem are all examples. Often, such concepts are introduced to students when they are about 10 years of age and then refined in subsequent grades, technical schools, and college. Familiar analogs (e.g., a factory) often serve as early mental models that students can use to form limited, but meaningful, understandings of complex target concepts (e.g., a cell). The analogy paves the way for the expansion of the target concept.

It is important to ensure that all students are familiar with the analog concept in order for it to be effective. Teachers should explain to students what an analogy is. Teachers should also encourage students to construct their own analogies and to keep in mind the limitations of analogies.

Highly Effective Science Analogies

In research studies, the effect of analogies has been inconsistent: Sometimes analogies increase learning and sometimes not. This inconsistency has been due to weak operational definitions of analogies, to constructions of analogies that have failed to map analog features systematically onto target



Analogies, Role in Science Learning, Fig. 2 An analogy between two inverse-square laws: Newton's law of gravitation and Coulomb's law of electrical force

features, and to analogies that have not capitalized on visual imagery. Instructional analogies are sometimes limited to simple assertions, such as "Mitochondria are the powerhouses of the cell," without explaining the analogy. These assertions, or simple analogies, do not provide the instructional scaffolding that many learners need, particularly in the initial stages of learning a concept.

A much better mechanism for providing instructional scaffolding is an elaborate analogy: "In an elaborate analogy, analog features are systematically mapped onto target features, verbal and imagery processes are active, and these processes mutually support one another" (Glynn and Takahashi 1998, p. 1130). Elaborate analogies provide a rich, situated context for learning. By systematically mapping verbal and visual features of analog concepts onto those of target concepts, analogies can facilitate the cognitive process of elaboration. Elaborate analogies have been found to increase students' learning of target concepts and their interest in the concepts (Paris and Glynn 2004).

An Example of an Elaborate Analogy

Joseph Priestly was thinking analogically when he proposed a law of electrical force. Priestly was familiar with Newton's law of universal gravitation, which holds that the gravitational force between any two bodies is inversely proportional to the square of the distance between them. Priestly speculated, correctly as it turned out, that the electrical force between two charges is also inversely proportional to the square of their distance.

Charles Coulomb experimentally confirmed the law of electrical force, and the law was named after him. The analogy between Newton's law of universal gravitation and Coulomb's law of electrical force is mapped out in Fig. 2. In Newton's law, the gravitational force between two objects is proportional to the product of their masses and inversely proportional to the square of the distance between those two objects. Newton's law contains a constant, G, which is the universal gravitational constant.

In Coulomb's law, the electrical force between any two objects has a similar inverse-square relationship with distance. When objects or charged particles are small in relation to the distance between them, then the electrical force is proportional to the product of the charges and inversely proportional to the square of the distance between the charged particles. Coulomb's law also has a proportionality constant, k.

So, Newton's law of gravitation is analogous to Coulomb's law of electrical force. Both are inverse-square laws, and both have constants. But, although the laws are similar, there are important differences between them. For example, m represents the mass of an object, and q represents the charge of a particle. And, although both laws have constants, the G in Newton's law is a very small number, whereas the k in Coulomb's law is a very large number. Yet another difference is that gravitational force only attracts, while electrical force attracts when charges are different but repels when they are similar.

Teaching-With-Analogies Model

The Teaching-With-Analogies Model (Glynn 1995, 2007) is based on cognitive task analyses of how analogies are used effectively in lessons, textbooks, software, and Internet sites. In both formal experiments and classroom settings, the use of the model has been found to increase students' learning and interest in science concepts.

The Teaching-With-Analogies Model includes six steps. When applied to the analogy between Newton's law of gravitational force and Coulomb's law of electrical force, these steps are:

1. Introduce the target concept, Coulomb's law, to students.
2. Remind students of what they know of the analog concept, Newton's law.
3. Identify relevant features of Coulomb's and Newton's laws.
4. Connect (map) the similar features of the laws.
5. Indicate where the analogy between the laws breaks down.
6. Draw conclusions about the laws.

The analogy between the laws breaks down because the Newton's law G is a relatively small number and the Coulomb's law k is a relatively large number. This means that the gravitational force between, say, two 1-kg masses is tiny, whereas the electrical force between two 1-C charges is comparatively large. An important conclusion to draw is that gravity plays a more important role than electricity at planetary levels, but electricity plays a more important role than gravity at atomic and molecular levels.

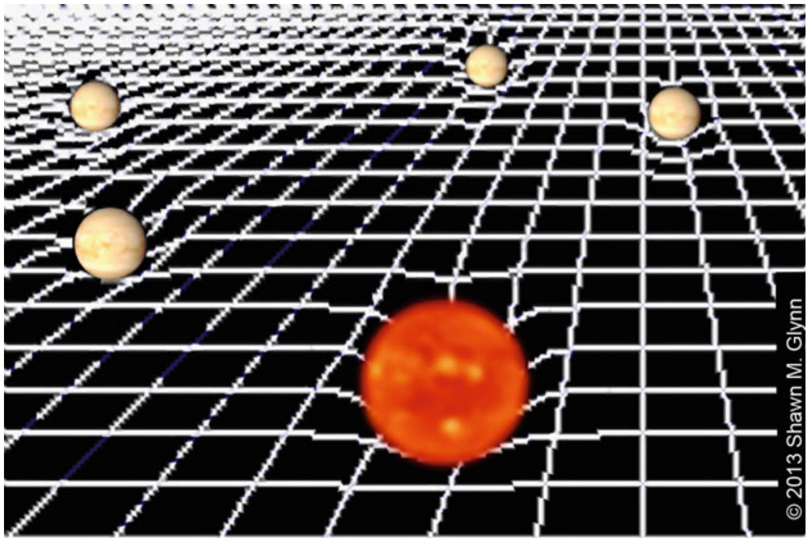
The Teaching-With-Analogies Model implies that teachers should try to select analogs that share many similar features with the target concept. In general, the more features shared, the better the analogy. Another implication is that teachers should verify that students have not formed misconceptions. One way to do this is to ask focused questions about features that are not shared between the analog and the target concept.

When teachers show students how to use the Teaching-With-Analogies Model, it becomes a Learning-With-Analogies Model (Glynn 1995, 2007), and the students can use its steps as guides when constructing analogies of their own (e.g., a heart is like a force pump, a kidney is like a waste filter, and a pulsar is like a lighthouse). Students are naturally inclined to generate analogies when learning science, but the analogies will be of higher quality if the students are taught how to systematically generate them. Sometimes these analogies are even more meaningful than those provided by teachers because the students draw on their own knowledge to construct them. Constructing analogies also helps students take a more independent approach to learning.

An analogy drawn between a concept covered earlier in a course (e.g., Newton's law of gravitational force) and one covered later (e.g., Coulomb's law of electrical force) is particularly effective because the earlier concept is familiar to every student. The previously discussed concept, however, should be reviewed to refresh students' memories.

An analogy can also foster students' transition to a new conceptualization of a previously taught concept. For example, as Newton conceptualized it, gravity is a linearly directed force: Objects with mass exert this attractive force. This conceptualization works well most of the time, and that is the reason it is still taught and frequently used. A better conceptualization, however, is that developed by Einstein: Gravity is a consequence of the shape of the universe. In this conceptualization, objects with mass alter the curvature of space-time, the 4-dimensional "fabric" of the universe. In Einstein's general theory of relativity, differential field equations describe how the shape of space-time depends on the amount of matter or energy in a region of space.

Because it is difficult to visualize 4-dimensional space-time, a 3-dimensional rubber sheet analogy is often used (see Fig. 3). Space-time is viewed as a sheet of rubber, stretched flat when there is no matter present.



Analogies, Role in Science Learning, Fig. 3 A rubber sheet analogy of space-time

If a massive object like a star is placed on this rubber sheet, the object pushes down into the sheet creating a cuplike depression. Less massive objects, like planets, create smaller depressions. An object like an asteroid traveling nearby the star would not pass the star in a straight line; the path would curve, as if the asteroid were rolling along the depression in the rubber sheet. If an asteroid were in the right position, going just the right speed, it might remain in the depression and orbit around the star.

The rubber sheet analogy helps students to draw important conclusions about space-time and Einstein's theory of general relativity. The curvature of space-time is responsible for gravity. Gravity is strong where space-time is curved and absent where it is flat. Although helpful in conceptualizing space-time, the rubber sheet analogy – like all analogies – breaks down. For example, the analogy is 3-dimensional rather than 4-dimensional, focusing on the spatial feature of space-time and ignoring the temporal feature.

Summary

Well-designed analogies are pedagogical tools that can support students' science learning. The steps in the Teaching-With-Analogies Model describe how to design effective analogies for use in classrooms, textbooks, software programs, and Internet sites. Well-designed analogies can help students understand many kinds of science concepts, including those with hard-to-visualize systems of interacting parts.

Cross-References

▶ Analogies in Science
▶ Analogies, Metaphors, and Models
▶ Analogies: Uses in Teaching
▶ Discussion and Science Learning
▶ Role-Plays and Drama in Science Learning

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Analogies: Uses in Teaching

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Keywords

Analog; Analogies; Science representations; Teaching

Externalizing Internal Mental Representations

Over the past two decades, consistent research findings have shown that a variety of external representations used by science teachers, science teacher educators, and science education researchers can lead to successful student learning outcomes. These external representations include analogies, metaphors, and models and model-based learning which have the effect of helping teachers and students externalize their internal mental representations providing avenues for discussion and more focused learning (see for example, Aubusson et al. 2006; Khine and Saleh 2011). This short entry deals with analogies as one form of external representation that is introduced by science teachers and used effectively with both elementary and secondary students when they learn a variety of science concepts.

Need for a Guide to Help Science Teachers Use Analogies Effectively

In science lessons, both teachers and students generate analogies, and sometimes these work well and sometimes they do not. Research has shown that analogies require explanation and analysis if they are to effectively contribute to students' science learning. Consequently, if analogies are to be used most effectively by science teachers, then a carefully planned teaching strategy is required that makes the analogies relevant to as many students as possible. As the vast majority of science teachers have no formal training in the use of analogies, it is not surprising that analogies used in teaching and learning are less effective than they could be.

In working with a group of science teachers who were interested in improving their teaching with analogies, Treagust et al. (1998) initially used an existing analogy-teaching model which was modified and adopted by teachers who taught a grade 10 optics class on refraction. The findings from this optics study and other studies led to the development of an approach called the FAR guide for teaching science with analogies, the letters being the three phases of the teaching strategy – focus–action–reflection (Treagust et al. 1998). This instructional strategy was designed to help teachers maximize the benefits and minimize the constraints of analogies when they arise in classroom discourse or in textbooks.

In the **focus** phase from his or her experience, the teacher decides whether or not the (1) *concept* is difficult, unfamiliar, or abstract, (2) what ideas about the topic that the *students* already know, and (3) whether or not the *analog* to be used is familiar to the students.

In the **action** phase, the teacher presents the analogy by (1) discussing those features of the analog and the science concept that are *alike*, drawing similarities between them and then (2) discussing those aspects where the analog is *unlike* the science concept.

In the **reflection** phase, the teacher and students discuss the analogy and *conclude* whether or not the analogy was clear and useful or confusing. Finally, the teacher reflects on the effectiveness of the analogy and whether or not *improvements* to the analogy should be made in light of outcomes.

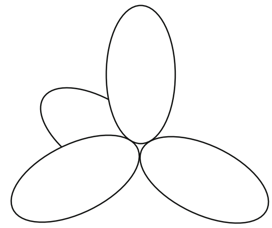
The phases of the FAR guide have become second nature to those teachers who become familiar with them, and these phases have been usefully applied to teaching and learning science concepts with analogies. A wide range of analogies for use in physics, chemistry, and biology lessons using the FAR guide is presented in Harrison and Coll (2008). One of these

49 analogies – balloon analogy for chemical bonds and molecular shapes – is presented below as a prototypical example.

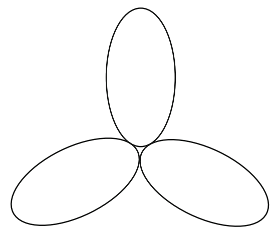
Balloon Analogy for Chemical Bonds and Molecular Shapes Using Focus–Action–Reflection (FAR Guide)

For this grade 11 chemistry lesson, the topic being taught is the forces between nuclei and electrons which result in the formation of covalent bonds that are electrostatic in nature. The repulsion forces between electron pairs around a central nucleus produce linear, trigonal planar, and tetrahedral molecules in, for example, ethyne, ethene, and methane, respectively. The teacher demonstrates the repulsion between adjacent electron pairs by means of four elliptical balloons inflated to their maximum with their stems tied together. The pneumatic pressure of four balloons forces them into a tetrahedral shape, and when one balloon is burst, the remaining three take up a trigonal planar shape. When a second balloon is burst, the two remaining become roughly linear (see Figs. 1, 2 and 3). Teachers can use this balloon model as an advance organizer for the lesson. This analogy works best once the valence shell electron pair repulsion (VSEPR) rules have been described which predict the shape of individual molecules based upon the extent of electron-pair electrostatic repulsion. Teachers typically use this demonstration along side other external representations such as space-filling and ball-and-stick models of molecules.

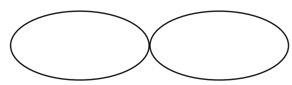
The FAR guide has been implemented with both secondary and elementary students. For example, Sickel and Friedrichsen (2012) engaged students (grade 9–12) in a predator–prey simulation to teach natural selection. The authors noted that, after using the FAR guide, classroom discussion was guided in a more purposeful way and that students had a more coherent understanding of biological processes and mechanisms. In a study with elementary students (grades 1–4) studying a variety of science topics, Smith and Abell (2008) noted that after implementing the FAR guide, teachers reported increased confidence and enthusiasm for teaching the topics and were more aware of the need for students to be familiar with the analog so that they could identify similarities and differences.



Analogies: Uses in Teaching, Fig. 1 Four balloons tied together form a tetrahedral shape



Analogies: Uses in Teaching, Fig. 2 Three balloons tied together (one is burst) form a planar shape



Analogies: Uses in Teaching, Fig. 3 Two balloons (another one burst) form a linear shape

Using Analogies to Engender Interest, Motivation and Conceptual Change

There is much potential for analogies to be used in the science classroom to not only improve conceptual understanding and engender conceptual change but also enhance student interest and motivation. Introducing analogies into science lessons and using them to achieve both conceptual and affective outcomes are consistent with many researchers who argue for a unity between the cognitive and emotional dimensions of learning. Similarly, children's and young people's thinking often involves visual imagery; by using their imagination, analogies used in the science classroom can create additional interest in the lessons. As noted above, researchers have reported that students enjoy lessons in which analogies were used to learn science concepts. Also teachers have exhibited enthusiasm and were animated when using analogies in their teaching. An excellent example of how analogies engender interest and motivation in science conceptualization is the interview with a student named Dana in the optics lessons reported by Harrison in Harrison and Coll (2008). Essentially, Dana's responses to questions about the optics lessons went from disinterested to enthusiastic and knowledgeable once the analogy was evoked. Thus, while the evidence is scant, there appears to be a prima facie case to investigate the relationship between learning and teaching with analogies and students' interest and enthusiasm for science.

Concluding Comments

The teachers who trialed this instructional strategy in their classrooms helped to refine the FAR guide to a point where it can enhance student understanding of the science concepts explained using analogies. Both teachers and researchers have reported viable learning outcomes with this approach. Provided teachers spend time negotiating each analog's familiarity and establishing the analogy's similarities and differences with their students, analogies can be powerful and motivating learning tools. The FAR guide does more than just establish analog familiarity and ensure valid shared and unshared mapping; it encourages teachers to regularly self-evaluate their teaching, and this should result in enhanced teaching and learning of science. Furthermore, when teachers use analogies effectively in their lessons, the opportunities for enhanced student interest and motivation are increased.

Cross-References

▶ Analogies in Science
▶ Analogies, Metaphors, and Models
▶ Analogies, Role in Science Learning
▶ Dilemmas of Science Teaching
▶ Evaluation of Textbooks: Approaches and Consequences
▶ Scientific Language

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Animation

▶ Scientific Visualizations
▶ Slowmation

Aquaria

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Introduction

An aquarium, or aquaria in plural form, is a site that offers visitors the chance to view water- and land-based animals (either marine or freshwater) in a museum-like environment; they include a variety of species including fish, amphibians, reptiles, and mammals; they include tanks, hands-on exhibits, interactives, educational programs, and sometimes touch experiences. Much of a person's learning during their lifetime happens outside of formal learning environments such as schools and universities, as documented by the National Research Council (USA) in *Learning Science in Informal Environments: People, Places, and Pursuits*. Free-choice learning at places like museums, zoos, and aquariums is learning that is self-motivated, lifelong, and personally guided by an individual's personal needs and interests. While the exact definition of a public aquarium can be debated, it is estimated there are somewhere between 125 and 150 public aquaria worldwide; around 75 of these are in the United States alone (source: Wikipedia, "public aquarium").

History and Educational Opportunities in Aquaria

While people have kept fish indoors and on display dating back to the Roman Empire, public aquaria are roughly 150 years old starting with the first public aquarium opening in the London Zoo in 1853. The Association of Zoos and Aquariums (AZA) estimates that the 225 aquaria and zoos accredited by AZA account for more than 175 million visits worldwide; the largest aquaria attract more than two million visitors a year. Much of what motivates people to visit these institutions is viewing live animals they would not normally get to see, and this offers a unique opportunity for aquaria to connect and engage with visitors through exhibits, programs, and live animal "touch" experiences and increasingly through web- and mobile-based experiences.

Learning in Aquaria

Most public aquaria consider themselves to be informal science learning institutions and have education departments that work with local school groups or whole education systems, providing materials before, during, or after field trips to complement and enhance the visit itself. The learning that occurs during field trips typically focuses on cognitive information tied directly to the school curricula for that particular grade. However, the majority of aquaria visitors come outside of field trips, and learning for these visitors tends to be more open-ended, visitor driven, and more of a combination of cognitive, affective, social, and other types of learning than exclusively cognitive learning. In fact, visitor learning is influenced most by individual visitors' interests, prior experiences, knowledge, and motivations for visiting. Regardless of who someone is, what visitors learn in aquaria tends to be focused on the animals, although visitors often learn about the animals' habitats and human impact on animals and the ocean.

Learning About Conservation-Related Issues

In the past decade, there has been a noticeable shift from zoos and aquaria exhibiting animals to including messages about conserving animals and their habitats; including conservation messages is now common in institutional mission statements. As a result, research is being conducted about how a visit impacts visitors' conservation-related attitudes, beliefs, and behaviors (Yalowitz 2004). Recent studies have looked at the cumulative impact of visits across aquaria and zoo visits, including the *Why Zoos and Aquariums Matter* study (Falk et al. 2007), finding that aquaria and zoo visitors bring a higher-than-expected knowledge about basic ecological concepts, experience a stronger connection to nature as a result of their visit, have their values and attitudes reinforced, are prompted to reconsider their role in environmental problems, and can see themselves as part of the solution. While this is good news to aquaria and zoos, the *Assessing Public Awareness, Attitudes, and Actions: America and the Ocean* study found that the public still had only a marginal understanding of how oceans work, their relative importance, and the challenges we face in keeping oceans healthy. However, this study found that certain audiences, like teens and "tweens" aged 10–12 years, had a higher level of awareness about ocean-related issues compared to adults.

Learning About Climate Change

Studies at informal science education venues have shown that science-based institutions such as aquaria have visitors who are more aware of and knowledgeable about climate change compared to the general public. A supplemental round of funding by the National Oceanic and Atmospheric Administration (NOAA) in 2009 specifically supported aquaria and zoos communicating about climate change; one project is designed to build a shared community where zoos and aquariums can share information about interpreting climate change (see www.climateinterpreter.org). Aquaria are also starting to categorize visitors based on the well-known Global Warming's Six Americas Study to gauge whether aquarium visitors have different attitudes from the general public regarding climate change. One recently released publication discusses recent approaches and research for specifically communicating climate change in zoos and aquariums (Grajal and Goldman 2012).

Summary

In summary, aquaria have had a long history first as attractions and then as educational institutions who can effectively communicate science content about animals and their place in the world. As aquaria make the shift to stressing the importance of protecting animals, their habitats, and encouraging environmental stewardship, they have great potential to not only communicate science concepts and issues but empower visitors to take care of the world in which they live.

Links

Association of Science and Technology Centers (ASTC) – represents science-based visitor-based organizations, such as science museums, science centers, natural history museums, zoos, aquaria, and the like.

Association of Zoos and Aquariums (AZA) – international association representing zoos and aquaria, with a particular focus on education.

ClimateInterpreter.org – a site for the zoo and aquarium community to share about how to most effectively communicate climate change to the public.

Informalscience.org – a repository of evaluation and research reports, many focusing on learning and education; one can search evaluation reports by "aquarium."

NOAA Ocean Education Grants for AZA Aquariums: FY09 – a series of grants "to support education projects designed to engage the public in activities that increase ocean and/or climate literacy and the adoption of a stewardship ethic."

The Ocean Project (TOP) – a nonprofit that "advances ocean conservation in partnership with zoos, aquariums, and museums around the world."

Cross-References

▶ Excursions
▶ Informal Science Education
▶ Informal Science Learning
▶ Visitor Studies

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Argument

► Argumentation
► Explaining as a Teaching Strategy

Argumentation

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Keywords

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Argumentation in Science Education

Argumentation may be conceptualized in a range of ways, at least two of which are relevant for science education: first, argumentation as justification, or the evaluation of knowledge claims in the light of available evidence, and, second, argumentation as persuasion of an audience (Erduran and Jiménez-Aleixandre 2008). Argumentation plays a central role in the building of explanations, models, and theories, as scientists use arguments to relate the evidence they select to justify the claims they reach through use of warrants (Toulmin 1958). In science education, argumentation studies can be framed in two complementary approaches: on the one hand a theoretical approach – grounded in epistemology – about appropriation of scientific practices, that is, epistemic practices associated with producing, communicating, and evaluating knowledge in science, and on the other hand a policy approach (central, for instance, to the Program for Indicators of Student Assessment, PISA) emphasizing the development of scientific competences, in particular the ability of using scientific evidence to draw and communicate conclusions and of identifying the assumptions, evidence, and reasoning behind conclusions. The rationales for argumentation in science education draw also from other fields, such as language sciences, psychology, and science studies. Rather than being a one-way relationship, argumentation studies and science education have the potential to inform these perspectives, leading to fruitful interactions.

It is not easy to disentangle the influences of these fields, as sometimes they are combined, as happens with science studies, highlighting the importance of discourse in the construction of scientific knowledge, and language studies. Not all linguistic interactions should be considered as argumentative, but only those concerning the process of contrasting two or more views or meanings and of negotiating a solution. From discursive interactions, the ones that can be regarded as argumentative are those involving, for instance, formulating claims, supporting them with evidence, or evaluating arguments. On the other hand, argumentation in science education is not just a linguistic activity, but requires drawing from the relevant knowledge, selecting appropriate sources, and analyzing it by means of particular skills. Developmental psychology has examined, for instance, the epistemological and cognitive prerequisites for engaging in argumentation. A developmental pattern of epistemic cognition is reviewed by Garcia-Mila and Andersen (in Erduran and Jiménez-Aleixandre 2008). There is also a perspective viewing argumentation as a psychosocial practice embedded in institutional, historical, and cultural contexts (Muller-Mirza and Perret-Clermont 2009), a view combining developmental, social, and sociocultural approaches.

A key feature of argumentation, according to Osborne, MacPherson, Patterson, and Szu (in Khine 2012), is the role of criticism in the construction of knowledge. The implication would be that learners should be provided with opportunities to engage in critique and evaluation. About the contributions of argumentation to science learning, Tiberghien (in Erduran and Jiménez-Aleixandre 2008) summarizes the place of argumentation in science education in terms of three goals: acquiring knowledge about nature of science, developing citizenship, and developing higher-order thinking skills. Jiménez-Aleixandre and Erduran (in Erduran and Jiménez-Aleixandre 2008) propose that argumentation may support the following: (a) the access to the cognitive and metacognitive processes characterizing expert performance, (b) the development of communicative competences and critical thinking, (c) scientific literacy, (d) the enculturation into the practices of scientific culture, and (e) the development of reasoning.

Research on Argumentation in Science Education

Research on argumentation in science education is a relatively recent phenomenon, beginning in the 1990s. Early studies concentrated on exploration of whether or not argumentation took place in science classrooms, often with a negative outcome in terms of children's inability to formulate sound arguments. A large number of studies focused on students' argumentation (Kelly and Takao 2002). In time, the focus shifted to the study of quality of argumentation and methodological approaches to the study of argumentation in science classroom. More recently work has been dedicated to the design of learning environments and professional development programs to support the implementation of argumentation in everyday classrooms. The emphasis in argumentation studies has varied in the work of researchers from different parts of the world. A distinctive feature of argumentation studies in Europe and in general of the attention given to argumentation throughout Europe in the last decade is its connection to the development of competences. In particular, argumentation is framed in the development of scientific competence in light of the PISA framework. In other parts of the world, for instance, in the United States, argumentation is framed in scientific practices. A great deal of research has been done in relation to argumentation in the context of socio-scientific issues (SSI). In relation to these issues, science is involved in a social debate, typically concerning personal or political decision-making related to health or environmental controversies. The notion of SSI is grounded on previous approaches as science, technology, and society or science-based social issues. While all socio-scientific issues are scientific, it needs also to be acknowledged that the controversies, either in the classroom or in society, have sometimes a stronger ethical component, while in other cases students need to appeal primarily to scientific explanations.

There have been numerous research and development initiatives across the world to integrate information and communication technologies (ICT) in argumentation studies. A key rationale for the choice of argument and argumentation as a genre in ICT has been based on the notion that learning activities should confront cognition and its foundations. In this sense, substantial amount of research has been dedicated to how best to scaffold argumentative processes ranging from generating to justification of claims. Research in the context of teaching and learning with tools such as scientific visualization tools, databases, data collection and analysis tools, computer-based simulations, and modeling tools has been widespread. Another trend in the use of ICT in argumentation research has been the contextualization of argumentation in scientific inquiry processes. ICT tools can provide a graphical platform in which participants may collaboratively construct an argument (on one computer or on different computers in asynchronous mode) or participate in synchronous discussions. The argumentative map produced during the construction or during the discussion is an artifact that participants can exploit in further activities, as opposed to face-to-face discussions from which students cannot "physically" extract previous outcomes.

A significant line of work in argumentation relies on models of professional development based on Lee Shulman' notion of teachers' "pedagogical content knowledge" as outlined by Zohar (in Erduran and Jiménez-Aleixandre 2008).

Other approaches to teacher education have extended the work of educational psychologists such as Deanna Kuhn in application to science education. In the context of argumentation, advocates for effective professional development have argued that the teaching of argumentation requires a model of pedagogy that is based on knowledge construction as opposed to knowledge transmission. Teachers' enculturation into new models of pedagogy to support argumentation requires systematic and long-term professional development.

Toulmin's Model for Analyzing Arguments

Toulmin's Argument Pattern (TAP) is a model or scheme for analyzing arguments that was developed by Stephen Toulmin (1958) in his book *The Uses of Argument* (updated in a second edition in 2003). Toulmin's model is intended for the purposes of describing argumentation in practice and of studying argumentation as it is practiced in the natural languages and therefore away from the schemes of formal logic. This practical nature makes it a useful tool in order to analyze discourse in situations where new knowledge is being generated, as science laboratories or classrooms. Formal logic frameworks, while being adequate for analyzing established knowledge, may be less fit for those other fluid, ill-defined contexts. According to Toulmin, TAP represents a "practical" or "substantial" argument instead of a theoretical argument in the form of premises to conclusions.

The focus of Toulmin's model is on the function of arguments in order to justify claims, placing the validity of an argument in the coherence of its justification. In this approach a justification of a statement or set of statements is characterized as an argument to support a stated claim. He proposes to move away from the logic-mathematical model of arguments and to draw on the jurisprudential model, using it as an analogy. His goal was to elaborate a tool of analysis more sophisticated than the model consisting of minor premise, major premise, and conclusion. Toulmin suggests that the examination of the form of arguments from different fields (e.g., law, science, and politics) yields a common pattern consisting of six elements or components, claim, data, warrants, backings, qualifiers, and rebuttals, which are discussed below. This scheme is known as Toulmin's Argument Pattern or TAP.

TAP embodies some points about arguments and reasoning, as, for instance, (a) that arguments involve not only supporting points of view but also attacking them, (b) that conclusions drawn from reasoning may be qualified, or (c) that standards of reasoning can be field dependent. As Hitchcock and Verheij point out, in the introduction to a special issue of the journal *Argumentation* in 2005 devoted to the influence of Toulmin's layout of arguments, each of these points is illustrated by Toulmin's layout: for instance, rebuttals illustrate point (a), qualifier point (b), and warrant and backing point (c).

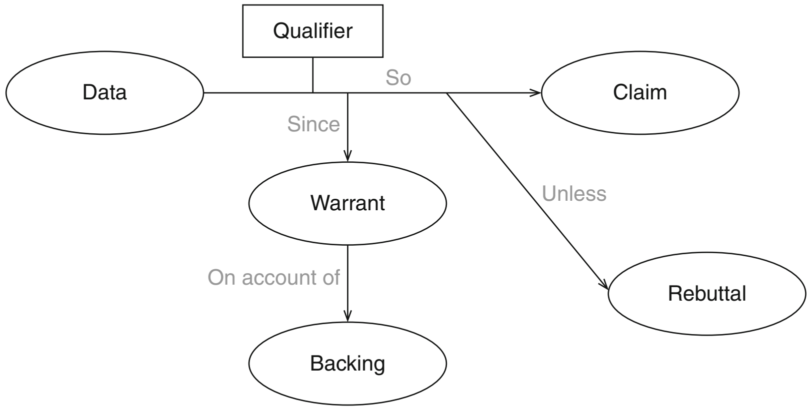
Components of Toulmin's Argument Pattern

In Toulmin's scheme, an argument, or in other words the result of coordinating an explanation with the evidence supporting it, has three essential components, in his own terms the first skeleton of a pattern: claim (C), data (D), and warrant (W). There are three components that account for other features of arguments: backing (B), modal qualifiers (Q), and rebuttals (R). Besides Toulmin's original characterization, some modifications of the components in science education literature are presented:

Claim: the statement, knowledge claim, or conclusion that has to be supported or disproved (in science, explanations seeking to interpret natural phenomena constitute a relevant sort of claim).

Data: observations, facts, or experiments that are appealed to as a foundation for the claim or, in more general terms, that are used in order to evaluate a claim. In science education the term *evidence* has been used in some argumentation contexts: it should be noted that is not fully

Argumentation, Fig. 1 Toulmin's Argument Pattern (Toulmin 1958)



interchangeable with *datum*. In other analyses data and warrants are collapsed under the term *evidence*.

Warrant: a statement that relates the claim to the data, in order to show that, taking these data as a starting point, the step to the claim or conclusion is a legitimate one. In science education the terms *justification* and *reasoning* have also been used instead of warrant.

Backing: generalizations making explicit the body of knowledge or experience relied on to establish the authority or trustworthiness of the warrants. In science education they may be, for instance, appeals to theories, and the term *background knowledge* has sometimes been used.

Modal qualifiers: indicate the strength conferred by the warrant and express the grade of certainty or uncertainty of an argument, for instance, "probably," "for sure," and "it depends."

Conditions for rebuttal: for Toulmin, they acknowledge the restrictions or exceptions to a claim. However, in analyses of argumentative contexts where a confrontation between two opposite explanations exists, a *rebuttal* means a criticism of the evidence of the opponent, as discussed in detail in Erduran's chapter in Erduran and Jiménez-Aleixandre (2008).

Toulmin also proposed a graphical representation for the relationships among these components that is reproduced in Fig. 1.

For Toulmin, some components of arguments are the same, while others differ across fields of inquiry. He termed the elements that are similar across fields as being field-invariant features of arguments, whereas those that differed were called field-dependent features. Data, claims, warrants, backings, rebuttals, and qualifiers are field invariant, while "what counts" as data, warrant, or backing are field dependent. Thus, appeals to justify claims used to craft historical explanations would not necessarily be the same kind of appeals used to support claims for causal or statistical-probabilistic explanations. The flexibility of Toulmin's model to function in both field-dependent and field-invariant contexts provides an advantage for understanding and evaluating the students' arguments in science classrooms.

Toulmin's Argument Pattern in Science Education

Toulmin's Argument Pattern (TAP) has been applied in science education in numerous ways. It has influenced the conceptualization of argumentation in science education theory, practice, and policy. Though not acknowledged explicitly, there are examples of curricular policy documents from around the world that have incorporated some of the notions and terminology embedded in the TAP framework, for instance, the Program for International Student Assessment (PISA), which emphasizes the role of evidence in the reaching of conclusions. Jiménez-Aleixandre and Erduran (in Erduran and Jiménez-Aleixandre 2008) discuss examples of steering documents and standards from different countries that incorporate ideas from Toulmin's model.

TAP has been used extensively as an analytical tool in the study of argumentation in the science classroom. As summarized by Erduran (in Erduran and Jiménez-Aleixandre 2008), apart from its methodological use, TAP has been used as a framework for understanding the nature of scientific reasoning, as a theoretical tool and representation, and as an indicator of problem-solving in expert-novice studies. In situating argumentation as a particular type of communicative interaction, Rigotti and Greco Morasso (in Muller-Mirza and Perret-Clermont 2009) propose a model that draws on the discursive nature of Toulmin's framework and may be useful for arguments in socio-scientific contexts.

Despite its various adaptations and uses, Toulmin's work has received much criticism within the science education community. A primary criticism has centered on the issue of difficulty in capturing dialogic argumentation. It has been argued that Toulmin's scheme is a model of rationale discourse adequate primarily for a monologue, although the inclusion of the modal qualifier can be conceived as the introduction of an element of dialogue. Richard Duschl (in Erduran and Jiménez-Aleixandre 2008) advocates that the focus of argumentation analysis should be on epistemic criteria and that TAP is not effective for the purposes of the clarification of "what counts" as claim, data, warrant, and backing or, in other words, the field-dependent dimensions of arguments. Duschl proposes Douglas Walton's reasoning schemes as an alternative to analyze dialectical exchanges in science classrooms. Further methodological difficulties have been described by other researchers, as, for instance, that organizing student discourse into Toulmin's argument components required careful attention to the contextualized use of language. Kelly and Takao (2002) discuss the ambiguity of Toulmin's categorical system, pointing out that in the context of actual arguments, claims may serve as data in more complex chains of reasoning, as is the case in written arguments. A second criticism raised by these authors is that Toulmin's approach does not consider the relative epistemic status of knowledge claims. In order to address these shortcomings, Kelly and Takao developed an analytic framework focused on the epistemic level of propositions within an argument and how they are connected within and across levels.

Apart from research-based applications of TAP in science education, there are examples of work where TAP has been used to inform the production of resources for teaching and learning as well as professional development of science teachers. For example, TAP has been used to structure the students' writing of arguments and the design of training programs for teachers. The adaptation of TAP as a structure and a process of argumentation has also yielded understanding of the hierarchy of pedagogical strategies that underlie effective teaching of argumentation (Zohar in Erduran and Jiménez-Aleixandre 2008).

Future Perspectives

Despite wealth of research in classroom-based research on argumentation since the mid-1990s, reviews suggest that the territory remains ripe for numerous lines of work in the future. An aspect of argumentation research that has not been addressed sufficiently in the literature is the relationship between disciplinary content or conceptual knowledge and argument structures and processes. There is also little work dedicated to the exploration of students' and teachers' perceptions of argumentation. Likewise, developmental trajectories of teachers in learning argumentation in a longitudinal fashion are virtually nonexistent. Future studies could build on investigations on the cultural or contextual factors that impact teachers' and learners' argumentation in science classrooms. The study of emotions, gender, and power relations in relation to argumentation is virtually inexistent in science education research. While acknowledging the potential of argumentation to engage students in scientific practices, McDonald and Kelly (in Khine 2012) point out the limitations of an increasingly specific focus on argumentation in student discourse, for instance, narrow focus on one type of discourse and analytic limitations in terms of understanding the quality of students' classroom science discourse. They suggest scientific sensemaking as a broader perspective on science discourse practices that would be more productive to support both science teaching and learning and science education research. This perspective may be one future direction for the integration of argumentation studies in broader frames. A fruitful new territory for argumentation research could draw from "science studies" – the interdisciplinary studies on science with implications for science education.

Cross-References

▶ Argumentation Environments
▶ Computers as Learning Partners: Knowledge Integration
▶ Discourse in Science Learning
▶ Scientific Language

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Argumentation Environments

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Definition

Argumentation environments are computer-based systems that engage and support learners in constructive and collaborative activities around argumentation, such as creating, editing, communicating, interpreting, and/or critiquing arguments. Scientific argumentation, as a process of building upon or refuting claims based on empirical evidence to arrive at agreed-upon scientific conclusions, challenges learners in that it requires both conceptual understanding of relevant content knowledge and mastery over various problem-solving and social skills. As such, argumentation environments typically consist of technology-based tools integrated into extended face-to-face or computer-supported activities for K-16 students and designed to address the dual pedagogical goals of helping students learn the practices of scientific argumentation (learning to argue), as well as the content knowledge necessary for engaging in those practices (arguing to learn) (Scheuer et al. 2010).

Features of Argumentation Environments

Two kinds of argumentation environments may be distinguished. Discussion-oriented argumentation environments emphasize the use of arguments in collaborative dialogue among peers, whereas argument modeling environments support the creation of arguments, often by piecing together primitives and testing these against an underlying model. Whether a system is discussion- or modeling-oriented has large impacts on the possible kinds of learner interactions, automated analyses, and feedback that can be generated. However, any one system may feature characteristics of both categories. Generally, although to varying extents, the tools within argumentation environments focus on scaffolding idea generation; information seeking; text planning, structuring, and linearizing; argument expansion, elaboration, and evaluation; and collaboration and debate. The manners by which these scaffolds are manifested reflect designers' pedagogical goals and theoretical perspectives on argumentation (Clark et al. 2007). Nevertheless, argumentation environments typically include several features in common (Hilton 2010):

(1) contextualizing representations, (2) access to relevant content information, (3) support for communication and collaboration, (4) argument representations, (5) socio-cognitive structures, and (6) metacognitive supports.

(1) *Contextualizing representations* embed argumentation in an overarching activity, helping learners realize the relevance of argumentation and motivating them to apply their knowledge and skills in meaningful ways. Students are either presented with or allowed to explore representations such as narrative, images, video, and other interactive media. These serve to establish a problem scenario and prompt students to develop solutions, in which they must take on particular perspectives, seek information, and justify and communicate their claims.

(2) *Access to relevant content information* helps reduce learners' cognitive load when engaged in constructing and communicating arguments. Through explorable content-rich representations, students may access student-generated or curriculum author-generated databases of information from which they may gather information to help establish a perspective on a given topic and to use as evidence in support or refute of claims in their arguments. These databases may be contained such that students explore it without leaving the environment, or else they may be provided access to external resources, such as the World Wide Web. Often, tools associated with these information databases support information processing tasks, such as gathering, documenting, and sorting information, as well as managing sources of that information. These tools allow students to create and maintain intermediate representations toward preparing final arguments. For example, some tools may allow open-ended note-taking, list creation, or direct annotation on an information source. Such tools may furthermore support cognitive actions such as sorting, grouping, and tagging individual information entries, that together help students prepare to formally present their ideas.

(3) *Support for communication and collaboration* generally consists of shared spaces with tools to promote social interactions and to encourage learners building and negotiating joint understandings. These supports often afford the co-construction of artifacts, including knowledge repositories, intermediate representations, as well as text and diagrams of final agreed-upon arguments. They may also offer platforms on which learners can review, critique, and debate each other's points of view.

Environments differ in the degree to which the computer mediates learners' interactions. For example, certain systems have embedded support for such communication and collaboration and thus allow interactions among spatially or temporally separated individuals via an entirely virtual space. In these cases, tools may permit synchronous and/or asynchronous communication among students via real-time chat applications or archived discussion forums. Other environments support only single-user interaction, but may instead promote face-to-face interactions within groups of students sharing the same computer station, or among individuals via a group projection system. Still other systems may support individual learners through student-to-computer interaction.

(4) *Argument representations* are the ways by which arguments are presented to learners. By offering visual ways to externalize ideas as learners formulate or review the structure of their arguments, they allow learners to recognize, through visual inspection, the relations between elements as well as any missing components of their arguments. Argument representations vary in appearance, often taking the form of text containers, linear or threaded discussions, matrices, or node-link graphs. They may also vary in the manners by which learners are able to interact them. For example, some representations may be individually or collaboratively constructed and may scaffold the construction of particular argumentative structures by limiting, requiring, or allowing learners to

create any number and particular kinds of elements and relations between them. Other representations may be system generated and provide learners with artifacts for inspection, reflection, and critique. Certain systems display argument representations as part of a linear series of activities, whereas others support the simultaneous use of multiple representations. Argument representations tend to reflect the particular conceptual primitives that make up an argument (e.g., hypothesis, data, evidence) and which differ depending on designers' underlying theoretical perspectives.

(5) *Sociocultural design* involves specifying and guiding sequences of activities to maximize the success of interactions among learners, as well as the quality of learners' resulting arguments. For example, some environments orchestrate social interactions by distributing roles in which learners must take on particular perspectives and tasks. Other systems group learners based on personal characteristics (e.g., gender, prior knowledge) or on their similar or opposing views determined from learners' responses to previous items. Still other systems moderate learner discussions in various ways, such as by seeding discussions with predetermined topics.

(6) *Metacognitive supports* encourage learners to monitor and reflect upon their understanding and on the quality of their own and of others' contributions. Supports may include visual or numeric displays that give learners information on group dynamics. These may include participation metrics in terms of interactions had with others and of contributions made or requiring attention by themselves and others during joint tasks. They may also include displays of socio-cognitive information in terms of levels of certainty and agreement among group members. Metacognitive supports may also involve various kinds of feedback, either generated by a human moderator or by the system itself. For example, learners may receive adaptive feedback on the quality of their contributions based on automated analyses of their submitted work, or generic text prompts to reflect upon the state of their understanding and to make decisions about the information they may require to further refine their ideas.

Assessment and Feedback

The technological capacities of computer-based argumentation environments offer various ways to assess and understand how people learn through argumentation and how such systems can support them (Scheuer et al. 2012). These techniques vary in sophistication depending on the nature of the objects of assessment, whether these consist of learners' natural language contributions or entries in tightly constrained input fields. Generally, analyses of argumentation focus on identifying the content and patterns of learners' discussions in order to characterize how learners communicate with one another. From archived interactions within a system, for example, researchers can count and categorize the kinds of exchanges that occur between learners in terms of their argumentative functions (e.g., claims, warrants, evidence). Machine learning and artificial intelligence techniques can also be used to automatically identify patterns in the structure of learner-generated arguments and to evaluate their quality in terms of their positive attributes (e.g., evidence-backed claims, logical chain of reasoning) or negative ones (e.g., irrelevant contributions, lack of responsiveness). By then relating these measures to assessments of learners' content understanding and other interactions in the environment, researchers may gain a sense of how conceptual learning and argumentation skills develop over time as a result of learners' interactions in the environment. Results from these automated analyses may then be used to generate various forms of feedback (formative, summative) at different times (immediate, on-demand), from different sources (human moderator or system generated), and in various modes (text messages, colored highlighting). Automated feedback may either be sent to teachers to inform them on how to guide subsequent activities, or it may be delivered directly to the learner.

Implications for Learning

There are several educational benefits of learning through argumentation that features of argumentation environments, such as scaffolded role play, co-constructed artifacts, and dynamic argument visualizations, aim to support (Andriessen 2006). For instance, learners not only become familiar with various argumentative structures, but by engaging in key processes of argumentation such as elaborating, reasoning, and reflecting upon ideas, students achieve deeper understandings of those ideas. Furthermore, by participating in argumentation, students develop their sense of social awareness and their skills in collaborating with others. At the same time, practice in argumentation helps students become better at arguing, and thus, more competent members of knowledge-based professional communities.

Online argumentation environments can furthermore support specific twenty-first century skills. They develop learners' adaptability to changing information and contexts by scaffolding investigations into unfamiliar topics and distributing roles that give learners practice taking on perspectives different than their own. They also develop complex communication skills by providing learners with tools that orchestrate productive interactions with their peers and that scaffold them articulating their ideas. Argumentation environments furthermore support non-routine problem-solving by helping learners seek patterns and explore alternative perspectives as they evaluate and integrate large amounts of seemingly disparate information. They support self-management and self-development by providing students with tools for monitoring and reflecting upon their own and their peers' contributions. Finally, these environments develop learners' systems thinking skills in that arguments are themselves systems of functional components; thus, scaffolding tools in argumentation environments help students consider how various pieces of information fit together to form a coherent whole.

Research shows impacts of argumentation environments on students learning to argue. Indeed, depending on how they are designed and used, the scaffolding features in argumentation environments have the potential to support students' developing argumentation skills that equal or exceed what is observed in oral argumentation. At the same time, another research suggests that students better manage their argumentation activities face-to-face than mediated by a computer. Designers thus strive to create learner-centered environments that maintain the benefits of face-to-face interaction while capitalizing on the advantages of technology for providing adaptive instruction and for relieving the burden on teachers to provide individualized support to large classrooms of students during open-ended science inquiry activities.

Software Architecture and Technology

A number of free and proprietary software exist that have been explicitly designed to support argumentation in educational science inquiry settings (e.g., as opposed to argumentation in the legal, political, or social sciences domains). Currently, most of these argumentation environments are built upon unique software architectures that are independent of prior technology developments. They use two primary formats to save and exchange data between systems: state based and action based, each of which offers different affordances for automated analysis and feedback. Other domain-general software tools, such as wikis, blogs, forums, and diagramming tools, have been appropriated to support argumentation in educational science inquiry settings.

Examples of Argumentation Environments Developed for or Used in Science Education

- Belvedere (http://belvedere.sourceforge.net/)
- Collaboratory Notebook (http://www.covis.northwestern.edu/software/notebook/)
- CONNECT: Confrontation, Negotiation, and Construction of Text

- Convince Me (http://hamschank.com/convinceme/)
- CSILE: Computer Supported Intentional Learning Environments (http://www.knowledgeforum.com)
- Digalo (http://www.argunaut.org/glossary/Digalo)
- Digital IdeaKeeper (http://www.umich.edu/~hiceweb/downloads/QuintanaAERA04.pdf)
- DREW: Dialogical Reasoning Educational Web tool (http://drew.emse.fr/)
- ExplanationConstructor (http://pages.gseis.ucla.edu/faculty/sandoval/research/projects/excon/)
- Idea Manager (http://wise.berkeley.edu/webapp/pages/features.html)
- Rashi (http://ccbit.cs.umass.edu/RashiHome/)
- Sensemaker (http://tels.sourceforge.net/sensemaker/)
- TC3: Text Composer, Computer supported and Collaborative (http://www.academia.edu/375095/Coordination_Processes_In_Computer_Supported_Collaborative_Writing)
- VCRI: Virtual Collaborative Research Institute (http://edugate.fss.uu.nl/~crocicl/vcri_eng.html)

Cross-References

▶ Argumentation
▶ Communicating Science, Classroom Assessment of the Ability to
▶ Computers as Learning Partners: Knowledge Integration
▶ Discourse in Science Learning

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Asian Ancestry

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In traditional Asian cultures, especially the Confucius tradition in East Asian countries, teachers were regarded as exemplary persons with knowledge, life experiences, wisdom, and compassion toward the world. Teachers were highly respected by the members of community; thus, their teaching and contributions to the community were influential and well accepted. Teacher-student relationship was built based on respect, trust, and care for each other. The traditional ways of knowing are based on the Confucian understanding of teaching and bringing up the younger generation to become good human beings with knowledge and wisdom (Hall and Ames 1987). Education was valued and teachers' status was high. Even though most educational traditions and practices have changed in response to modern societal changes, education is still highly valued and emphasized in Asian cultures.

Asian countries were rapidly industrialized and globalized in the nineteenth and twentieth centuries, adapting and transforming modernized education models from Western societies such as school subjects, school systems, curriculum, etc., into their local situations. In many Asian countries, schools use the same national curriculum which is authorized by the government. In junior and senior high schools, science is taught by science teachers who specialized in science and science education (specifically biology, chemistry, physics, and earth science). Elementary science is taught mostly by teachers who specialized in elementary education, not specifically in science.

One of the current fundamental issues faced by teachers and students in Asian countries is the assessment system. In many countries, there are exam systems to evaluate students' knowledge and skills for university entrance. Such assessments have resulted in content-based curriculum and teaching practice in public schools (Kim et al. 2013) and also caused the emergence of problematic private education involving private tutoring and cramming for exams.

Despite the high level of student achievement in international assessments in science (e.g., TIMMS, PISA), exam-focused education in Asian countries has caused concern about students' creativity, inquiry skills, and attitudes toward science (Bybee and McCrae 2011). Recognizing this concern, many countries have started to recognize the importance of critical thinking, creativity, and problem-solving skills for the twenty-first-century learners and have attempted to innovate science curriculum and teaching practice with inquiry focus (Kim et al. 2013).

Cross-References

► Black or African Ancestry
► Cultural Influences on Science Education
► Cultural Values and Science Education
► Latino Ancestry
► Pacific Island Ancestry

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Assessed Curriculum

► Curriculum

Assessing Science Communication: An Overview of the Literature

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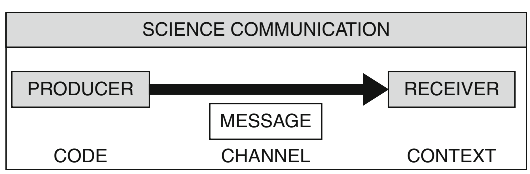
Introduction

The literature on assessment of science communication in classroom settings is vast and focused on a broad range of communicative behaviors, including talking, writing, reading, and listening. One useful way of understanding this literature is in terms of a message transmission model (see Fig. 1) wherein teachers and students take turns playing the roles of producers and receivers of a science message. A message (scientific information) is produced in a linguistic code (e.g., the English language) and transmitted via a particular channel (oral or visual) through the performance of communicative acts (e.g., utterances or texts) in a given context (e.g., whole-class discussion, lab write-up, written test). From this perspective, science communication entails production as well as reception of a scientific message. Much of the existing research has focused on the assessment (formal and informal) of one or more of these different dimensions of science communication.



Assessing Science Communication: An Overview of the Literature, Fig. 1 Message transmission model of science communication

Communicative Production of Science

The primary focus of this literature is the assessment of student-written production of science. Various studies have examined the use of writing templates to scaffold student-written communication in the context of science inquiry activities. The Science Writing Heuristic (SWH) is one such tool that has been used widely. Theoretically, the SWH represents a bridge between more personal, expressive forms of writing and the recognized form of the genre, the scientific laboratory report, which represents canonical patterns of presenting results, most especially the link between claims and evidence.

The SWH guides student-written communication through the provision of a series of prompts (What are my questions? What did I do? What did I see? What can I claim? How do I know? How have my ideas changed?). Keys et al. (1999) describe how the use of SWH in an eighth grade earth science class improves several aspects of student-written communication in science lab reports, including evidence-based reasoning, nature of science, and metacognition.

Considerably less attention has been given to the assessment of teacher production of science messages (both oral and written). One exception is a recent study by Glass and Oliveira (2014) who assess the communicative practices of five elementary teachers faced with the task of orally delivering a science text of relatively high linguistic complexity. Assessment of teacher oral production was conducted quantitatively through the combined use of two computer programs to measure relative linguistic complexity of both speech and text: the Simple Concordance Program SCP4.9 and the vocabulary profiler Classic-VP English v.3. This computer-based assessment revealed that oral discussions had an increased percentage of less sophisticated words (everyday parlance) and reduced use of more sophisticated vocabulary (academic terms) than found in the science books. In other words, teachers resorted to accommodation (i.e., provision of simplified linguistic input) in order to promote student comprehension (i.e., reception) of the textual contents of children's science books.

Lastly, some research has also been conducted on science curriculum developers' communicative production of written messages, particularly in science textbooks. Catley et al. (2010) point out that noncladogenic diagrams (ambiguous evolutionary depictions that place organisms in a linear progression rather than nested sets) in biology textbooks and popular science articles miscommunicate macroevolution as a process of biological change that is both anagenic (an entire species directly evolving into another rather than splitting or branching into two) and teleological (purpose or need driven). This research highlights the potential for visual miscommunication of science in curricular materials at the secondary and college levels.

Communicative Reception of Science

Research on the receptive end of science classroom communication has been primarily focused on the assessment of student reading, often underscoring students' difficulties in making sense of expository science texts written in the scientific genre. Norris and Phillips (1994) report that high school students tend to disregard hedges (tentative expressions such as probably, possibly, approximately, and occasionally) when reading popular science texts from the media and are generally unable to interpret those hedges as signals of tentativeness and inconclusiveness. In addition to ascribing higher certainty to the text than originally intended by the author, many students also misunderstand the epistemic status of written statements in popular science reports, often confusing justifications with evidence and conclusions.

Several studies have also examined students' reception of graphical or visual messages from curricular materials (e.g., pictorial representations in science books). This research shows that poorly designed images can lead to misunderstanding and confusion in picture-based science communication, regardless of topic or grade level. Colin et al. (2002) describe secondary students' difficulties in interpreting textbook images of optical phenomena (diffuse reflection, Young's principle of interference, converging lenses, Romer's discovery of the finite speed of light, and colors), including a tendency to ascribe a realistic status to light rays (represented by arrows), a story-like view of optical phenomena due to the classical left-to-right orientation of textbook illustrations, and mistaking colored lights for paints.

Conclusion

In sum, the existing literature highlights the multifaceted and diverse nature of science classroom communication. Communicative assessment can focus specifically on the production or reception of varied types of messages (speech, texts, visual images, etc.) by varied parties (science instructors, learners, curriculum writers, etc.) and take place in many types of contexts (classroom discussions, silent text reading, visual inspection of curricular images, etc.). Careful and reflective consideration should be given to these different aspects or dimensions in effort aimed at assessing the quality of communication in science classroom settings.

Cross-References

► Communicating Science, Classroom Assessment of the Ability to
► Communicating Science, Large-Scale Assessment of the Ability to

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Assessing Students at the Margins

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Assessing students at the margins can refer to either or both nonmainstream *students* or nonmainstream *settings*. The former might be females, students of color, or students from a language background other than English. For science education, nonmainstream settings include contexts such as museums and community-based programs.

Regardless of the particular student population or context, fairness in the assessment process is key. The *Standards for Educational and Psychological Testing* (AERA et al. 1999) describe fairness as encompassing lack of bias, equitable treatment, equality in outcomes, and opportunity to learn. The latter notion is further conceptualized by Pullin and Haertel (2008) to include the content taught and educational resources as well as classroom processes. Attention to these issues is important for all students; it is even more so for nonmainstream students who are often misrepresented or underserved by the assessment process.

From an assessment design perspective (Shaw 2005), the use of bias review panels and the approach known as universal test design (Thompson et al. 2002) aim to remove potential barriers and biases, while an assessment is being developed. For example, consider students whose native or primary language is different from that of the test, known as English learners (ELs) in the USA. Eliminating complex language that is irrelevant to the content being assessed can make assessment items more accessible to such students, thus improving the accuracy of the information provided by the assessment. With respect to assessment delivery, accommodations such as longer time and use of bilingual glossaries have been shown to increase fairness for ELs without advantaging them over native English-speaking peers (Abedi et al. 2004).

In many cases, the above strategies are coming to be seen as mainstream approaches for assessing students at the margins. They are readily applicable to school-based assessments, be they teacher-developed or large-scale external. Yet science learning is not confined to the four walls of a classroom. Assessment in nonmainstream settings offers interesting challenges and opportunities. In such settings comparability may be less of a concern such that standardization has less importance. Grasping what students have learned and are able to do is still worth knowing.

Fusco and Barton's (2001) work with a community-based science program offers insights to assessment in settings at the margins. Their efforts focused on performance assessment, which they saw as "an excellent resource to help create a participatory and inclusive practice of science that draws more closely and critically from the culture and practices of young people" (Fusco and Barton 2001, p. 352). This vision of fairness redefines marginalization through student advocacy, agency, and empowerment. Such "learner relevant assessment" strives to improve learning through critically incorporating student knowledge and background into all phases of the process.

Learner relevant assessment calls for an expanded definition of opportunity to learn and its consideration of what is taught as well as how. It draws on the notion of "culturally relevant pedagogy" and its propositions of students' academic success, cultural competence, and critical consciousness (Ladson-Billings 1995). Learner relevant assessment connects also to the concept of "cultural validity" (Solana-Flores and Nelson-Barber 2001), the effectiveness with which assessment addresses the socio-cultural influences that shape student thinking and the ways in which students make sense of items and respond to them (p. 555).

Learner relevant assessment envisions a process of assessment influenced by nonmainstream students' "daily lives, the assets they bring to [assessment] practices," along with "the possibility of a co-opted [assessment process] that would be respectful of who they are and are becoming" (Rahm 2010, p. 4). This is what assessing students at the margins is truly about.

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Assessment

► Coherence

► Computers as Learning Partners: Knowledge Integration

► Learning Progressions

Assessment Framework

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Keywords

Assessment framework; NAEP; PISA; TIMSS

Assessment frameworks are guides for the design of the assessment. These portray the structure of the assessed curricula providing a context for discussing the purpose of the assessment and what it is trying to measure.

Trends in International Mathematics and Science Study (TIMSS) framework include mathematics, science, and contextual frameworks. There are defined mathematics or science content domains covered by the assessment at fourth and eighth grades. Each topic area belonging to a content domain is presented as a list of objectives written in terms of student understandings or abilities that items are designed to elicit. There are also defined three cognitive domains – knowing, applying, and reasoning, at both fourth and eighth grades, mathematics and science. The understandings and abilities required to engage in scientific inquiry are included within the two dimensions of the assessment framework – the content and cognitive dimensions. Contextual framework identifies the major characteristics of the educational and social contexts that will be research for improving student learning (Mullis et al. 2009).

Programme for International Student Assessment (PISA) framework presents reading, mathematics, science, and questionnaires frameworks. The concepts of *reading literacy*, *mathematical literacy*, and *scientific literacy* are described in terms of the skills students need to acquire, the processes that need to be performed, and the contexts in which knowledge and skills are applied. Accessing and retrieving information, forming a broad general understanding of the text, interpreting it, reflecting on its contents, and reflecting on its form and features are considered key aspects in demonstrating the students' proficiency in reading. Mathematical literacy is assessed in relation to mathematics contents defined mainly in terms of four overarching ideas (quantity, space and shape, change and relationships, and uncertainty) and to processes (the use of mathematical language, modeling, and problem-solving skills) in five situations (personal, educational, occupational, public, and scientific). The assessment of scientific literacy is designed in relation to scientific knowledge or concepts related to science in life and health, science in Earth and environment, and science in technology. It also targets the following processes: acquire, interpret, and act upon evidence. PISA questionnaire framework presents the information to be collected at four different levels: the educational system as a whole, the school level, the instructional setting, and the student level. It presents also some dimensions for the analyzing the policy relevance of the data (OECD 2010).

The National Assessment of Educational Progress (NAEP) framework encapsulates a range of subject-specific content and thinking skills appropriate for the testing of three grade levels – 4, 8, and 12 (http://nces.ed.gov). In addition, NAEP framework contains details about the design of the context questionnaires addressed to school, teacher, and student that helps to understand student achievement in context. The framework serves for revising curricula and also could serve as model for measuring the skills in innovative ways.

Cross-References

- ▶ Assessment: An Overview
- ▶ Inquiry, Assessment of the Ability To
- ▶ National Assessment of Educational Progress (NAEP)
- ▶ Programme for International Student Assessment (PISA)
- ▶ Scientific Literacy
- ▶ Third International Mathematics and Science Study (TIMSS)

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Assessment of Doing Science

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Keywords

Curriculum; ICTs; Laboratory Work; Representation; Summative

This contribution examines assessment practices associated with the "doing of science." All assessments are predicated on assumptions about *what* knowledge is of value and *how* this knowledge might be developed and made visible. Hence this contribution begins by reviewing developments in the goals for science education and then considers how assessment practices associated with the goals of "doing science" have played out in different ways for different purposes at the different levels of the education system (international, national, and classroom). Issues associated with the equity and inclusion, the situated and social nature of learning, and the use of information and communication technologies are also addressed.

What Is Involved in Doing Science? A Focus on Expansive Curriculum Goals

Hands-on and practical tasks are widely recognized as a distinctive feature of school science, but the nature of these activities along with understandings of what is involved in doing science has changed over time. The interrelated nature of curriculum, pedagogy, and assessment has meant that shifts in curriculum goals have required innovation in both pedagogy and assessment. It is no longer sufficient that teachers monitor student conduct of a teacher-prescribed confirmatory experiment or even the development of student investigative skills per se. Curriculum, pedagogy, and assessment need to combine to develop students as citizens who are willing, able, and sensitive to occasions when they could take science-informed actions in their homes and communities. Students need to appreciate how scientists generate, legitimate, and communicate science and to meet the demands of the "knowledge society" they need to develop the capacity to be lifelong learners of science. Given that assessment is a key message system for according value within schools, any assessment of students "doing" science needs to encompass and attend to the full breadth of these learning outcomes.

Research has highlighted the value of pedagogies that explicitly focus on the development of student argumentation, modeling and scientific reasoning capabilities, and the affordances of units that are grounded in socio-scientific or local issues and that offer students with opportunities to participate in science inquiry. The implementation of these pedagogical approaches has required analysis of the nature of the learning outcomes aimed for, what performances would indicate proficiency in a given outcome, and what kinds of tasks would develop and require the desired learning outcomes. The new pedagogies have demanded and afforded new opportunities for student assessment to make visible what students know and can do.

Who Is Assessing and Why?

A consensus is emerging that better assessments need to be developed to capture and communicate the breadth of student learning across all levels of the educational system. International organizations such as the OECD and UNESCO, national and state governments, and schools, teachers, students, parents, school communities, and employers are all important stakeholders in and audiences for the assessment of student achievements in the doing of science, albeit for different reasons and consequences. While the assessment needs at each of these levels are not the same, it is desirable that assessments at the different levels come together to support a common set of learning goals, rather than working at cross-purposes. A balance needs to be achieved between formative assessment, where the intention is to support and enhance teaching and learning, and summative assessment that sums up and reports on student achievement at a particular point of time for accountability and certification purposes.

Internationally the PISA has been influential in directing attention to scientific literacy as a key outcome for science education (OECD 2013). It has contributed to developments in the assessment of student science capabilities through the use of context-based assessment items and the assessment of student knowledge and attitudes. In 2006 and 2009, PISA pilot-tested the computer-based assessment of science (CBAS), designed to measure science knowledge and inquiry processes. Combined, these developments have been important through a wash-back onto national priorities and practices and, subsequently, onto classroom teaching and student learning.

At the national level, countries around the world have moved to include learning outcomes to do with inquiry and scientific practices in their assessment for system accountability and student qualification programs. Policy and practice reviews to date suggest that the nature and level of specification of outcomes from practical and inquiry learning are variable within and across the years of schooling and across country settings. There is no clear evidence for what level might be optimal in terms of supporting valid, reliable, and productive teacher and student assessment practices. Current concerns at the national level in many countries revolve around the potential for assessments designed for system accountability to restrict curriculum time spent on science at the primary school level and to narrow the science curriculum at all levels of schooling to material that can readily be tested through paper-and-pencil-type tasks. In the USA and UK, there is evidence that this is limiting student opportunities to experience the practical data/knowledge generating and testing aspects of science.

At the classroom level, researchers are continuing to find that teacher instruction and assessment at the beginning, throughout and at the end of practical and inquiry tasks, are often restricted to conceptual outcomes. From their actions it seems that teachers assume that student understanding of links between concepts and theories and of science-specific ways of generating, validating, and reasoning with and representing evidence will emerge from their observations of phenomena, and so they miss opportunities for formative assessment to support students to make these connections.

Student involvement in the assessment of their progress through self-assessment is important from an assessment point of view as a means for fostering student learning capacity and autonomy. It is essential within student-directed inquiry. Additionally, student involvement in the assessment process through peer assessment is important from an assessment point of view as a source of timely and focused feedback. It is congruent with students having opportunities to engage in and gain expertise in argumentation, reasoning, and modeling as part of explaining and justifying their science ideas to others. Collaboration and critique are important aspects of how scientists work and central to many current pedagogical innovations. However, a collective focus poses a challenge for assessors once the goal moves beyond supporting learning (formative assessment) to documenting for others what science an individual knows and can do (summative assessment). This matter is one that requires further exploration given the "social turn" in understandings of learning and the strength of research evidence and wide policy recognition that all assessments should, and can, support teaching and learning in some way.

Very little attention has been paid to parents and school communities as stakeholders for assessment beyond their being an audience for information on individual student achievement or school-aggregated information. Curriculum aspirations that include students being able to continue learning science and take science-related actions in their everyday lives, coupled with proposals that community linkages can support the engagement in science of disenfranchised student groups, suggest that this is an area in need of development.

The How of Assessment of "Doing Science"

The assessment of students' doing of science is challenging and has been made more complex as the goals for science education have expanded to include student participation in inquiry, modeling, argumentation, and so on. Recognition of the situated social nature of learning and its links to the transformation of identity has added further complexity. Some of the key challenges and practices include those related to the relative merits and practicality of direct and indirect assessment of student practical/inquiry competencies, of holistic or component assessment of student inquiry capabilities, of individual or student group practices, and of the use of multiple modes and means (Harlen 1999; Hodson 1992). At the same time, research is emerging that suggests information and communication technologies; the development of learning progressions for particular topics and for inquiry practices has the potential to help policy makers, curriculum developers, and teachers meet these challenges.

Debate exists about the relative merits and practicality of direct and indirect assessment of student practical/inquiry practices, skills, and orientations (Reiss et al. 2012). With direct assessment student practical and inquiry skills are assessed by teacher observation of students as they engage in an investigative task. With indirect assessments student competency in terms of a specific or generic skill is *inferred* from their reports of the work they have undertaken or via pencil and paper test questions. Several studies have found differences in student performance in practical investigations, depending on whether a direct assessment mode or a written assessment mode is used. It has suggested that written tasks elicit evidence of what students *know* about practical work/inquiry and how it should, in principle, be undertaken rather than on their competency in terms of actually being able to *do* practical work themselves. Typically, direct assessment is advocated as it captures both the process and the product of student learning.

With regard to high-stakes summative assessment, including assessment exit qualification purposes, different countries use different combinations and forms of direct and indirect assessment. Tasks used in direct assessment can be teacher or externally designed, supervised, graded and the grades moderated, to various degrees. Often the awarding body provides a bank of tasks and of exemplars of student responses at different levels of achievement to support teacher grading. In some contexts direct assessment data is collected on one occasion; in other contexts it is collected over a range of tasks, contexts, and topics. In the UK, for example, the collection of data is loosely controlled by the teacher and can be undertaken by a group, but the analysis and communication of results are done individually under test-like conditions.

Given the influence of high-stakes assessment on curriculum and pedagogy, it might be expected that the inclusion of inquiry and practical work in high-stakes assessment would promote and enhance the teaching and learning of these aspects. In contrast, studies are emerging that indicate the tendency to train students to do investigations has had the effect of conflating the teaching, learning, and assessment of investigations. Research has identified that teachers can narrow their practice of formative assessment to ensuring students comply with criteria required for the award of external qualifications credits. It also appears that to yield good marks within the full range of possible scores, teachers tend to select investigations that they are familiar with which then restricts the pool of investigations students experience and limits their involvement in investigations they develop for themselves. The issues to do with the reliability of teacher judgments and of teachers teaching to the assessment have also been identified, raising questions about the validity and reliability of student results. A counterargument is that such teaching to an assessment is only problematic when an assessment task is limited in its expectations of students; otherwise teacher scaffolding would be seen as part of enhancing the alignment of pedagogy and assessment with desired student performances.

Outside formal summative assessment, teacher classroom assessment practices tend to span a continuum of integration with teaching and learning from more formal and planned to embedded and on the fly. Ongoing informal teacher formative assessment via interaction generates information on student learning that is generated and used in the same context to provide feedback on student learning. The use of interaction coupled with curriculum-embedded assessment tasks, including the collection of student workbooks, where the information is used formatively has been found to effectively support student learning as teachers scaffold and guide student inquiry. Although contested, there is some evidence that teachers can accumulate evidence through these means that can then be revisited to make a summative judgment about student achievement that takes account how and what they have learned.

Task design is a key aspect of instruction and assessment. Sociocultural views of learning and assessment, which are currently exerting a substantial influence in science education and assessment research, recognize the situated social and cultural nature of learning and its expression or demonstration. From this perspective, student practical work and inquiry processes and products cannot be evaluated in isolation from the context of production where this context includes the task format, topic, and other resources in the assessment setting although the extent to which these contextual and content-related elements influence student performance is still a matter of debate. There is considerable research support for the use of authentic situations and real-life contexts as part of teaching and formal assessment but student familiarity/lack of familiarity with a context and its meaning in their community and culture can be a source of bias. Suggestions to address these matters include finding contexts likely to be unfamiliar to all students and the compilation of a portfolio of student work across the range of contexts students encounter in class. Other suggestions are to use different contexts for different topics and to incorporate more contexts by assessing smaller, specific aspects of an inquiry. Counter to many of these suggestions, research has demonstrated the key contribution of content knowledge in student practical work and inquiry with little evidence of the generalizability of skills assessments across science subjects. In addition, there is some evidence suggesting that the conduct of an investigation is largely a holistic task and breaking it down into separate skills might misrepresent the essence of the process, which requires the integration of a variety of skills and ideas and thus of student capabilities. These matters of context familiarity and presentation are of particular importance when test results are used to determine students' further study or career options.

Context-based performance assessments can support students to demonstrate abilities in scientific inquiry by requiring them to interact in various social groupings and use a variety of communicative modes. However, this aspect of performance assessments can be affected by student cultural norms. For example, some communities do not socialize their children to making public displays of achievement such as those valued in schools; others place an obligation on the more knowledgeable person to share their knowledge, irrespective of their ages, while still others value the production of a high-quality physical product.

Advocates of performance assessment argue that it provides students with more flexibility and options for expressing what they know and can do and recommend it as a means for accommodating student diversity and addressing issues of equity and inclusion. However, contextualized summative tasks come with reading and representation interpretation demands for student understanding of the context and what is required of them. Students, particularly, those whose first language is not English can find it difficult to make sense of a task and express what they know quickly and easily when a written response is required. Opportunities to edit or to display their knowledge in less language-embedded tasks can be of benefit to these students as can curriculum-embedded performance assessments that are subsequently aggregated to produce a summative assessment of student learning.

Modern digital and information and communication technologies present new possibilities and new challenges for teaching, learning, and assessment through the variety of means they afford for investigating phenomena; for generating, analyzing, and representing data; for working collaboratively; and for the communication of ideas to an audience. The ability to capture student inputs permits collecting evidence of processes such as problem-solving strategy use as reflected by information accessed and selected, numbers of attempts, approximation to solutions, and time allocation. Recent developments include the trialing of adaptive testing, including knowledge and skills diagnosis, the provision of immediate feedback to teachers and students accompanied by scaffolding for improvement, and the potential for accommodations for special populations.

Technology-based simulation tasks can support students to design and conduct experiments, including them being able to quickly and efficiently pose and answer a series of "what if" questions as they change different variables. Findings can be graphed or represented in a variety of ways prior to students reaching a conclusion and writing a final response. Because simulations use multiple modalities and representations, evidence is emerging that students with diverse language and experiential backgrounds may have better opportunities to demonstrate their knowledge than are possible in text-laden print tasks. Students can use video, digital photographs, and audio to document and provide commentary on their own learning journeys.

A number of research groups are exploring the viability of web- and simulation-based units that incorporate tools for curriculum-embedded student reflection and self-assessment, teacher formative feedback and task customization, and end-of-unit summative assessment, with some groups seeking to develop systems where these final assessments have the technical quality required to be part of a state accountability system. A learning management system can generate embedded assessments for teachers and students that indicate the level of additional help students may need and classify students into groups for tailored follow-on off-line reflection activities, which further guide students to use scientific discourse. Since many new media tend to be inherently social, but most existing assessment systems are fundamentally individualized, their use introduces clear tensions and challenges making newly salient questions such as the following: Is it ever possible to gauge individual contributions to fully participatory activities? On the other hand, some scholars are arguing that eventually evidenced centered design combined with modern technologies has the potential to support "seamless" collection of multiple pieces of evidence embedded in ongoing work through an assessment system that would seem so natural students would not realize that it had even occurred.

Assessment involves the making of judgment about the status of student learning against some referent. A number of jurisdictions have developed standard-based criteria to be used to judge student acquisition of a particular level of accomplishment in the different aspects of the inquiry process. Similar criteria/rubrics are being developed to assist teachers in making decisions about and providing support for student scientific argumentation, modeling, and reasoning. Researchers with an interest in learning progressions, initially focused on content areas such as the nature of matter and evolution, are now turning to investigate the development of student competency in inquiry practices as these might be activated, developed, and expressed over a variety of contexts. To date these researchers have taken the grain size of a learning progression to be a single aspect of inquiry, such as mechanistic reasoning, modeling, and coherence seeking, while acknowledging that progress in one aspect of inquiry may be inextricably linked to progress in others. This work can be expected to have substantial implications for large-scale and classroom assessment of students doing science in terms of teacher expectations for and guidance of student learning and for student monitoring and action on their own learning progress.

Where and When to Assess the Doing of Science

The current imperative that school science prepares students to use and continue to learn science throughout their lives poses a substantial challenge to the robust assessment of students doing science. This challenge relates to how student knowledge construction, critique, and use over time and out of the classroom/school and into their future might be captured and documented. Implicitly it requires that assessment tasks, like learning tasks, have value, meaning, and traction beyond the classroom. Grounding assessment tasks in a real-life context, as discussed above, goes someway towards addressing this issue. So too do attempts to require students to show that they can apply their skills, knowledge, and understanding in "unfamiliar contexts." Other options for addressing this challenge include students demonstrating or presenting what they know and can do to an audience beyond the teacher, and sometimes beyond the rest of the class. This could involve students writing storybooks for younger children which they then read to younger students; students preparing posters or constructing local environmental impact statements which are publically displayed and/or sent to interested members of the community; a class preparing and presenting what has been learned to a school assembly to which their families are invited; or staging a mock public debate for which they collect and marshal evidence to support a point of view. In these instances students need to focus on the demands and indicators of success of real-life audiences. Optimally, students' sharing and demonstration of knowing result in learning and/or action of benefit to others. In the case of the last two examples, parents gain a more direct insight into what their child knows and is capable of. In yet other studies students have been involved in community-based projects in which, although student learning is often still assessed via conventional means, evidence of what has been learned is embedded in the class contribution to the community. Examples of this type of instruction and assessment tend to revolve around environmental issues such as water monitoring.

Concluding Comments

Assessment practices are part of a multilayered interactive system in which curriculum, pedagogy, and student and societal expectations and experiences all exert an influence. What it means to do science has expanded from a focus on practical skills to science-informed action. New pedagogical approaches in support of these goals are being developed. The challenge remains to develop assessment at all levels of the system that will complement these expanded goals and help make the learning process and what has been learned visible to learners and other interested stakeholders.

Cross-References

- ▶ Argumentation
- ▶ Assessment of Knowing and Doing Science
- ▶ Inquiry, Learning Through
- ▶ Laboratory Work, Forms of
- ▶ Laboratory Work: Learning and Assessment
- ▶ Multimodal Representations and Science Learning

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Assessment of Knowing and Doing Science

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The essential function assessment serves is the measurement of students' science knowledge and abilities at a moment in time. Data from the measurement answer the question: What do students know and what are they able to do? The simplicity of the question belies the challenges posed when interpreting data that answer the question.

What do students know? The breadth of scientific knowledge and differences in the depth to which it can be known contribute to the complexity of possible answers. The PISA 2009 Assessment Framework distinguishes two categories of science knowledge, knowing of science and knowing about science. Knowledge of science includes knowing the fundamental concepts, principles, laws, and theories of the physical, life, and Earth and space sciences. Knowledge about science includes knowing the modes of inquiry, philosophical perspectives, and history of the natural sciences. Because the development and practice of the natural sciences is closely aligned with technology and engineering, knowing of and knowing about technology and engineering are components of science knowledge included in assessment. The breadth and diversity of science knowledge contributes to the complexity of answers to the question, what do students know.

Depth of knowledge is also confounding factor. In the literature of science education, a distinction is made between just knowing something, a principle for instance, and understanding it. However, the essential characteristics on which the distinction is based are seldom described. Because depth of knowledge is weakly conceptualized, the nature of the empirical evidence from which valid conclusions regarding depth of knowledge can be made is difficult to describe. Consequently, interpretation of data describing what students know is challenged by knowing the depth to which students know it.

What are students able to do? Skills, abilities, and practices are generic terms used to answer this question. Science skills, abilities, and practices are extensive in number and related to diverse activities including the design and conduct of inquiries; the construction of science explanations and arguments, and the reasoning modes applied in the natural sciences. The breadth and diversity of science skills, abilities, and practices contributes to the complexity of answers to the question.

While claims are made that certain assessment tasks are exclusive measures of what students know and others exclusively measure what students can do, in fact, every assessment task measures both knowing and doing. Students' knowledge, skills, abilities, and practices are inferred from observations of actions or products of action. The action may be as simple as penciling in the circle next to the correct response to a factual question, such as how many bones are in the human body. Even simple tasks such as demonstrating knowledge of a fact require generic skills including reading and following directions. More challenging tasks such as writing an explanation of an observation require generic skills, science knowledge, and science-specific abilities. If the action, writing, produces an explanation that has the characteristics of a scientific explanation, we infer that the student knows the characteristics of scientific explanations and has the ability to apply that knowledge to write an explanation. The explanation is also evidence of the student's knowledge of the science principles relevant to the phenomena observed and the student's ability to apply that knowledge appropriately. Generally the appropriate application of science principles is considered evidence that the principle is understood rather than just known.

The breadth and complexity of scientific knowledge and abilities and their interaction make interpretation of data that answer the question what do students know and what are they able to do challenging. This challenge is particularly relevant when attempting to compare data from different assessments. Absent detailed information about the knowledge and abilities measured comparisons may be spurious.

Cross-References

▶ Assessment of Doing Science
▶ Assessment of Knowing Engineering and Technology and Doing Engineering and Technology: Overview
▶ Cross-Disciplinary Concepts and Principles in Science, Assessing Understanding of
▶ Inquiry, Assessment of the Ability to

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Assessment of Knowing Engineering and Technology and Doing Engineering and Technology: Overview

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Keywords

Assessment; Concepts; Engineering; Practices; Technology

A variety of meanings have been associated with the terms engineering and technology. The definitions for this entry are based on numerous documents produced by USA sets of experts. The National Academy of Engineering report, *Standards for K-12 Engineering Education?* (NAE 2010), surveyed standard documents in engineering, technology, science, and mathematics to identify common engineering concepts and skills. The National Assessment Governing Board supported the development of the *Technology and Engineering Literacy (TEL) Framework for the 2014 National Assessment of Educational Progress*. The National Research Council of the National Academies has published the *Framework for K-12 Science Education*, which, along with a draft *Next Generation Science Standards,* integrates engineering ideas and practices with those in science (NRC 2012; Achieve 2012). Definitions of engineering and technology can be culled from these frameworks and standards developed by national engineering and science organizations, as well as from standards for engineering and technology for state, national, and international assessments.

The definitions of engineering and technology are the starting points for developing assessments of understanding them. Similarly, conceptualizations of the engineering design process are the starting point for developing assessments of engineering practices that both use and produce technologies. This entry begins with a summary of prominent conceptualizations of engineering and technology and the practices of applying them. The definitions are followed by descriptions of an assessment design framework that can be used to develop and analyze assessments of engineering and technology. Descriptions of some potential types of assessment tasks and items to test understanding and application of engineering and technology are provided.

Definitions of Engineering and Technology

Engineering is defined as a systematic and iterative approach to designing objects, processes, and systems to meet human needs and wants. *Technology* is defined as any modification of the natural or designed world developed to fulfill human needs or desires. Technologies, therefore, are products and processes resulting from application of engineering design processes. Technologies also often function as tools and processes used to support engineering design. In most reports that set forth frameworks or standards for engineering, technology, and science, the three domains are described as related by their focus on systems in the real world, yet different in the roles that the disciplines play in understanding and modifying the world. Engineering and technology often apply science knowledge to meet human needs and desires.

Sources of Conceptualizations of Engineering and Technology

Standards for K-12 Engineering Education?

The purpose of the National Academy of Engineering report was to survey contemporary frameworks, standards, and practices in engineering to determine if a national set of engineering standards could be proposed (NAE 2010). The report summarized key ideas of engineering and recommended that engineering concepts and processes should be integrated into and linked with contemporary frameworks and standards in science, technology, mathematics, and other disciplines. The report identified a set of the most commonly cited core engineering concepts. The central engineering construct was "design" – understanding and doing it. Other important concepts included understanding constraints, understanding systems, and optimization. Central skills included modeling, system thinking, and analysis. In addition, the report emphasized the importance of understanding the relationship of engineering and society and the connections among engineering, technology, science, and mathematics.

Technology and Engineering Literacy (TEL) Framework for the 2014 National Assessment of Educational Progress

The TEL framework is unique in its focus on assessing the interrelationships of engineering and technology. In the framework, technology and engineering literacy is defined as the capacity to use, understand, and evaluate technology as well as to understand technological principles and strategies needed to develop solutions and achieve goals (NAGB 2010). The framework lays out three areas of technology and engineering literacy, the types of thinking and reasoning practices that students should be able to demonstrate, and the contexts in which technologies occur. Three main assessment areas are specified: Design and Systems, Information and Communication Technology, and Technology and Society. Within Design and Systems, three subareas of essential knowledge and skills are identified: nature of technology, engineering design, system thinking, and maintenance and troubleshooting.

Principles for the nature of technology expand the scope of common conceptualizations of technology beyond computers and the internet. The broader view includes every way people manipulate the natural environment to satisfy needs and wants. Therefore, technology includes all the various devices and systems that people make to fulfill some function. The framework lays out key principles for the nature of technology: (1) technology is constrained by the laws of nature; (2) scientists examine what exists in nature and engineers modify natural materials to meet human needs and wants; (3) technological development involves creative thinking; (4) technologies developed for one purpose may be adapted for other purposes; (5) science, technology, engineering, and mathematics and other disciplines are naturally supportive; (6) the pace of technological change has been increasing; and (7) tools help people to do things efficiently, accurately, and safely. The framework then lays out assessment targets for the nature of technology for grades 4, 8, and 12.

The engineering design subarea in the TEL framework is described as an iterative, systematic process for solving problems. These processes are among the practices of engineering. The process begins with stating a need or want and identifying the criteria and constraints of the challenge. Then, potential solutions are explored referencing relevant scientific and technical information. Potential solutions are compared, and models and prototypes are constructed, tested, and evaluated to see how they meet the criteria and constraints of the problem. Two additional components of Design and Systems are system thinking and maintenance and troubleshooting. System thinking is a way of thinking about devices and situations so as to better understand interactions among system components, root causes of problems, and the consequences of various solutions. Maintenance and troubleshooting is the set of methods used to prevent technological devices and systems from breaking down and to diagnose and fix them when they fail. For each of these Design and Systems components, assessment targets for grades 4, 8, and 12 are presented.

The framework also specifies components, principles, and assessment targets for grades 4, 8, and 12 for the pervasive technology area of Information and Communication Technology (ICT). ICT is presented as a separate assessment area within technology and engineering literacy because of the central place ICT plays in learning and functioning in school, the workplace, and daily living. ICT sub areas to assess include understanding and use of technologies for (1) construction and exchange of ideas and solutions, (2) information research, (3) investigation of problems, (4) acknowledgment of ideas and information, and (5) selection and use of digital tools. Assessment targets for ICT at grades 4, 8, and 12 are presented.

The assessment area of Technology and Society addresses the effects that technology has on society and on the natural world and the sort of ethical questions that arise from those effects. The area is further divided into interaction of technology and humans, effects on the natural world, effects on the world of information and knowledge, and ethics, equity, and responsibility. Assessment targets for grades 4, 8, and 12 are presented.

The TEL framework also describes three crosscutting practices: understanding technological principles, developing solutions and achieving goals, and communicating and collaborating. The framework provides numerous examples of how these practices apply to the Design and Systems, ICT, and Technology and Society areas.

Framework for K-12 Science Education and the Draft Next Generation Science Standards

The framework includes engineering and technology as they relate to applications of science (NRC 2012; Achieve 2012). Engineering is used to mean engagement in a systematic design practice to achieve solutions to particular human problems. Technology is used to include all types of human-made systems and processes. Two core engineering ideas are specified. The first is engineering design – how engineers solve problems. The second core idea is understanding the links among engineering, technology, science, and society. Engineering design is subdivided into three components: (1) defining and delimiting a problem, (2) developing possible solutions, and (3) optimizing the design solution. Links among engineering, technology, science, and society are partitioned into (1) interdependence of science, engineering, and technology and (2) the influence of engineering, technology, and science on society and the natural world. The framework describes grade band end points for each of the three components.

The framework also describes the key practices that scientists use as they investigate and build models and theories about the world and the key engineering practices that engineers use as they design and build systems. Science and engineering practices include asking questions and defining problems; developing and using models; planning and carrying out investigations; analyzing and interpreting data; using mathematics, information and computer technology, and computational thinking; constructing explanations and designing solutions; and engaging in argument from evidence. The framework describes grade band end points for these practices.

The draft *Next Generation Science Standards* provide more specific guidance for assessing engineering design that produces and uses technology. Performance expectations are presented for the engineering design components. The performance expectations integrate the engineering core ideas with cross-cutting concepts such as systems and models and cause and effect and also with science and engineering practices.

Each of the frameworks and standards described above can serve as resources for specifying the engineering and technology concepts and practices to assess. In the following section, the use of a systematic assessment design framework is presented to support the selection or development of assessments.

Assessment Design

The focus of this entry in the encyclopedia is on methods for assessing understanding of engineering and technology and the practices for applying the engineering design process and the technologies that both can support the design processes and are a result of them.

Assessment Purposes

The selection or development of assessments will depend on the purposes of the assessments and the planned interpretations of the data. An assessment may be intended to provide diagnostic feedback and be used in a formative way to allow adjustments during instruction to improve performance. Or, assessments may be intended to provide summative information about proficiency levels of knowledge and skills following courses or projects.

Formative Assessments

Assessments intended as formative feedback for students and teachers about progress on learning outcomes can be embedded throughout learning activities in extended projects. The more extended the project, the more opportunities will be available to build in ongoing assessments and to adjust instruction. Ideally, the design of both the learning activities and assessments would occur simultaneously, stimulating iterative cross-checking that the learning activities are designed to directly promote all the specified engineering and technology knowledge and practices, that systematic assessments of progress on all these targets are planned, and that provisions for scaffolding and instructional adjustments can be made.

Learning progressions may guide the sequence of assessments within learning activities and be linked to types of common misconceptions or ineffective problem-solving and inquiry strategies. Careful analyses from embedded formative assessments of the unfolding conceptual and problem-solving development planned throughout a project can allow in-depth attention to problem-solving practices ranging from design and prototyping to communication of solutions. Assessments of the particular engineering and technology knowledge and strategies can be made "just in time" as students are applying the concepts and in the process of engaging in the practices. Extended engineering projects offer opportunities to assess more knowledge and practices, more often, and in more depth.

Summative Assessment

An assessment may be intended to serve a summative purpose to report on the status of proficiency at a point in time. Summative assessments may be administered at the end of a project or course or at end points such as units or project phases. These purposes will have implications for the criteria used to select, design, or interpret assessments.

Evidence-Centered Assessment Design

A useful framework for understanding the structure and functions of assessments is evidence-centered assessment design (Mislevy et al. 2004). Evidence-centered design is intended to structure an assessment argument. The argument begins with the claim that specified knowledge or skills have been learned. Evidence to support the claim comes from the types of questions or tasks that will elicit observations and performances of the targeted knowledge or skills. Summaries of performances, typically in the form of scores to be reported and interpreted, then are used as evidence to complete the argument. Therefore, evidence-centered assessment design tightly links the targeted knowledge and skills (student model), with assessment tasks and items to elicit evidence of these targets (task models), with specifications of how the evidence will be scored and analyzed to report proficiencies (evidence model). The evidence-centered assessment design framework can be used to analyze and evaluate existing assessments of the knowledge or practices targeted or to guide the systematic development of new ones.

The essential first step will be to settle on the definitions of engineering and technology – the specific knowledge about them and practices to be tested. These knowledge and practice targets would become the first component of the student model. A second component of the student model would be the cognitive demands or levels of reasoning required. Cognitive demands could range from identifying definitions and examples of the concepts and practices to analyzing descriptions of the technology and engineering concepts and practices in a project as it unfolds to evaluating others' use of the technologies and engineering design practices.

The engineering design process creates plans for developing solutions. Solutions may be tangible artifacts or technologies, such as digital devices or farm machinery. Solutions may also be new or improved technological processes such as more efficient manufacturing procedures or pharmaceutical clinical trials. These solutions are *technologies* that have been developed to address needs in areas of the designed world such as medicine, agriculture, energy, transportation, manufacturing, and construction. ICT projects may set goals to be achieved by use of multimedia resources. Students tend to think of technology in terms of computers and digital technologies, not in terms of the artifacts and solutions engineered in the many other areas of the designed world. Students are expected to understand that there are technologies in all these areas, from pills, plows, plugs, planes, and pinions to pickup trucks. Specifications of the knowledge to be tested will need to decide what students need to understand about the engineering processes, the role of technologies in them, and the technology products. Statements of what the student needs to know and the level of reasoning for showing it will become the assessment targets of the student model.

The task model(s) for an assessment specifies the kinds of contexts, problems, and items that would elicit evidence that the students understood the engineering design and technology ideas and concepts and could use them to solve problems and achieve goals. Simple items could ask for students to identify concepts and components of an engineering design project and the technologies used and produced. Descriptions of needs addressed by an engineering project producing solutions could include questions to determine that students understood that the solutions, whether new tools or new processes, are technologies. At stages in the design process, students could respond to questions and post work samples to demonstrate that they were able to apply the design concepts and processes.

Types of embedded assessment tasks and questions can vary. Conventional question formats can be inserted to check for basic knowledge. Tasks that ask students to document their work in progress may include entries in design notebooks and periodic submissions of interim material such as sketches, prototypes, pilot test data, and presentations.

Tasks and items can be designed around scenarios presenting engineering design problems and/or ICT goals in a range of applied contexts. The overarching problem could be to select and construct engineering processes to use in attempting to solve the problem. Within tasks could be inserted questions about the appropriate supporting technological tools to use and about the resulting solution as a technological advance.

The SimScientists program at WestEd has developed simulation-based models of systems to assess understanding and use of science and engineering practices (Quellmalz et al. 2012b; http://simscientists.org). As shown in Fig. 1, a scenario was developed in which students are working to establish a sustainable research center in Antarctica. By harnessing available sunlight and wind, scientists at the station are able to generate electricity, which can be used for the electrolysis of water, which in turn results in the production of hydrogen gas. The simulation-based assessments have been designed to assess core ideas about atoms and molecules, changes in state, properties of matter, and the science practices of designing and conducting investigations. The scenario could be adapted to also assess engineering and technology by augmenting the scenario with sets of tasks about the design, testing, and troubleshooting for an energy production, conversion, and storage system that contributes to a sustainable research center.

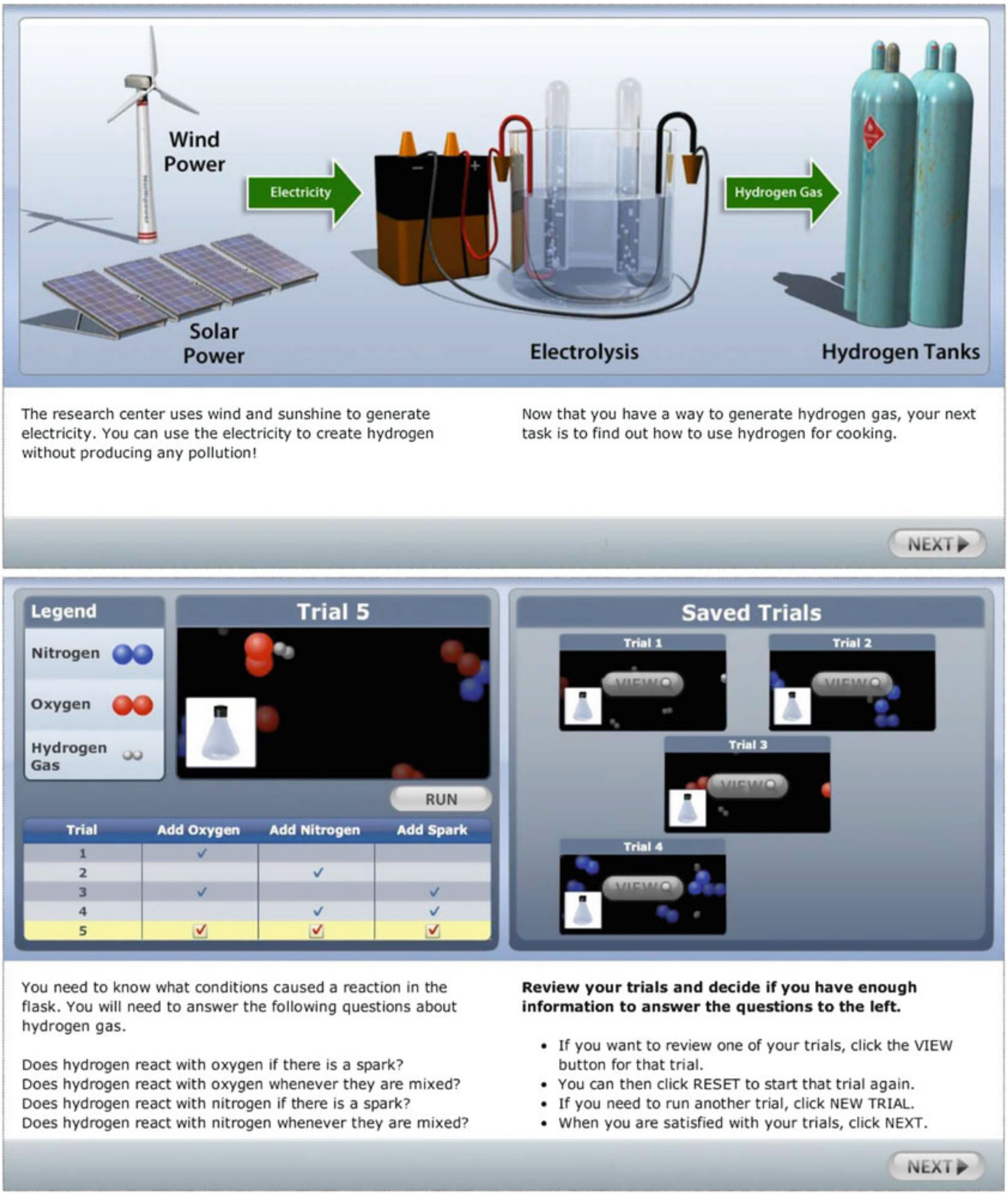
As foundational computer models of systems, natural and man-made, are developed, they can support the development of tasks to assess engineering, technology, and science concepts and practices and also to assess twenty-first-century skills such as communication and collaboration (Quellmalz et al. 2012a). For example, students could be asked to construct descriptions for the Antarctic Research Center Board for a proposed sustainable energy plan or to critique if solutions proposed by others meet the design constraints. A virtual collaborator could be queried to seek relevant information about the trade-offs of alternative sustainable energy treatments.

Final project artifacts and presentations can be used in summative assessments of specific engineering projects or performance assessment events. Rubrics for evaluation of the performances, artifacts, and exhibitions should go through standard assessment development procedures and technical quality screening for reliability and validity (AERA/APA/NCME 1999). Project-specific reports should interpret evidence on all targeted knowledge and practices. Postings of portfolios of final projects and explanations of how they meet criteria can serve as examples of successful performance.

Summative assessments of student learning should carefully align tasks and items in existing or newly developed measures with all the knowledge and practices claimed to be benefitted by prior learning activities. A custom-made summative assessment for a particular project or curriculum should provide an alignment document describing the links between the assessment tasks and items and the targeted engineering and technology standards. Studies of the technical quality (reliability and validity) of these project-specific summative assessments should be conducted and documented (AERA/APA/NCME 1999).

Design of Large-Scale, Cross-Program Summative Assessments of Engineering and Technology

Claims for the effects of multiple engineering and technology programs on learning will need to carefully align the scope of the claims to the scope of the learning outcomes. One approach is to analyze program effects on learning by examining performance on separate tests of engineering and technology. Existing large-scale assessments in the separate disciplines, such as district, state, or national tests, will only be aligned with some of the intended outcomes in one discipline, let alone in multiple disciplines. A large-scale technological literacy or science test, for example, will test a broader range of content than any one engineering or technology program would claim to affect. Moreover, problem-solving and design practices do not tend to be well measured by conventional item formats prevalent on most large-scale tests. A specific program, curriculum, or project can compare student performance on targeted



Assessment of Knowing Engineering and Technology and Doing Engineering and Technology: Overview, Fig. 1 SimScientists simulation-based assessment

standards to results of an entire math, science, engineering, or technology test, or to subsets of items within each test that are directly aligned with the targeted knowledge and practices. The more closely aligned program-specific engineering and technology targets are with subsets of items within a large-scale science, engineering, or technology test, the more likely program effects will be detected by analyses of performance on these aligned item clusters.

Preferably, large-scale, summative assessments would be especially designed to measure engineering and technology learning within applied problems and contexts. Scenario-based assessment tasks could set up relevant, applied, real-world challenges. For instance, students could be asked to address design problems related to the use of wind turbines in an urban area. Task and question sets related to the scenarios would tap key concepts and practices for engineering and technology. Students could be asked to design a study about amounts of wind or sunlight in different areas of the city, to compare the benefits of alternative wind turbine designs, to evaluate environmental effects such as dangers to birds, and to then analyze and report the data.

The evidence model for an assessment would involve determining what kind of scoring and reporting would convey that the student understands the engineering and technology conceptual targets and their application in applied problems. Scoring rubrics are commonly developed to evaluate these variable and open-ended performances and artifacts. The rubrics for specific assignments should derive from more broadly accepted criteria in the field for the quality of work as indicated by its appropriateness, breadth, and depth. The challenge is to develop criteria that relate to general quality features, but that can be clearly applied to the specific project's problem. The rubrics should be usable by students as well as teachers. Practice using the rubrics and checking that multiple users apply them consistently are fundamental elements of sound assessment practice. Moreover, in a balanced assessment system, criteria for rubrics for classroom-level, project-specific activities would be criteria also applied in summative performance assessments. Therefore, criteria would apply to effective use of engineering and technology concepts and practices, rather than to unique information about the design of a bus or an airplane wing. Monitoring and recording formative progress assessments is recommended for comparing project-specific performance on assessment targets to performance on summative measures. Specific reports about the conceptual and practice assessment targets would be needed.

The assessment selection or development process can use the framework of evidence-centered assessment design framework to guide analyses of existing tasks and items or to guide the development of new, appropriate tasks and items. The framework would ask if the knowledge to be tested and practices are clearly specified (student model) and if the tasks and items will provide evidence of conceptual understanding and application, perhaps in a range of applied areas such as ICT, agriculture, medicine, and manufacturing (task model). The framework would also ask if the scoring and reporting clearly allowed decisions to be made about whether the understanding of the targeted concepts of engineering and technology and the use of the practices are sufficiently strong (evidence model). The decisions could then be used as formative assessments that would diagnostically inform further instruction or as summative assessments to support a proficiency report. The key to sound assessment is that the assessment argument is clear and supported.

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Assessment Specifications

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Keywords

Assessment specifications; NAEP; PISA; TIMSS

Assessment specifications refer to the design of a plan that is used to develop the assessment indicating the main features to be covered. They identify the topics and skills to be tested and the emphasis given to each category. Also, they document the student population to be assessed, test booklets' design, question types, constructed-responses scoring, and achievement reporting and provide samples of items. The released examples from previous cycles are offered to illustrate how the learning acquisitions are measured and also to present a range of response formats and coding and scoring features. The role of the specifications is to provide a foundation of terms, processes, and procedures so that all involved with the development or consumption of assessment results may operate from a common understanding. They represent the first step to take for constructing the assessment being continually reviewed and modified to reflect the current state of knowledge.

For example, Programme for International Student Assessment (PISA) 2009 is administered to 15-year-olds. The specifications include information about the tested domains in that cycle – reading is the major domain and mathematics and science are minor domains. For the paper-based assessment, there are 37 reading units comprising 131 cognitive items, 18 mathematics units with a total of 34 items, and 18 science units with 53 items. The item formats are either selected response multiple choice or constructed response. The items are organized in units around a common stimulus – passage text, table, graph, or diagram setting out a real-life situation. Items have to be developed with respect to the major framework variables defined for each tested domain – text type variable, text format variable, situation variable, and aspect variable (for the reading domain); competency and content category (mathematics domain); and competency and knowledge type (science domain) – and have to represent a wide range of difficulties. Their distribution across categories is also provided. The items are allocated to 13 clusters (seven reading clusters, three mathematics clusters, and three science clusters). The items are assembled in 13 standard test booklets; each booklet is composed of four clusters according to a rotated test design, each cluster representing 30 min of testing time. Each student is randomly assigned 1 of the 13 booklets administered in each country. Student responses in all participating countries and economies are scored following certain procedures. The coding scheme is developed to enable markers to code the student responses in a consistent and reliable manner. Codes are applied to test items, either automatically capturing the alternative chosen by the student for a multiple-choice item or by an expert judge selecting a code that best describes the response given by a student to an item that requires a constructed response. The dichotomous scoring provides full credit or no credit. Partial-credit scoring is used for some of the more complex constructed-response items. Such items scored polytomously receive full-credit score, one or more partial-credit scores, or no-credit score. The code, of either type, is then converted to a score for the item. The students' scores are represented on a common achievement scale using item response theory methods that provide an overall picture of the assessment results for each country (OECD 2012).

Trends in International Mathematics and Science Study (TIMSS) assesses the mathematics and science achievement of students in their fourth and eighth years of formal schooling. The assessment specifications identify the content and cognitive domains for the TIMSS fourth- and eighth-grade assessments and their percentages in the testing time for both mathematics and science. The entire assessment pool of items at each grade level is packed into a set of 14 achievement booklets, each item appearing in two booklets. There are 28 item blocks: 14 mathematics blocks and 14 science blocks. Each block groups approximately 10–14 items at the fourth grade and 12–18 items at the eighth grade. The assessment time is established to 72 min for fourth grade and 90 min for eighth grade. Two-item formats are employed: multiple choice and constructed response. The format that best enables students to demonstrate their proficiency determines the choice of item format. The students' responses at constructed-response items are scored using the scoring guide. In the scoring guide the essential features of appropriate and complete responses are described. The focus is on evidence of the type of the cognitive process the question assesses. Each descriptor is accompanied by examples of partially correct and fully correct responses and incorrect answers. Each multiple-choice question is worth one score point. Constructed-response questions are generally worth one or two score points. Reporting scales are available for each content and cognitive domain in mathematics and science at each grade level (Mullis et al. 2009).

Cross-References

▶ Assessment: An Overview
▶ National Assessment of Educational Progress (NAEP)
▶ Programme for International Student Assessment (PISA)
▶ Scale Scores
▶ Third International Mathematics and Science Study (TIMSS)

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Assessment to Inform Science Education

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Keywords

Accountability; Data-driven decision making; Formative assessment; Proximal formative assessment; Summative assessment; Validity

Assessment in science education, like other disciplines, is evolving into measures designed so that they can be used to inform instruction and learning, not be used just for accountability purposes. It is essential that instruction and assessment be linked and form a feedback loop in which assessment results inform instructional decisions, but the assessments must be closely aligned to the instructional objectives in order for this to happen. The tighter the feedback loop, the more instructionally relevant the data become. The longer the delay, the less useful the data will be for instructional purposes. For example, state accountability testing often occurs in the spring and results are delivered to educators for the following academic year. There are two major issues here. First the test may not be sufficiently aligned to the educational objectives. Second, the duration between testing and delivery of the results may render the data less than useful. Such data are referred to as autopsy or dead-on-arrival data. What may differ for science, as opposed to content areas such as English language arts and mathematics, is that science is not always tested for state accountability purposes. There still may be summative science assessments, but just not for high-stakes purposes.

Another issue centers around the issue of validity. Validity is often seen as a property of the assessment; that is, does the assessment measure what it purports to measure? Another view is that validity resides in the interpretation made on the results. Assessments used for accountability may be designed to provide an estimate of how well students have mastered a particular content area, such as biology or chemistry, but they may not be designed in a manner that can provide teachers with the grain size of data that can inform instruction. Such tests may provide total test scores or subscores but may not allow teachers to drill down to specific content or even items to enable diagnoses of learning deficits. Thus, these tests may be valid as summative measures, but less valid for instructional purposes.

A trend that has gained traction centers around formative assessment. Whereas summative assessments are seen as measuring the culmination of learning on a specific unit, topic, or course, formative assessments are seen as more closely tied to instruction, helping teachers to understand students' learning strengths and weaknesses so that further instructional steps can be identified (see Black and Wiliam 1998; Bennett 2011). Stiggins (2005) differentiates between assessments *for* learning and assessments *of* learning. Assessments *of* learning are seen as summative indicators of what students have learned and are typically used for accountability purposes, whereas assessments *for* learning provide indications of what students have learned or not learned so that the information can help to drive instruction. These assessments have different purposes, and therefore different kinds of interpretations can be made from them. The most instructionally valid measures are assessments *for* learning. Formative assessment is a process, not just a measure (Bennett 2011). They are designed to be used by teachers to directly inform their instructional practice. The feedback loop between instruction and assessment is tight. Assessment is conducted in real time. Erickson (2005) refers to this as "proximal" formative assessment.

A major threat to the use of formative assessments, as Erickson (2005) notes, is whether teachers know how to interpret the results and link them to "pedagogical moves." This is what Mandinach (2012) refers to as pedagogical data literacy and what Means et al. (2011) call instructional decision making. A key skill for teachers is their ability to take data from an assessment, classroom activity, or project, understand what the students know and don't know, and then transform those data into actionable instructional steps. This skill is one that is not well addressed in typical professional development around data-driven decision making (Mandinach and Gummer 2012). It may, however, be a component of training around formative assessments. Thus, for science and other disciplines, assessments to inform instruction rely not only on test design, but also on the duration of the instructional/assessment feedback loop and teachers' ability to interpret the data in ways that allow them to transform the results into actionable instructional knowledge.

Cross-References

▶ Evidence-Based Practice in Science Education
▶ Evidence-Informed Practice in Science Education
▶ Formative Assessment
▶ Test
▶ Validity and Reliability of Science Assessments

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Assessment: An Overview

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Assessment involves the collection of information to be used in making decisions. Some assessment information is used to describe the status quo, some to measure change, and some to make comparisons. Ultimately, however, the information is applied to making decisions. The decisions range from those having immediate effects on individual students to those having long-term effects on all of a nation's students or on large populations of students within a nation. Few if any of the decisions are made on the basis of information alone. Philosophical, political, economic, and theoretical factors influence decisions and may override the information relevant to making the decision.

The importance of data in making educational decisions has global dimensions and is characterized by ever-increasing expenditures by nations on the design and implementation of **assessment systems**. At the classroom level there has been an increase in professional development for teachers to develop their abilities to design classroom measures that yield information, enabling them to make good instructional decisions and to use data from external assessment to facilitate their educational decision making.

Information/data is collected by individuals (students, teachers, principals, and administrators), by agencies with jurisdiction over a country, by agencies with jurisdictions over segments of a country, and by independent organizations formed by cooperative agreements among nations. Examples of independent organizations responsible for cross-national assessment are the International Association for the Evaluation of Educational Achievement (**IEA**) which oversees the design and implementation of **TIMSS** (Trends in International Mathematics and Science Study) and the Organization for Economic Co-operation and Development (**OECD**) which oversees the design and implementation of **PISA** (**Programme for International Student Assessment**).

The information/data from assessments is used to make many different kinds of decisions. The information that may have the most profound impact on student learning is that gathered by students as they either consciously or intuitively become aware of their own knowledge and abilities and how these match with the expectations of their science teachers and parents. Helping students systematize their **self-assessment** abilities is a goal of science education. Information/data collected by teachers is used to make instructional, grading, and promotion decisions. **Formative assessment** is used to describe information collection and analysis resulting in information used by teachers to make decisions regarding instructional practices related to materials and pedagogical strategies for their classes and for meeting the particular instructional needs of individual students. **Summative assessment** is used to describe the collection of information to be used to grade students and to make decisions regarding promotion.

Instructional, grading, and promotion decisions are based not only on information collected by teachers. Data from external assessments administered by countries and regions within countries are sometimes used to evaluate the effectiveness of educational materials and strategies, to determine grades, promotion, and future educational opportunities for students. (Insert examples here for several counties.)

Data/information about student performance from regional or country-wide assessments is sometimes used to make decisions regarding teacher compensation and placement in schools.

Data from assessments tracking performance over time or comparing the performance of students in different countries or regions often stimulate and inform policy development at the country or regional level. The United States' National Assessment of Educational Progress (**NAEP**) is an example of a nationally mandated assessment that influences educational policy at the national level. Examples of country wide science assessments include the German Abitur, the Israeli Bagrut, and New Zealand's National Education Monitoring Project (NEMP).

The posited relationship between the strength of a country's education system and that country's economic strength is the origin of interest in cross-national assessment activity and educational policy development aimed at preparation for the workplace and higher education. Comparisons of student performance on national assessments with performance on TIMSS and PISA are highly influential in national policy discussion. Consequently student performance on these assessments is **high stakes**.

Typically, the information collected by teachers describes that which students know about science and those science-related abilities that students are able to perform. This knowledge and these abilities are closely aligned with the objectives of the science curriculum students are experiencing. **Larger-scale** assessments collect more extensive information including information about students' science knowledge, abilities, and **attitudes** toward science, as well as background information about students (gender, socioeconomic status), science teachers (years of experience, academic preparation, favored instructional strategies), and opportunity to learn science (per-pupil expenditures, science instructional materials, science laboratory facilities, and Internet and computer access).

Science knowledge and abilities have many components. Among the topics students are expected to know about or to understand are scientific theories, principles, and concepts; cross-disciplinary principles and concepts; the nature of science; the history of science; the interrelationships of science, technology, and engineering; and the interactions of science and society. Among the abilities students are expected to develop are **inquiry** (**enquiry**), **communicating science ideas** (**explanation**, **argumentation**), and **self-evaluation**. Not all components of science knowledge or all abilities (skills) are assessed on all large-scale assessments. Some components, attitude toward science, for instance, are included in the main assessment of some assessments (PISA, for instance) and in the background information of others (NAEP, for instance).

Large-scale assessments are challenging to design. Typically a consensus process is engaged to determine the science content that will be assessed and background information that will be collected. The results of the consensus process are presented in a document, often referred to as the **assessment framework**. Either in the framework or in a separate **specifications document**, details of the assessment are described. The specifications include the relative emphasis the different components of science knowledge and understanding will receive, the kinds of items (selected and constructed response items, hands-on) that will be used, and the content of the background material that will be surveyed.

Time is a major constraint on the translation of the framework and specifications into the operational assessment. The student time available for responding to assessment tasks and teacher/administrator time available to respond to background questions is limited, constraining the breadth of content and background information that can be measured.

Including students with special needs and language learners is a challenge to ensuring that an assessment adequately samples the population of interest. Extensive testing in **cognitive laboratories** of assessment tasks to determine the **cognitive demands** of the tasks and language characteristics that make items difficult to understand is an essential part of the development of assessment instruments. Providing **testing accommodations** and **adaptive testing strategies** are approaches to implementation of the assessment to ensure that special needs and language are not preventing students from demonstrating their science knowledge and abilities.

Reporting the results of large-scale assessments is challenging involving the definition of various levels of student performance (**achievement levels**) and showing the relationship of the achievement levels to the tasks which students performing at each level successfully perform. Task performance is typically translated statistically to **scale scores** and achievement levels defined by locations on the scale (**cut scores**).

The quality and relevance of assessment information to possible decisions is a central issue in the decision-making process. In large-scale assessments statistical considerations influence the quality of the data. The characteristics of the population sampled, sample size, constructs measured, the way in which constructs are measured, instrument administration, methods of data reduction, and analysis ultimately determine the statistical quality (**validity and reliability**) of data collected no matter the decision under consideration.

In addition to statistical quality, the match of the constructs measured to the decisions under consideration determines the relevance of the information (data). If, for instance, the decision is to choose which of two science curricula to implement, data comparing differences in students' scores on a standardized mathematics assessment is poorly matched to the decision under consideration. Ultimately, evaluation of the quality of assessment information/data and its use in decision making requires consideration of the question: does the quality of the information warrant the decision made?

Cross-References

- ▶ Assessment of Doing Science
- ▶ Assessment of Knowing and Doing Science
- ▶ Assessment of Knowing Engineering and Technology and Doing Engineering and Technology: Overview
- ▶ Formative Assessment
- ▶ Large-Scale Assessment
- ▶ Programme for International Student Assessment (PISA)
- ▶ Scale Scores
- ▶ Student Peer Assessment
- ▶ Student Self-Assessment
- ▶ Summative Assessment
- ▶ Third International Mathematics and Science Study (TIMSS)
- ▶ Validity and Reliability of Science Assessments

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Assessment: PISA Science

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Keywords

Measures

The assessment of the science component of the OECD's PISA project introduced a radically new intention for the assessment of science learning and operationalized this with a novel instrument that included item types that had not previously been used in such large-scale testing, either nationally or internationally.

The OECD's commission for the PISA project in 1998 was to provide information to participating countries about how well prepared their 15-year-old students were for twenty-first-century life in the domains of reading, mathematics, and science – an unusually prospective brief for the assessment of learning. Fifteen-year-old students were chosen because in a number of countries, it is the age when compulsory study of science and mathematics can cease.

This commission required PISA Science to be not another retrospective assessment of students' science learning, as is customary at the levels of classroom, school, regional, national, and international assessments (like those used by the IEA in its ongoing TIMSS project). Such testing is closely tied to the intended curriculum for science and can be used to indicate a student's readiness to progress to the next level of schooling or to further study of the sciences beyond schooling in universities or other tertiary institutions.

Future preparedness for life in society as an assessment intention was quite unknown in 1998 among the OECD countries. There were, thus, no existing models for such testing, and the one had to be developed that would lead to measures of the students' capability to apply their science knowledge to twenty-first-century contexts involving science and technology (S&T).

This innovative intention to measure preparedness was applauded and endorsed by the member countries of the OECD, but there was widespread skepticism about what would be found by such a study, since the application of science knowledge in unfamiliar contexts was not something that existing science education in schools was emphasizing. It was encouraging that the students in many countries performed well on the tests although there was clear scope for improvement in all cases.

Future Preparedness as a Goal for Science Learning

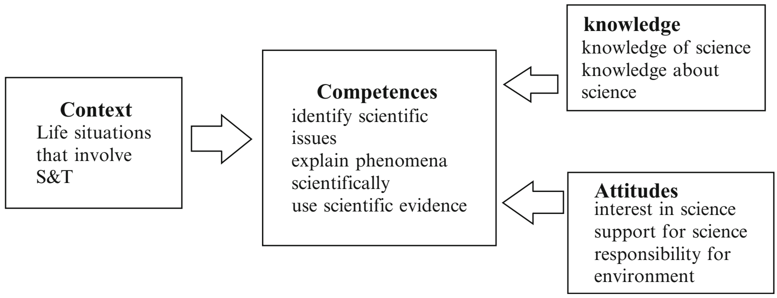
It is quite common to find the science content knowledge for teaching and learning listed in a curriculum's statement under a dual heading of knowledge and understanding. It is as if these two words are synonymous, since there is usually no explanation that they may be intended to refer to different learning of the same content from shallow recall to deeper application.

When this difference was made explicit, the countries interested in PISA Science suggested that it would primarily measure how well their students can apply the science knowledge they have learned to novel S&T contexts and hence go beyond the simple recall and application of the science as it is taught or presented in textbooks.

The organization of PISA meant that science was a minor domain in PISA 2000 and 2003, so that the Science Expert Group had the opportunity to explore several approaches to its task before settling on a framework that would deliver a defined goal for student achievement in 2006 when science was the major domain. The framework is presented in Fig. 1.

The goal was a measure of students' scientific literacy defined as an individual's:

- Scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomena, and to draw evidence-based conclusions about science-related issues



Assessment: PISA Science, Fig. 1 Framework for PISA Science 2006 (from OECD 2007)

- Understanding of the characteristic features of science as a form of human knowledge and inquiry
- Awareness of how technology shapes our material, intellectual, and cultural environments
- Willingness to engage in science-related issues with science as a reflective citizen (OECD 2000)

With this definition, PISA Science was firmly committed to what Roberts (2007) was to describe as a Vision II approach to science knowledge, that is, one that looks outward to science and technology (S&T) in the everyday real world rather than inward to the sciences as specialized disciplines (Vision I).

The scientific literacy definition was differentiated as three cognitive and three affective scientific competences – identifying scientific issues, explaining phenomena scientifically, and using scientific evidence and interest in science, support for science, and responsibility toward resources and environments. The more specifically described competences were then the guides for the design of test units consisting of an S&T context about which several items could be asked relating to these competences. A fuller description of this use of science contexts in assessment and some of its shortcomings are discussed in Bybee et al. (2009).

The Mode of Assessment

The use by PISA Science of a paper and pencil mode of assessment has both positive and negative outcomes for science education. This mode made the testings, in general, a familiar activity to many (but not all) of the countries' students. Since PISA Science was not bound by a curriculum sense of science, PISA could use fewer simple multiple-choice items and hence more of more valid types of item, complex multiple choice, and free response. The inclusion of the range of item types in the projects should encourage countries and their schools to also use a wider range of assessment items since the more precise and open ones can then offer diagnostic as well as formative indications of student learning.

The development of the achievement tests for PISA Science (and for TIMSS) has involved procedures to ensure validity and reliability that go beyond those used in most countries. They include extensive face validity of the items among panels of experts, linguistic and cultural analyses for bias, and statistical analysis of extensive trials with student samples in several countries to establish each item's discriminating power (for PISA see McCrae 2009). These thorough approaches to test development now stand as exemplary models for the development of similarly intended assessment instruments at a national, regional, or local level of education, where extra-school tests and even fewer of the intraschool tests set by science teachers have such good item design.

Difficulty Level of Items

Retrospectively, the very large number of responses to its items enabled six levels of difficulty to be identified. The cognitive demand in the items of any of these levels was then described leading to quite new understanding of this feature of science learning that provides an indication of these depth dimensions for science learning that can have diagnostic usefulness for teachers when teaching an associated topic (OECD 2007).

Assessment of Affect About Science

In the years since PISA began, there has been an accelerating stream of reports from international and national studies that indicate a decline in student interest in science and in science careers, particularly across the more developed countries. As in its approach to cognitive science learning, PISA Science broke new ground in associating interest in, support for science, and responsibility for the environment to the specifics of the science content and context as well as with a more generic measure of the first two. Thus, affective items were embedded in the contextual units as well as being asked in the student questionnaire.

The embedding of affective along with cognitive items in the main assessment test was a major innovation and contribution to science education in two ways. Firstly, it signaled very clearly that both types of learning were natural expectations from compulsory school science. Secondly, the embedding meant that students could respond positively to the specific science in one contextual unit and negatively to what underlay another contextual unit. A much richer portrayal of their affect resulted. This approach to affective responses to science is discussed in detail (see Olsen et al. 2011).

A negative aspect of PISA Science lay in its use of the paper and pencil mode, since there are now a number of commonly agreed curriculum goals for school science education that are not amenable to this mode of testing. The classic and abiding example of these is the assessment of practical performance in science, but now decision making about socio-scientific issues, context-based science, and science project work in and outside school can be added as not amenable to this mode of testing (see Fensham and Rennie 2013). The OECD's and PISA's silence on this point can be interpreted as suggesting they are not of worth.

Another unfortunate practice in these large-scale projects is that they release only a small fraction of the items from any one testing so that their elegance as scales is never publicly evident. By now however, enough items have been released for them to be used as reliable "item banks" for the types of science learning that PISA Science intends.

Cross-References

- ▶ Accommodation in Assessment
- ▶ Interests in Science
- ▶ Programme for International Student Assessment (PISA)
- ▶ Validity and Reliability of Science Assessments

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Assimilation

▶ Piagetian Theory

Attained Curriculum

► Curriculum

Attitude Differences and Gender

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Attitude Differences and Gender in Science Education

In US secondary and postsecondary schools, it is common to hear talented female students telling their peers that they are "not a [math/science] person," even if their grades in these subjects suggest otherwise. Girls seem to develop this idea at a young age. Analyses of national data on US youth indicate that there are no notable gender differences in whether students "like science" in fourth grade, but differences emerge in eighth grade and grow stronger by 12th grade: 56 % of boys like science as compared with only 48 % of girls. This data shows that girls also have a greater tendency to report that they are not "good" at science (Bae et al. 2000, pp. 52–54). Fourth grade girls report being more likely to persist in science even if given a choice and less likely to consider science a "hard" subject, but this pattern is flipped by 12th grade, when 36 % of girls say they would not take more science (as compared to 30 % of boys) and 56 % say science is hard (as compared to 44 % of boys).

Studies suggest that gendered differences in attitudes toward science develop early, shaping female and male students' pathways from early exposure to science through their choice of career. Parents and teachers play a role in shaping children's gendered attitudes about science. When gender is salient in the classroom, preschool children appear to display preference for same-sex peers and exhibit behavior more closely in line with gender stereotypes (Hilliard and Liben 2010). When young people internalize the gendered messages they receive about certain career fields (e.g., science careers), they may steer away from areas in which they perceive that they are not expected to do well. Studies suggest that this pattern is heightened among the most mathematically and scientifically talented girls, representing a critical pool of potential "lost" scientific talent. These girls may consider their female identity to be mutually exclusive with a scientific identity. They may also be less likely to believe that they are indeed scientifically talented. Evidence suggests that girls develop lower assessments of their mathematical and scientific ability – irrespective of their observed ability – as compared to otherwise similar boys. These culturally influenced attitudes help to explain females' higher rate of selection out of the pipeline to scientific careers. Biased attitudes about gender and science tend to be implicit, but nevertheless can shape behavior – including engagement and achievement (Nosek and Smyth 2011).

These biased attitudes have important effects on the available labor pool of scientists. Even though girls and boys who choose postsecondary specializations in the physical sciences, engineering, mathematics, and computer science have similar profiles, overall girls seem more likely to choose postsecondary majors in male-dominated fields like biology, clinical and health sciences, and the social and behavioral sciences, even when controlling for ability (Perez-Felkner et al. 2012). Males remain more likely to complete doctoral degrees in these scientific fields than females, across all racial-ethnic groups. The persistence of this trend is perhaps even more puzzling considering recent and mounting evidence that women are outpacing men in educational attainment, an emerging global phenomenon. Importantly, promising research shows that enrolling introductory physics undergraduates in short values-affirming writing assignments narrows the gender gap in course performance (Miyake et al. 2010). In conjunction with related research on the negative effects of salient gender stereotypes on female students' performance on scientific tasks, these findings suggest that policy interventions aimed at affirming young women's place in the sciences might mitigate the negative effects of persistent culturally influenced attitudes to the contrary.

Cross-References

► Achievement Differences and Gender
► Attitudes, Gender-Related
► Careers and Gender
► Gender
► Gender-Inclusive Practices
► Socio-Cultural Perspectives and Characteristics

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Attitudes to Science and to Learning Science

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Introduction

The study of school students' attitudes towards science and learning science has been a prominent feature of science education for 40–50 years. Concerns about declining attitudes have led to many studies of the possible influences on students' attitudes and of strategies that can be undertaken to improve attitudes.

The entry draws on five selected major review articles to demonstrate key findings from a range of studies and to explore the field for future reference. The first of these, by Osborne et al. (2003), sets out the main issues arising from an extensive review of the literature up to 2003. The authors explore what is meant by attitudes towards science, provide an overview of how attitudes have been measured, and discuss findings about the influences of gender and environment (including teaching) on attitudes and what is known about the relationship between attitudes and achievement. The second article by Barmby et al. (2008) provides additional analysis of and references to attitude studies, with specific commentary on a range of similar issues arising from their own research.

More recently, with reference to the Programme for International Student Assessment (PISA), where students' interest was a component of scientific literacy, the focus in reviews by Christidou (2011) and Krapp and Prenzel (2011) has shifted towards studies of students' interest in science. The relationship between attitudes and interest is explored from analyses presented in these two articles, together with further insights into the measurement of students' interest. Additional to this focus on interest, the work of Swarat et al. (2012) presents a more detailed investigation into students' interest in school science that could enhance our understanding of how school science can serve to influence students' attitudes.

Attitudes Towards Science: What Do We Mean?

Osborne et al. point out that there has been a lack of clarity of meaning with respect to attitudes. These authors draw on earlier work to make a distinction between attitudes towards science and scientific attitudes; the latter being "a complex mixture of the longing to know and understand, a questioning approach to all statements, a search for data and their meaning, a demand for verification, a respect for logic, a consideration of premises and a consideration of consequences. . .these are the features that might be said to characterize scientific thinking" (p. 1053). Attitudes towards science on the other hand are the "feelings, beliefs and values held about an object that might be the enterprise of science, school science, the impact of science on society or scientists themselves" (p. 1053).

Osborne et al. draw attention to the complexity of attitudes and the many constructs that can comprise attitudes. They also focus on the relationship between attitude, intention, and behavior, with reference to the theory of reasoned action developed by Ajzen and Fishbein in the 1970s, which is concerned with predicting behavior. As Osborne et al. report, this theory has been applied to a range of attitude and behavior studies in science education, some of which demonstrate how attitudes towards school science (as distinct from science in society) influence choice to study science. A further, more precise, definition of attitudes is used by Barmby et al. who recognize three components of attitudes as cognition, affect, and behavior – "a person has knowledge and beliefs about objects that give rise to feelings about them, and these two components together may lead a person to take certain actions" (p. 1078). This definition of attitude is similar to that of student engagement as used in many other studies of student affect in science.

The more recent focus on interest raises the question of what "interest" means in relation to "attitude." Whereas Osborne et al. refer to interest as a form of attitude, Krapp and Prenzel draw attention to a distinction between attitude and interest, suggesting that a difference arises with respect to the evaluation criteria that are the focus: "general, nonpersonal evaluation viewpoints are decisive for an attitude to a particular object, whereas the subjective value attached to the knowledge about this object is important for interest" (p. 31). Thus, one can have a negative attitude towards something yet be interested to know more about it. The focus on interest in science and school science has contributed to our understanding of how attitudes may be shaped by both personal and environmental characteristics. Krapp and Prenzel draw on previous work in making a distinction between individual interest and situational interest, the overall notion of "being interested" coming from both personal motivation and also the conditions of a learning situation (interestingness).

Measurement of Attitudes and Interest

Many instruments have been devised to measure attitudes towards school science, and both quantitative and qualitative methods have been used in attitude studies. Osborne et al. review subject preference studies that include the use of surveys that require students to rank subjects and also focus group studies that explore views in more depth. Most common, however, is the use of questionnaires that consist of Likert scale items where students are asked to agree/disagree with various statements such as "science is fun"; "I would enjoy being a scientist" (p. 1057). Most scales use a five-point range – strongly agree/agree/not sure/disagree/strongly disagree – and include a set of items designed to cover a range of constructs and which have been piloted to test for reliability. A number of examples are included in Osborne et al.'s review. These authors caution that scales that include items covering a range of different attitude constructs cannot lead to a single attitude score, as this would be meaningless. Examples of qualitative studies in Osborne et al.'s review point to their value in providing insights into the origins of attitudes to school science.

Barmby et al. measure clearly defined attitude constructs in their study using a questionnaire, and these include "learning science in school; practical work in science; science outside of school; importance of science; self-concept in science; future participation in science" (p. 1077). The reliability values and factor analyses confirmed that the three factors of learning science in school, science outside of school, and future participation in science could be brought together to provide a combined "interest in science" measure.

In their review, Krapp and Prenzel point out that more domain-specific interest measures are less frequently used. They discuss at length the issues pertaining to domain-specific interest measures and describe an example of a differentiated instrument used for a study in physics, which included three dimensions: topics, contexts, and activities – within which were eight topic categories, seven context areas, and four kinds of activity, in all, 88 items. Factor analysis could then determine the construct of "interest in physics." This kind of breakdown of what the interest is about can enrich studies that look at specific subjects/domains of science and environmental factors. Krapp and Prenzel review other research approaches for studying interest, including observations, interviews, and databanks available on the Internet.

Attitudes in Relation to Various Factors

This section provides an overview of the findings reported in the five articles that focus on key issues relating to students' attitudes towards and interest in science and school science. Where it exists, a distinction is made between findings that relate to science, as opposed to school science or learning science.

Age

Osborne et al. report on a range of studies that show a decline in attitudes towards science in early adolescence, in some cases even earlier. A more detailed analysis of studies does highlight a distinction between attitudes towards science and attitudes towards school science, as many 15-year-olds have positive attitudes towards science, finding it interesting, useful, and relevant, particularly in relation to technological advances, whereas school science is seen as rooted in past discoveries. Barmby et al. found a steep decline in attitudes towards learning science between students aged 11 and 13. Qualitative evidence showed that reasons for this decline in attitudes included lack of practical or lab work, weak explanations, and the perception that school science is not relevant. Krapp and Prenzel question the theoretical and practical relevance of how these trends are measured and judged, as they do not provide an insight into interest development in specific subgroups or subjects. These authors call for a more exact analysis of data from longitudinal studies. They report on one such study in physics that demonstrated that when physics is taught so that students can recognize a direct connection to practical life situations, then interest remains stable or increases.

Science Subject/Domain

Students' attitudes to school science can vary according to subject (Osborne et al.); some findings indicate that biology is perceived as more relevant as it addresses students' interests in their own bodies and health and disease, whereas the physical sciences are seen as less relevant, particularly chemistry, with topics such as the Periodic Table, the Haber process, and the Blast furnace being seen as least relevant. Osborne et al. also report on subject preference studies that show chemistry to be less appealing than physics. Many studies show gender differences in attitude towards different subjects and topics; Christidou reports that physics is the least attractive discipline for girls, who tend to be more attracted to studying animals and health or aesthetic topics. Swarat et al. report on research that shows the interest of younger students to focus on biology, technology, and astrophysics. Their research with students in the sixth and seventh grades shows that activities or topics based on technology or the human body are significant predictors of overall interest in science.

Gender

Research undertaken between 1970 and 1990 demonstrated that boys had more positive attitudes to school science than girls (Osborne et al.). Analysis of reasons indicated a range of possibilities from the early childhood experiences of boys playing with more scientific toys to perceptions of difficulty of the subject – girls believing themselves to be better at other subjects. Studies undertaken after 1990 provide evidence that girls believe themselves able to follow careers in science, even though they are less likely than boys to do so. However, gender influences are complex, as personal attributes such as self-concept and self-efficacy are operating with environmental effects such as single-sex schools or style of teaching. Krapp and Prenzel highlight the importance that such attributes play in explaining gender-specific differences in interest in science.

As Barmby et al. report, more recent studies have shown that the factor "who students want to be" has more prominence than previously and they conclude that attitudes are influenced by the current social contexts in which they are conducted. They also report that differences between boys' and girls' attitudes towards science outside school increase markedly with age, the difference being quite small at age 11 and more marked at age 13–14 years. Decline in attitudes to learning science in school occurs with both boys and girls but is still more pronounced with girls. With reference to international studies, Krapp and Prenzel report that differences between boys' and girls' interest in future careers in science are now only small. Moreover overall interest is more markedly different between less industrialized countries (where interest is higher for both males and females) and countries with advanced technological development.

Christidou focuses more specifically on students' images of science and scientists that reveal gender stereotypes regarding professions perceived as scientific. Girls more than boys see science as "competitive, impersonal, abstract, rule-founded, certainty-bounded, deprived of imagination and as a product of individual effort made exclusively by male scientists" (p. 144). Though her review of studies also suggests that boys are more interested in science than girls, particularly in relation to some subjects (see above), she has found convergence in male and female interest in topics related to human biology, plants and animals, light and sound, and astronomy. Moreover, girls are more influenced by the interpersonal dimension – the presence of other people who they admire.

Environmental Factors

Though background factors such as parental influence and socioeconomic status can play a part in contributing to students' attitudes towards science and school science, the most significant determinant of attitude is classroom environment (Osborne et al.) and in particular quality of science teaching: "Good teaching was characterized by teachers being enthusiastic about their subject, setting it in everyday contexts, and running well-ordered and stimulating science lesson. . .. talking with the students about science, careers and individual problems" (p. 1068). One important aspect of good teaching that these authors report is specialist knowledge, for example, low attitudes to science subjects could be attributed to teachers teaching outside their specialist subject with less enthusiasm.

Christidou also reports on the relationship between negative attitudes and the way science is taught. Teachers themselves need to have a positive stance towards science and scientists in order to inspire their students. The situation is not helped when school science is fragmented into isolated disciplines, and is limited in how it addresses values and social issues. Christidou's review also looks at the popular images of science in relation to students' interest and attitudes towards science. In focusing on the implications of how science is perceived by students, she reviews studies that have aimed to enhance students' involvement in science through providing different learning environments. For example, she points out that involvement in a variety of informal out-of-school science activities may be associated with a firmer commitment to science and science learning. Swarat et al. focus on "activity type" in their study of students' interest and show that inquiry-based teaching practices impact positively on motivation, interest, curiosity and enthusiasm. Their study on instructional episodes shows how different types of activity account for most variation in students' interest, as opposed to content topic or learning goal.

Achievement

The nature of any relationship between attitude and achievement has been a key concern of many studies, but the evidence is inconclusive regarding this relationship (Osborne et al.). While some studies show a positive correlation, others show that students can achieve highly in a subject without having a positive attitude towards it.

Implications for Future Research

The authors of these selected articles call for an agenda for future research to establish a greater understanding of how pedagogic practice can enhance students' attitudes. In spite of the wealth of studies reported in these articles, research is still needed that looks at the way science is presented to students, including the values connected to science (Christidou). Developments in science pedagogy could be the focus of attitude research; studies that build on Swarat et al.'s work on activity could determine the kinds of classroom interventions that are appealing to students and influence students' interest in and attitudes towards science and learning science. Related to this issue is the education of future science teachers and research on the impact of such preservice education; teacher educators and school mentors could focus on raising the awareness of new teachers of what students find interesting, relevant, and inspiring to engage with science. Changes in the curriculum could also form part of an agenda for future research, including how the content of the curriculum (including its omissions) is relevant to students' developing values, interests, and attitudes.

Attitudes, once formed, may be relatively stable for individuals, but the shaping of attitudes is complex and also context dependent, which makes the task of determining attitudes in a changing world dynamic and never-ending. As Osborne et al. point out "attitude cannot be separated from its context and the underlying body of influences that determine its real significance" (p. 1055). Findings of studies conducted over different time periods relating to age, gender, and cultural background do vary as different contexts and influences operate. Ongoing research is needed to capture changing trends in the relationship of age, gender, and culture to attitudes towards science.

Attitude studies that have included mixed methods have provided quantifiable data that is supported by more in-depth analyses that deepen our understanding of how attitudes towards science are influenced. The development and use of inventories that measure motivation and personal attributes of students can be coupled with studies of pedagogy and learning environments to determine relationships between variables. Longitudinal studies that take into account a host of such variables can be used to inform policy and pedagogy – how to resource and support science and communication about science and to fund the pre- and in-service education of science teaching.

Though we already have a rich resource of research in this field, these five articles provide some ideas for possible future research on attitudes towards science that would have considerable benefit for science education.

Cross-References

▶ Affect in Learning Science
▶ Attitudes Toward Science, Assessment of
▶ Competence in Science
▶ Interests in Science

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Attitudes Toward Science, Assessment of

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Students' Attitudes and their Measurement

Most children come to school ready and willing to learn. International surveys of primary age children generally reveal high levels of interest and positive attitudes of children to subjects such as science. Unfortunately, as children move through the education systems, their positive attitudes toward science typically decline, and increasingly fewer students are interested in studying science and to work in science-related careers.

Science and technology have enabled remarkable achievements, and their role in society continues to grow as the world faces the new challenge brought about by globalization and the serious test of how to protect the environment while promoting economic growth and sustaining an increasing world population. In order to successfully address these challenges, countries will have to make major investments in scientific infrastructure and the ability to attract, retain, and reward qualified individuals into science-related professions. Countries will also have to secure broad public support for scientific endeavor and ensure that all citizens are able to make use and benefit from science in their lives.

People's attitudes toward science are an integral part of whether they can be considered scientifically literate or not, as they determine whether individuals are willing to engage with science: attitudes and motivation in fact play a significant role in how interested people are in science and technology, how much attention they devote to scientific issues and technological progress, and how they respond to scientific challenges. The Programme for International Student Assessment (PISA) has examined how well 15-year-olds worldwide perform in science since 2000 and in 2006 closely examined what attitudes students have toward science and how motivated they are to study science and to work in science-related careers. In 2015 PISA will monitor closely student attitudes toward science for a second time and by so doing will be able to illustrate trends in what students think about science and their views on why studying science matters for them and society more widely.

Students participating in the PISA 2006 study sat for a 2-h test aimed at assessing their level of proficiency in science, mathematics, and reading. After completing some specific test questions related to science, students were asked to report their support for a number of statements directly linked to the science topics they had just encountered. After the test, students also completed a questionnaire where they were asked questions about themselves, their household situation and also whether they agreed or not to a series of statements developed to assess their attitudes toward science. Students' responses to the assessment-embedded questions and to the background questionnaire were used to develop measures identifying several aspects of student attitudes toward science: what motivates students to learn science and how motivated they are, to what extent students value and enjoy science, whether students believe in their own science abilities, whether they believe they can perform specific scientific tasks, and whether students expect to work in science-related occupations. The sections below describe how PISA measured attitudes toward science in 2006 and illustrate gender and socioeconomic disparities in students' attitudes toward science.

Motivation to learn science. PISA distinguishes two forms of motivation to learn science: students may want to learn science because they enjoy it and find it interesting, intrinsic motivation to learn science, but they may also wish to learn science and excel in science because they perceive learning science as useful, extrinsic motivation.

Intrinsic motivation refers to performing an activity purely for the joy gained from the activity itself: students are intrinsically motivated to learn science when they want to learn science because they find science interesting and enjoyable and when they want to study science for the pleasure it gives them, not because of what they will be able to achieve upon mastering science subjects. Intrinsic motivation affects how engaged students are, the learning activities students enroll in, student performance in science, and the types of careers students aspire to have and choose to follow. Generally, intrinsic motivation declines from elementary school to higher education, but can be importantly shaped by what teachers do, by students' peers, by classroom instruction and dynamics, as well as by parental motivational practices, attitudes, and behaviors. PISA indicates that, within countries, students who have high levels of intrinsic motivation to learn science are highly proficient in science, although countries where students have, on average, comparatively high levels of intrinsic motivation to learn science are not necessarily the countries with the strongest science performance in the PISA assessment.

PISA 2006 provides three measures of students' intrinsic motivation to learn science: general interest in science, enjoyment of science, and interest in learning science topics. The first two measures were computed using students' answers to the student questionnaire. Students were asked how interested they were in learning about the following science topics: physics, chemistry, biology of plants, human biology, astronomy, geology, the ways scientists design experiments, and what is required for scientific explanations. The *index of general interest in science* combines students' answers on whether they have "high," "medium," "low," and "no" interest to learn these topics. *Enjoyment of science* was assessed asking students to answer whether they "strongly agreed," "agreed," "disagreed," and "strongly disagreed" that they enjoyed five different aspects related to science and learning science. The *index of interest in learning science topics* on the other hand was assessed using embedded questions in the assessment of students' performance after students had worked on cognitive items so that object-specific interest could be evaluated. The students were asked to indicate their interest in the topics, objects, and activities that they had just encountered.

Extrinsic motivation to learn science refers to the motivation that drives students to learn science because they perceive it as useful to them and to their future studies and careers. Extrinsic motivation was measured in PISA 2006 by assessing students' instrumental motivation to learn science and by assessing students' future-oriented motivation to learn science. *Instrumental motivation* to learn science was measured asking students to report whether they "strongly agreed," "agreed," "disagreed," or "strongly disagreed" to five statements aimed at capturing the importance students attach to learning science because it is useful, because it will help students succeed in their future jobs, or because it will help improve career prospects. Instrumental motivation to learn science is an important predictor of course selection and career choices, and results from PISA 2006 indicate that students perceive science to be useful and that they believe science can help them in their search for jobs and can help them pursue better career prospects (OECD 2007). Although instrumental motivation to learn science was highly correlated with science performance in some countries, in others the relationship was weaker or negative, with few differences between boys and girls. *Future-oriented motivation to learn science* was assessed by asking students to report whether they "strongly agreed," "agreed," "disagreed," or "strongly disagreed" that they would like to have a science-related career, to continue studying science after completing secondary school, and to continue to use science in their future lives. Future-oriented motivation to learn science was positively associated with science performance in 42 PISA participating countries and economies, including all OECD countries except Mexico, and the strength of the association is quantitatively important in as many as 20 PISA 2006 countries and economies.

Support for science. In 2006 PISA explored the extent to which students appreciate science and scientific inquiry and whether they believe science plays an important role in their own lives by asking students questions about how much they support and value science. Responses provided in the context of the student background questionnaire were used to develop a measure of students' general value of science and a measure of students' personal value of science. Responses that the students provided to questions that were embedded in the science assessment, after students had encountered specific test questions, were used to capture how students value science in relation to specific topics. Personal values of science are fundamental antecedents of emotional feelings about science such as enjoyment, motivation for learning science, and motivation for a long-term engagement in science. When students value science in their own lives, they are more likely to enjoy science and to be interested in scientific topics. Both general and personal values of science are related to students support for scientific inquiry.

A general value of science indicates to what extent students value the contribution of science and technology. The majority of students participating in PISA 2006 reported that they value science, and while almost all students participating in PISA reported that they believe science is important to understand the natural world and that scientific and technological advances usually improve people's conditions, significant proportions of students did not agree that advances in science and technology usually bring about social or economic benefits. While the overwhelming majority of students reported valuing science in general, far fewer students feel that science directly related to their own lives and behavior: students across all participating countries and economies had lower levels of *personal value of science* than general value of science. Scientific inquiry refers to valuing scientific ways of gathering evidence, the importance of considering alternative ideas, the use of facts and rational explanations, and communicating with others. On average, only 59 % of students reported that they would use science when they left school, 64 % of students reported that they would use science as adults, and only 57 % of students agreed that science was very relevant to them. When participating students were asked about their support for scientific inquiry immediately after they had solved specific science tasks in the PISA science assessment, students reported strong levels of *support for scientific inquiry*, for example, students supported research to develop vaccines for new strains of influenza and they valued the systematic study of fossils and that scientific research should be at the basis of statements about the causes of acid rain.

Personal beliefs. In 2006 PISA also assessed students' self-beliefs as science learners. Students with positive self-beliefs believe in their own ability to handle scientific tasks effectively and to overcome difficulties and in their own academic ability. Autonomous learning requires both a critical and a realistic judgment of the difficulty of a task as well as the ability to invest enough energy to accomplish it. Students' views about their own competences have been shown to have considerable impact on the way they set goals, the learning strategies they use, and their performance.

Self-efficacy goes beyond how good students think they are in subjects such as science. It is more concerned with the kind of confidence that is needed for them to successfully master specific learning tasks and therefore not simply a reflection of a student's abilities and performance. The relationship between students' self-efficacy and student performance may well be reciprocal, with students with higher academic ability being more confident and higher levels of confidence, in turn, improving students' academic ability. A strong sense of self-efficacy can affect students' willingness to take on challenging tasks and to make an effort and persist in tackling them: it can thus have a key impact on motivation. To assess self-efficacy in PISA 2006, students were asked to rate the ease with which they believe they could perform eight listed scientific tasks. For each of the eight scientific tasks, the average percentages of students reporting that they could do it either easily or with a bit of effort vary considerably. Seventy-six percent of students on average reported that they felt confident explaining why earthquakes occur more frequently in some areas than in others. Similarly, 73 % of students reported that they could recognize an underlying science question in a newspaper report on a health issue. Around 60 % of students on average reported that they could interpret the scientific information provided on the labeling of food items, predict how changes to an environment will affect the survival of certain species, and identify the science question associated with the disposal of garbage. Less than 60 % of students reported that they could describe the role of antibiotics in the treatment of disease or identify the better of two explanations for the formation of acid rain. Students were least confident with discussing how new evidence could lead to a change of understanding about the possibility of life on Mars, with only around half of 15-year-olds in OECD countries reporting that they could do so easily or with a bit of effort.

Students' *academic self-concept* is both an important outcome of education and a trait that correlates strongly with student success. Belief in one's own abilities is highly relevant to successful learning. It can also affect other factors such as well-being and personality development, factors that are especially important for students from less advantaged backgrounds. In contrast to self-efficacy in science, which asks students about their level of confidence in tackling specific scientific tasks, self-concept measures the general level of belief that students have in their academic abilities. To what extent do the 15-year-old students assessed by PISA believe in their own science competencies? On average, 65 % of students reported that they could usually give good answers in science tests. Overall, however, a large proportion of students (between 41 % and 45 % on average) said they were not confident in learning science, reporting that they did not agree that they learned school science topics quickly or understood concepts or new ideas very well. Furthermore, 47 % agreed that school science topics were easy and that learning advanced science would be easy.

Within countries, student attitudes toward science are associated with higher performance in the PISA science assessment in virtually all OECD countries; however, countries that have, on average, positive attitudes toward science are not necessarily countries with high mean science performance. For example, PISA, as well as other international studies such as TIMMS and ROSE, suggests that students in low-performing countries have relatively high levels of interest in science, while students in high-performing countries show relatively low levels of interest in science. Within countries internal motivation to learn science and instrumental motivation to learn science, participation in science-related activities, self-efficacy, and science self-concept are all strongly associated with science performance, with self-efficacy having the strongest association. Results from PISA 2006 suggest that, across OECD countries, students who have values on the index of student self-efficacy that are one standard deviation above the OECD mean score 28 points higher on average than students with average levels of self-efficacy. The score point differences associated with one standard deviation rises in the index of general interest in science and in the index of student self-concept in science are also close to 20 points. The differences are lower in relation to both the index of student participation in science-related activities and the index of instrumental motivation to learn science (16 and 14 points, respectively).

Gender differences. PISA indicates that 15-year-old boys and girls generally perform at similar levels in science, but boys and girls do not hold similar attitudes. For example, boys tend to have greater self-concept and greater self-efficacy in science than girls, as well as higher levels of enjoyment of science and instrumental motivation to learn science, but boys and girls have similar levels of intrinsic motivation to learn science. Recent meta-analyses show that boys have consistently more positive attitudes toward science than girls, especially toward physical science and engineering. Girls, on the other hand, tend to be more interested in health and life sciences. In 2006, PISA asked 15-year-old students what they expect to be doing in early adulthood, around the age of 30. In general boys and girls reported expecting to pursue careers in very different fields. In recent years, girls in many countries have caught up with or even surpassed boys in science proficiency. Better performance in science or mathematics among girls, however, does not mean that girls want to pursue all types of science-related careers. In fact, careers in "engineering and computing" still attract relatively few girls. Results from PISA 2006 suggest that among OECD countries, on average, fewer than 5 % of girls, but 18 % of boys, expected to be working in engineering and computing as young adults. In no OECD country did the number of girls who expected a career in computing and engineering exceed the number of boys contemplating such a career. Moreover, the ratio of boys to girls who wanted to pursue a career in engineering or computing is large in most OECD countries: on average, there were almost four times as many boys as girls who expected to be employed in these fields.

Even among the highest-achieving students, career expectations differed between boys and girls; in fact, their expectations mirrored those of their lower-achieving peers. For example, few top-performing girls expected to enter engineering and computing. Although few girls expected to enter some science careers, such as engineering and computing, in every OECD country more girls than boys reported that they wanted to pursue a career in health services, a science profession with a caring component. This pattern holds even after nurses and midwives are excluded from the list of health-related careers. On average across OECD countries, 16 % of girls expected a career in health services, excluding nursing and midwifery, compared to only 7 % of boys. This suggests that although girls who are high achievers in science may not expect to become engineers or computer scientists, they direct their higher ambitions toward achieving the top places in other science-related professions, such as those in the health field.

Differences by socioeconomic background. PISA reveals that socioeconomically advantaged students tend to have more positive attitudes toward science, as well as higher science performance, than their less advantaged peers. Given the strong association that exists between science performance and attitudes toward science, could the socioeconomic gap in science performance be closed if socioeconomically disadvantaged students had more positive attitudes toward science? What role do attitudes toward science play in helping disadvantaged students overcome the adverse circumstances determined by their socioeconomic background?

Results from PISA 2006 (OECD 2011) indicate that socioeconomically disadvantaged students tend to have less positive attitudes toward science than socioeconomically advantaged students. They also tend to engage less in science activities, feel less prepared for science careers, attend fewer science courses, and spend less time in science lessons at school. For example, disadvantaged students report being less interested in science and having lower levels of self-efficacy than their more advantaged peers in every OECD country and in most partner countries and economies. The differences in the extent to which disadvantaged students and their more advantaged peers report having low levels of instrumental motivation to learn science, participation in science-related activities, self-concept, and information on science-related careers are also significant in most OECD and partner countries and economies.

PISA 2006 further reveals that both disadvantaged students and their more advantaged peers benefit from having positive attitudes toward science. With a few exceptions, disadvantaged students benefit, on average, as much as their more advantaged peers from having positive motivation, participation in science-related activities, confidence, and perspectives future careers in science. There are, however, some important differences across areas. For example, in several countries, the association between attendance at compulsory science courses and performance is stronger for disadvantaged students than for their more advantaged peers. In addition, in a number of countries disadvantaged students appear to benefit less than their more advantaged peers.

These results suggest that positive attitudes toward science are associated with increases in the PISA score across all socioeconomic groups but crucially that the increases are smaller for disadvantaged students in some countries. Policies aimed at promoting greater motivation to learn science and positive attitudes and approaches to science learning may therefore result in absolute improvements in science achievement but may also run the risk of contributing to wider performance gaps across social groups unless they are targeted at specific populations.

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Attitudes, Gender-Related

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Gender; Science education

Gender is defined in various ways, but for the purposes of the encyclopedia entry on gender-related attitudes, gender is considered a social construct, not a biological one; that is, gender is not determined by one's DNA and hormones, but rather by the accumulation of one's sociocultural experiences.

Gender-related attitudes are initially developed and formed in a child's home, affected by the actions and attitudes of teachers and friends, and reinforced by experiences in the workplace – or in society in general. Self-confidence in studying science, attribution of success in science, fear of failure in science, participation rates in science, perceptions of the usefulness of science, and performances in science all contribute to one's gender-related attitudes about science. Further, gender-related attitudes contribute to a student's aspirations and interest in science and are heavily influenced by teacher beliefs, expectations, and classroom behaviors.

Gender-related attitudes in science education have been studied extensively since the early 1980s. During that time, girls, compared with boys, have consistently reported more negative attitudes towards science in local, regional, national, and international studies. Although gender-related differences decline as students proceed through school and the decline is greater for girls than for boys, girls' interest in science does not increase over time (Scantlebury 2012).

Cross-References

- ▶ Attitude Differences and Gender
- ▶ Attitudes to Science and to Learning Science
- ▶ Interests, Gender-Related

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Augmented Reality

▶ Tangible and Embodied Interactions for Learning

Ausubelian Theory of Learning

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David Ausubel: An Introduction

David Ausubel was born in 1918 and graduated from the University of Pennsylvania with honors in psychology in 1939. In spite of his outstanding undergraduate record, Ausubel suffered from the prevailing medical school prejudice against Jewish students and could not get admitted to any of the best medical schools. Instead, he studied Experimental Psychology at Columbia University and earned an MA degree in 1940. He completed the MD degree at Middlesex University in 1943 and then did three psychiatric residences with the US Public Health Service in Kentucky, the Buffalo Psychiatric Center, and Bronx Psychiatric Center. After military service in Germany, where he worked in the United Nations Relief and Rehabilitation Administration, Ausubel earned a PhD degree in Experimental Psychology at Columbia University in 1950. It was at Columbia that he first began to formulate his ideas that evolved into his *assimilation theory* of learning first published as a paper in 1962 and then as his 1963 book, *The Psychology of Meaningful Verbal Learning*. In 1968 he published a more comprehensive book, *Educational Psychology: A Cognitive View*. This book extended his theoretical ideas and applied them to other areas of educational psychology. In this work Ausubel offered educators an alternative theory of learning to the behavioral psychology that was almost universally embraced by psychologists in the 1960s. It was his theory of learning I adopted and adapted to my research and instructional design programs from 1963, first at Purdue University and then at Cornell University.

When I was a graduate student in Education at University of Minnesota, I took a graduate course in Theories of Learning. The text was Hilgard's 1948 book, *Theories of Learning*, and it presented only behaviorists' theories of learning. I recall complaining to the professor teaching the class that there was nothing in these theories that was useful to classroom teaching. While he did not deny my claim, he argued that Hilgard's book was the only one of its kind and was almost universally used in universities. I recall that my colleague at Cornell, Bob Gowin, had a similar reaction to a similar course at Stanford University where he did his graduate studies at about the same time. After the information processing/cognitive psychology revolution of the 1980s, it is hard for present-day scholars to appreciate what a profound departure from the prevailing educational psychology Ausubel was promoting with his new theory.

In 1965, I attended a conference on Concept Learning at the University of Wisconsin, and here I had a chance to have extended conversations with Ausubel about his theory.

These conversations helped me gain insights into his theory and its application to education. These conversations began a continuing dialogue with Ausubel, and in 1977, he invited me to assist in the revision of his 1968 *Educational Psychology: A Cognitive View*. During the course of these revisions, where I revised the key chapters dealing with his assimilation theory, I got deeper insights into his thinking. I was also amazed at his prodigious knowledge of the literature. On several occasions I recall calling Ausubel to discuss his interpretation of some research studies that did not seem evident to me. On all of these occasions, he would describe his thinking in reaching the conclusions he did from these studies. Considering there are over 1,400 research references in his 1968 book, I marveled at his ability to discuss specific studies over the phone. Ausubel had a remarkable intellect, a genius in his own way! I marveled at how he could sift through the dustbins of behavioral psychology and tease out research findings that could be used to contribute to his assimilation theory.

The Core of Ausubel's Theory

In the epigraph in his 1968 book, Ausubel wrote:

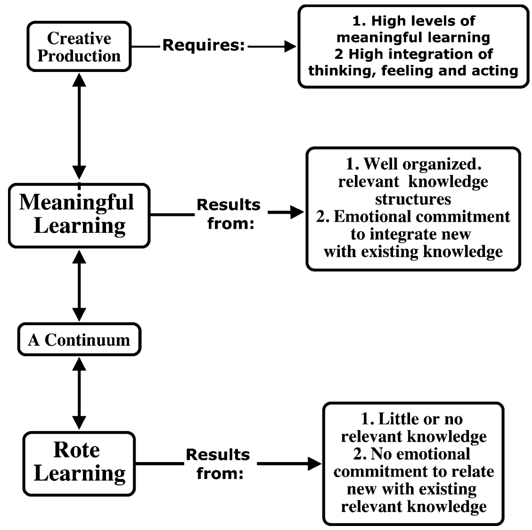
> If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly.

Now this may appear to be simple enough, or even to some simplistic. However, it is not easy to ascertain carefully what the learner already knows on a given topic, and it is even more difficult to determine how best to teach him/her effectively. Indeed many of the major research programs focused on the learning and teaching of science that have been conducted over the last 30–40 years, including mine, have at their core been concerned in some form with one or both of understanding ways to determine "what the learner already knows" and then what it would mean to teach the leaner "accordingly."

When Ausubel speaks about what a learner already knows, he is speaking about the concepts and propositions that have meaning for this learner. In our work we have slightly modified Ausubel's definition of these terms to better fit current epistemological thinking. We define a *concept* as a perceived pattern or regularity in events or objects, or records of events or objects, designated by a label, such as a word or symbol. *Propositions* are two or more concepts linked to make a meaningful statement about events or objects. Propositions can also be thought of as the fundamental units of meaning, for concepts standing alone convey little meaning. Getting smart about a domain of knowledge requires building a powerful cognitive framework of concept and propositions for that domain, together with supportive feelings and skills necessary to achieve this organized body of knowledge.

The Essential Principles of Ausubel's Theory

Ausubel's theory has six basic principles: *The first two principles* are ***rote learning***, which occurs when the learner makes little or no effort to relate new knowledge to relevant elements of knowledge the learner already knows, whereas ***meaningful leaning*** occurs when the learner makes a deliberate, conscious effort to relate new concepts and propositions to existing, relevant concepts and propositions. Only the learner can choose to learn *meaningfully*, although there are strategies that can encourage this kind of learning. In the 1970s Ausubel argued that rote learning and meaningful learning are two different, distinct ways of learning. I argued that it was my experience at that time indicated that the quality and extent of meaningful learning depended both on how much effort and commitment the learner makes to relate new learning to



Ausubelian Theory of Learning, Fig. 1 The rote-meaningful learning continuum (Novak 2010)

her/his existing knowledge and also on the quality and degree of organization of that existing relevant knowledge. Therefore, cognitive learning should be viewed as a continuum, varying from very rote, arbitrary acquisition in information to very high levels of meaningful learning. More recently I have argued that creativity could be viewed as essentially very high levels of meaningful learning. This view is expressed in Fig. 1.

While Ausubel accepted the idea that rote and meaningful learning can be viewed as a continuum, he always held that creativity was a special capacity possessed by relatively few very gifted people. To be sure, only a very small fraction of the population have the capacity to organize their thinking, feeling, and acting in ways that lead to the extraordinary creativity of an Einstein or a Mozart. However, most normal individuals can on occasion gain novel insights in a limited sphere knowledge creation. This view is discussed later in this entry.

The third key principle of Ausubel's theory is ***subsumption***. When new concepts and propositions are incorporated into relevant, more general concepts and propositions, ***subsumption*** occurs and both the existing superordinate knowledge and the newly incorporated idea are modified. Ausubel maintained that subsumption is the most common form of meaningful learning. This view has been supported by our research and the research of others. In extreme rote learning, the process of subsumption does not occur where one can think of the new bits of knowledge as just kind of floating around in cognitive space, each in isolation of all other elements. There are two negative results from this kind of rote learning. First, there is no enhancement and refining of meanings for existing concepts and propositions. Consequently these existing ideas do not (and cannot) become more powerful subsuming concepts nor more differentiated ideas that can serve better for problem solving or creative work. Second, faulty ideas or ***misconceptions*** held by the learner do not get "corrected" or altered into more accurate forms. Research has shown that students who learn primarily by rote are poor at solving novel problems and they do not modify and correct their faulty conceptions; nor do they consider in any way relevant alterative conceptions they use to interpret their world.

The fourth principle in Ausubel's theory is ***obliterative subsumption***. This occurs when over a span of time, discrete ideas are subsumed into more general concepts and later can no longer be recalled as discrete ideas (hence "obliterative"). These concepts and propositions have contributed to elaborating the more general idea into which they were subsumed, but we can no longer recall them independently. All of us have experienced occasions when we knew that object or event belongs to a certain category of things or events, but we cannot recall the details of that object or event. Obliterative subsumption that occurs after some meaningful learning event is not the same as forgetting that occurs after rote learning. There remain some enriched concepts and propositions in your cognitive structure and these will *facilitate* new, relevant learning. When forgetting occurs after rote learning, there is usually *interference* or retarded learning of related material. No doubt the reader can recall being confused in trying to recall something recently learned because of the new ideas are still jumbled up with similar things in our minds and we cannot sort out the details. For many of us, including me, a good example of this is trying to recall names. Unless I have made some kind of meaningful connection to a person's name and something related to that name, I might forget the name in a minute or two!

The fifth principle in Ausubel's theory is ***superordinate learning***. This kind of learning occurs when several concepts or propositions are recognized as really subordinate units of some larger, more inclusive idea. For example, children learn that there are pigs, cows, dogs, and similar animals. When they acquire the superordinate concept of mammal, i.e., something with hair or fur and females with mammaries to nurse their young, superordinate learning has occurred. Similarly, one may learn about many events that occurred in France and Europe in the fourteenth to seventeenth centuries. This lays the foundation for coming to understand the period as the ***renaissance*** and this adds a superordinate concept to enrich the meanings of the individual events you have studied.

Finally (the sixth principle), there is Ausubel's principle of ***integrative reconciliation***. An example of this principle at work is when a child realizes that multiplication is really just a form of repeated addition. The child now sees that $2 \times 3 = 6$ is the same as $2 + 2 + 2 = 6$. So much of mathematics would be more easily learned and remembered if teaching was designed for encouraging repeated integrative reconciliation of component ideas. Of course, this is also true in every other discipline.

A general comment about these six principles: Many people have found it difficult to grasp Ausubel's assimilation theory of learning. In part, and in common with the totality of any complex theory in any discipline, this is because each of the principles in this theory is related to all the other principles. One cannot really understand integrative reconciliation until one understands meaningful learning and superordinate learning. One cannot grasp the meaning of all six principles in a single sitting or session. One must get a beginning understanding of each and gradually refine and build those meaning over time with numerous examples and experiences. Profoundly important ideas are profoundly difficult to master. My counsel is to just begin to work with these ideas and they will become more clear and powerful over days, weeks, and months.

Advance Organizers

Ausubel also advanced the idea of advance organizers, and at times in the past, it seemed he was better known for this than for his theory of learning. His, and others', research shows that if one precedes a segment of instruction with a more general, more abstract segment of instruction on a topic to be studied (an "advance organizer"), this can help the learner integrate the new details to be learned with existing relevant subsumers, thus facilitating meaningful learning. The advance organizer serves as a kind of "cognitive bridge" helping the learner to recognize existing relevant concepts and propositions she/he possesses and facilitating subsumption of the new information.

The idea of advance organizers is not part of his theory of learning but rather an instructional strategy. Other psychologists have advanced similar ideas usually termed ***scaffolding*** (Hogan et al. 1997) learning. In either case, the goal is to help the learner assimilate new more explicit material to be learned into her/his cognitive structure. When an advance organizer is well planned, it should help the learner see relationships between some more general, relevant idea they already know and the more specific, more detailed concepts and propositions to be learned. In other words, a good advance organizer facilitates the subsumption of new relevant concepts and propositions.

Many studies have shown that the use of advance organizers significantly enhances meaningful learning of more detailed, relevant information, including two studies done by one of my graduate students. Kuhn found that biology laboratory students who were given an advance organizer to study prior to instruction on homeostasis and levels of biological organization did significantly better when tested on these ideas at the end of the laboratory and 3 weeks later, when compared with students not given these advance organizers. Some research studies have failed to show a positive effect for "advance organizers," but in most of these cases, either there were inappropriate advance organizers or the achievement tests used did not require significant meaningful learning. Testing only for recall of specific details is not likely to show the advantage of using an advance organizer, because there is no logical reason to suggest that an advance organizer could do anything to assist rote learning.

Primary and Secondary Concepts

Ausubel distinguishes between primary concepts and secondary concepts. *Primary concepts* are those acquired from direct experience with objects or events, and these can be acquired readily by the young child. *Secondary concepts* are derived from perceived regularities in relationships between primary concepts, and these are more difficult to acquire. Energy is an example of a secondary concept, and acquisition of this concept requires direct experiences with objects or events that manifest the concept and guidance in observing the manifestations of the regularity that defines the concept. A young child can learn about atoms and molecules and energy and energy transformations providing they are given experiences where these concepts are manifest and they are given guidance to observe the patterns or regularities that manifest the concept. Thus, children can be provided with experiences and guidance to understand the particulate nature of matter and the effect of adding heat to a sample of matter, such as heating a balloon. In a 12-year longitudinal study, we showed that 6–8-year-old children when provided with appropriate experiences and audio guidance in their observations can begin to acquire functional concepts of matter and energy and energy transformations (Novak and Musonda 1991). Moreover, as these children progressed through the grades, those who had this early instruction demonstrated twice as many valid concepts about the nature of matter and energy and less than half as many misconceptions, compared with similar students who did not have this early instruction.

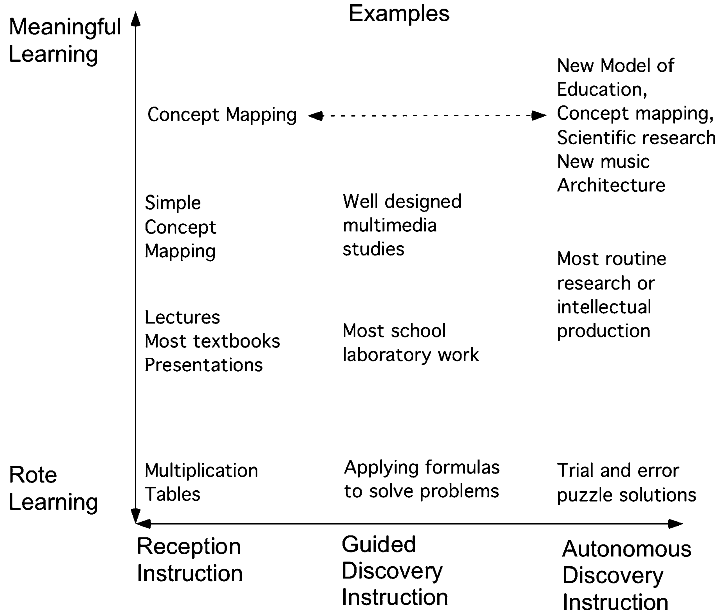
Reflections on Ausubel's Theory of Learning

Ausubel held a more conservative view about the learning capabilities of young children than many of the researchers who subsequently worked with his theory. I think this is due to the fact that he did very little research with young children, whereas the work of others (including my research programs) has involved this age group. In the last 20 years, there have been numerous studies by a range of researchers (from cognitive scientists to early childhood educators with expertise in science) that show we have consistently and grossly underestimated the learning capabilities of young children.

Many researchers, including many graduate students, embraced Ausubel's theory as a powerful and useful theory to guide their research on learning science. However, most of my colleagues in Science Education in the USA rejected his ideas or simply ignored them. The work of Piaget, interpreted as if he was a developmental psychologist, began in the mid-1960s to dominate thinking in Science Education in the USA and to a lesser extent in the UK and some other countries. The ways in which researchers interpreted Piaget held that children's intellectual development progressed in stages that were highly age determined and could not be accelerated. The unfortunate result of this doctrinaire interpretation of Piaget's writing in the USA, and in particular the less complex parts that related to views about stages of intellectual development, was that the teaching in the country of basic concepts of science such as the nature of matter and energy was delayed until around Grade 8 at the earliest. The consequence was that powerful superordinate concepts dealing with the nature of matter and energy were not introduced in elementary school and much learning facilitation that could have resulted from such teaching was lost.

It might be argued that no harm is done by delaying instruction in basic science concepts if it were not for the highly documented fact that children build their own *alternative* science concepts based on everyday experiences. While consistent with the child's interpretations of their experiences, the majority of these alternative concepts are completely inconsistent with science, and so are faulty concepts or misconceptions. For example, children think that one must keep applying a force to an object to keep it moving at a steady speed, whereas the much more powerful science explanation of this phenomenon is that for this motion the resultant force on the object is zero (and so no continuing force is needed if we remove the friction of air and the surface traveled). Children believe that plants get their food from the ground, since they observe people applying "plant food" to lawns and gardens. Without a basic understanding of atoms and molecules and energy and energy transformations, they cannot understand how plants synthesize their own food from carbon dioxide in the air and nutrients absorbed by the roots and transported to the leaves. Once these faulty alternative conceptions are acquired, thousands of studies have shown it is notoriously difficult to help students learn valid science concepts. Perhaps the central reason for this is that the faulty concepts seen by the child as relevant still function as Ausubelian subsumers to anchor learning of new relevant concepts and propositions, often further elaborating and distorting the alternative conception. Even conscientious efforts on the part of the teacher and the students to learn new material meaningfully can fail due to the student's faulty alternative conceptions (see Proceedings of International Conferences on Science and Mathematics Misconceptions held at Cornell University at: www.mlrg.org).

An early exploration of the value of Ausubel's theory for guiding and interpreting research and instruction in science was undertaken in 1971, when two of my graduate students and I reviewed over 100 published research studies in science education with the view of looking at these studies through the lens of Ausubel's theory of



Ausubelian Theory of Learning, Fig. 2 High levels of meaningful learning can be achieved by both reception learning approaches and discovery approaches, and both approaches can result in little meaningful learning when poorly done (Novak 2010)

learning (Novak et al. 1971). We found most of the studies sorely lacking in theoretical foundations, many using inappropriate data analysis, or lacking adequate control of variables and frequent use of inadequate assessment tools. More relevant here is that we found that Ausubel's theory would better explain the data obtained and could have guided better instructional and research design. One of the most powerful tools invented to establish what a learner knows, to represent expert knowledge, and to facilitate learning of new knowledge is the *concept map*. This tool was developed in Novak's research program at Cornell University in the early 1970s and is now used in all disciplines for all ages all over the world. Further discussion of this tool can be found in in the entries ► Concept Mapping and ► Concept Maps: An Ausubelian Perspective. Ausubel's learning theory was the primary theoretical foundation for the development of this tool.

For many years the science education literature, both research and professional, and wider public debate about science teaching and learning have been replete with recommendations for greater emphasis on *inquiry* approaches to teaching and learning. Sometimes, indeed too often, these recommendations derive from simplistic views of "discovery," "child centered," and other slogans. More substantively, many of these recommendations derive from the mistaken view that *reception learning*, where the learner is guided to acquire new knowledge primarily through didactic teaching, is basically inferior to "discovery" or "inquiry" approaches to learning. Ausubel points out that while poor reception teaching leads primarily to rote learning, with all the inherent shortcomings, when well done, reception learning can not only be highly efficient but also provide many of the benefits and future utility of knowledge acquired when reception instruction is well done. This is not to say that discovery or inquiry learning should have no role in school learning, as there are ancillary benefits that are valuable, such as learning to design experiments and gaining skills in using scientific equipment. As shown in Fig. 2, well-designed reception instruction can lead to highly meaningful learning, and poorly designed inquiry instruction can result in little or poor learning for understanding.

Today almost all educational psychologists subscribe to some form of cognitive or socio-cognitive learning theory. The pioneering work of Ausubel is of central relevance to cognitive considerations. It still merits careful study and remains a viable and powerful theory of human learning.

Cross-References

- ▶ Alternative Conceptions and P-Prims
- ▶ Alternative Conceptions/Frameworks/Misconceptions
- ▶ Cognitive Acceleration
- ▶ Concept Maps: An Ausubelian Perspective
- ▶ Conceptual Change in Learning
- ▶ Developmental Perspectives on Learning
- ▶ Imagination and Learning Science
- ▶ Information Processing and the Learning of Science
- ▶ Metacognition and Science Learning
- ▶ Metaphors for Learning
- ▶ Piagetian Theory

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Authentic Assessment

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Keywords

Alternative assessment; Computer simulation; Direct assessment; Field experience; Group discussion; Open-ended problem; Performance assessment; Portfolio

Definition

Many definitions of *authentic assessment* have been proposed in order to distinguish it from other kinds of assessment (e.g., Darling-Hammond et al. 1995; Wiggins 1998). Darling-Hammond et al. (1995) posited that authentic assessment is designed to provide students with opportunities to demonstrate what they can do in a situation that requires the application and production of knowledge, rather than mere recognition or reproduction of correct answers. According to Darling-Hammond et al., authentic assessments are contextualized in students' lives and learning experiences and so well-integrated into the teaching and learning process that they are indistinguishable from instruction.

Despite subtle differences among the proposed definitions of authentic assessment, it is a well-accepted notion that assessment becomes *authentic* when it exemplifies the real-life behaviors and challenges experienced by actual practitioners in the field, rather than merely eliciting easy-to-score responses to simple questions (Darling-Hammond et al. 1995; Wiggins 1998). A widely accepted framework for determining the authenticity of an assessment design was proposed by Wiggins (1998). According to Wiggins, an assessment task is authentic if it (1) is realistic, (2) requires judgment and innovation, (3) asks students to carry out work in the subject, (4) replicates the context in which adults are evaluated in the workplace or personal life, (5) assesses the students' capability to use a repertoire of knowledge and skill to perform a complex task, and (6) allows opportunities to rehearse, practice, consult resources, get feedback on, and refine performances and products. Table 1 contains Wiggins's summary of the key differences between authentic and typical tests.

Evolution of the Term

Early scholarship on authentic assessment was driven by an interest in assessment methods that were closer to classroom practice and more

Authentic Assessment, Table 1 Key differences between traditional tests and authentic tasks (Adapted from Wiggins 1998)

Indicators	Tests	Authentic tasks
Output requirement	Require correct responses	Require quality product and/or performance along with justification
Pretest/ assessment exposure by students	Must be kept from students to ensure validity	Tasks, criteria, and standards are communicated to students in advance
Connection to real-world	Are disconnected from a realistic context and constraints	Require application of knowledge and skills related to realistic problems likely to be encountered outside of school
Type of knowledge and skill required	Contain items requiring use or recognition of known knowledge or skills	Are challenges in which knowledge and judgment must be innovatively used to produce a quality product or performance
Evaluation	Simplified to be easily and reliably scored	Involve complex and nonarbitrary tasks, criteria, and standards that can yield valid inferences about student learning
Frequency	Usually taken only once	Are iterative, typically including recurring essential tasks and standards
Validation	Depend on highly technical correlations	Provide direct evidence prompted by tasks that have been validated against key discipline-based challenges in adult practices
Result	Generate a score	Provide diagnostic feedback to improve performance and learning

naturalistic than traditional testing, which was criticized for failing to measure many of the important aspects of meaningful learning (Chittenden 1991). Proponents argued that authentic assessment could evoke student interest and persistence through the employment of apt, challenging, realistic tasks and produce gains on conventional tests and in student learning (Wiggins 1998).

Archbald and Newmann's (1988) book on authentic academic achievement is often referred to as the earliest work that sought to promote assessment that centers on a variety of meaningful, real-world tasks. Wiggins (1998) brought the idea of authentic assessment to a broader audience through a series of publications advocating the concept and the use of authentic tests or assessments with real-world applications. By the 1990s, the topic had generated substantial interest. Persuaded by Wiggins's claim that understanding is developed and revealed through authentic work, feedback, and the use of knowledge in diverse contexts, educational researchers and practitioners experimented with alternatives to traditional testing (Darling-Hammond et al. 1995).

Initial efforts were stymied by difficulties with creating an operational definition that distinguished between *authentic*, *alternative*, and *performance* assessment. For example, there was some debate about whether *performance assessment* is synonymous with or a component of *authentic assessment*. There is now general agreement that assessment can be performance-based without being truly authentic: A performance assessment is not considered authentic if it does not involve tasks with realistic value (Wiggins 1998).

Another issue in the literature involved the distinction between authentic and alternative assessment. Since the term *alternative assessment* typically connotes any assessment other than traditional paper-and-pencil tests (Fischer and King 1995), authentic assessment usually can be a treated as a concept subsumed by alternative assessment.

Chittenden (1991) argued that terms such as *authentic*, *alternative*, and *performance* assessment are essentially nontechnical placeholders which should be replaced by more functional terms such as *portfolios* and *exhibitions*. This practical suggestion is reflected in the research literature: Since authentic assessment takes a variety of forms, empirical studies focus on a particular type of authentic task such as a *portfolio*, *hands-on laboratory*, *field experience*, *open-ended problem*, *computer simulation*, or *group discussion*. Therefore, although the term *authentic assessment* is still used to indicate a general category of assessment that involves tasks that model and demand important real-world work and elicit performances that allow direct examination of student learning and understanding (Wiggins 1998), more recent literatures tend to use activity descriptions that depict particular tasks and procedures associated with authentic assessment.

Cross-References

- ▶ Assessment of Doing Science
- ▶ Assessment of Knowing and Doing Science
- ▶ Assessment to Inform Science Education
- ▶ Authentic Science
- ▶ Embedded Assessment

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Authentic Science

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Science is a way of thinking used to develop explanations of natural phenomena using evidence and logic. Authentic science is essentially the same thing, the term only having been coined to distinguish and separate the scientific ways of thinking from classroom science activities that do not, in fact, reflect the spirit and behavior of science. It is argued that traditional experiences in many classrooms charged with teaching about the science disciplines are outdated, in that they do not facilitate the learner in learning to think and behave in the manner of actual scientists. Authentic science is a variation of inquiry teaching that aligns closely with how scientists do their work and differs from traditional school science laboratory exercises (commonly called "laboratories" in the USA). Many traditional laboratory experiences are static and contrived, leading the student to a predetermined "correct" result, often known to the student. This is not to say such educational activities are totally without merit; but this change, from engaging students in experiences in which they already know the answer to engaging students in investigations similar to those conducted by scientists, is overdue.

The term "authentic science" refers to a science experience that embodies more of the qualities of actual or real science. Authentic refers to using data and logic to create an explanation for something not known or understood and using skepticism about the best explanations or applications to society. Authentic science involves engaging students in answering scientific questions currently being investigated by scientists in today's world. Traditional school "science" sometimes does not meet these criteria, and so the term authentic science was created to describe those science activities and experiences that come closer to meeting those standards. The importance of doing authentic science in classrooms is in the outcome for students, that of critical thinking. For example, Bybee (2006) described the way scientists work and think, "How scientists know and explain the natural world and what they mean by explanation and knowledge are both directly related to the processes, methods and strategies by which they develop and propose explanations" (p. 2). Many educators acknowledge that the nature of inquiry that takes place in a scientist's laboratory differs to a certain degree from school science inquiry. Yet, school children can learn how to construct models and develop scientific arguments much like a scientist does, in developing explanations (Bybee 2006; NRC 2012). Authentic science differs from the view of science many children acquire through their experiences in traditional science classrooms. Making science learning in classrooms more aligned with authentic science practice has been a common goal of educators for over a hundred years. For example, as early as 1910 Dewey advocated that children should engage in authentic inquiry. By engaging students in authentic science, it is assumed that students will learn more about the practices of science (NRC 2012). Many science educators anticipate that if students can experience authentic science, they will become active learners, they will have the opportunity to understand the nature of science, and further, they will become lifelong learners. Yet there has been little progress made in changing classrooms to embrace more authentic science practices. Traditional school labs often give step-by-step directions that prevent the learner from experiencing what it means to think like a scientist. Teachers often disconnect the practices of authentic science from "school science." Studies show that it is rare for teachers to shape their teaching practice by their declared epistemological beliefs; one reason may be the perceived barriers posed by their school administration and state national policies.

To give students more authentic experience of science, some educators advocate increased use of out of classroom experiences, including visiting scientists' laboratories. Other experiences include spending extended time in scientific research laboratories. Some educators have suggested that apprenticeships in real scientific laboratories will translate directly into greater understandings of the nature of science. Interestingly, this apparently reasonable assumption is not fully supported by empirical studies.

In revising very structured classroom exercises to be more open-ended thus resembling authentic science, it is hoped that students will come to understand the nature of scientific inquiry and appreciate aspects of the nature of science. One method of integrating authentic science in the classroom involves the use of technology or as termed by cognitive scientists, learning technologies. One example of a learning technology that aligns with authentic science is probeware, equipment that is connected to a computer. Using probeware, children can collect real-time data and make interpretations, much like a scientist, if the lesson involves ill-structured problems and questions with no answer already known to the student.

Authentic science in the science classroom tries to replicate the kind of thinking done by scientists but, to be engaging, is also relevant to students. Authentic science forms a basis for developing effective ways of teaching children science. There have been and remain some critics of this way of teaching. However, its supporters claim that some critics indiscriminately lump many pedagogical approaches – constructivist, discovery, problem based, experiential, and inquiry based – under the category of "minimally guided instruction" (Hmelo-Silver et al. 2007, p. 99). Just moving authentic scientists' science into the classroom is not automatically effective for students, without some modification of the curriculum and support from teachers. There are various forms of authentic science teaching in the science education literature. For example, some researchers describe their particular authentic approach to science learning as inquiry-based, project-based, or problem-based learning. In each case there is a real-world question or problem that sets up the learning experience.

Recent reforms in science education advocate that teachers engage children in posing and using authentic scientific questions, giving priority to data, using data as evidence in developing explanations and examining alternative explanations, using mathematics, building and using models, developing and using arguments, and communicating and defending explanations (NRC 2012). A fairly recent emphasis in the classroom is a focus on model-based instruction and use of argumentation. Regarding modeling, teachers guide students in building and using models and in learning about the nature of models and how scientists use models. Children engaged in model-based instruction learn how to reason about data and phenomena by using models. In developing students' use of argumentation as used by scientists, teachers support children in interacting with their peers, in discussing and debating their ideas. Children learn how to construct an evidence-based argument and defend it. This kind of teaching demands that a teacher has in-depth understanding of science concepts and principles, in addition to competency in supporting children in discussions of data interpretation, model building, and argumentation.

Authentic science in the classroom enables students to engage in investigations that are meaningful to them and are similar to tasks carried out by scientists (Chinn and Malhotra 2002). There is some empirical evidence that when students engage in authentic science in classrooms, they value the authenticity of the investigation. One example of an authentic science experience is an environmental study of a pond, stream, or river near a school. In this case, students use equipment to collect temperature, dissolved oxygen, turbidity, depth, and other physical parameters. In addition students can learn how to sample and identify the living organisms, such as macro-invertebrates, which serve as water quality indicators. When students analyze these data, they can, with support of the teacher, develop a model of the pond, stream, or river and make predictions. These data can be collected over several years to track changes in water quality over time. Although students realize that they themselves are not trained scientists, when carrying out similar kinds of authentic activities, they believe they can contribute meaningful data for others.

Authenticity can also provide a meaningful context within which children can actively reflect on aspects of nature of science (Schwartz and Crawford 2005). When students engage in authentic science in a classroom community, they can participate in social practices similar to those of a scientific community. Participation in a modeled authentic scientific community can help make science accessible to students of diverse cultures and students from populations not usually represented in the scientific community. There is an expectation that authentic science in classrooms can and will motivate students. However, more research is needed to determine the extent to which authentic science may increase an interest in learning science, in students of underserved populations.

Cross-References

▶ Inquiry, as a Curriculum Strand
▶ Laboratory Work: Learning and Assessment

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