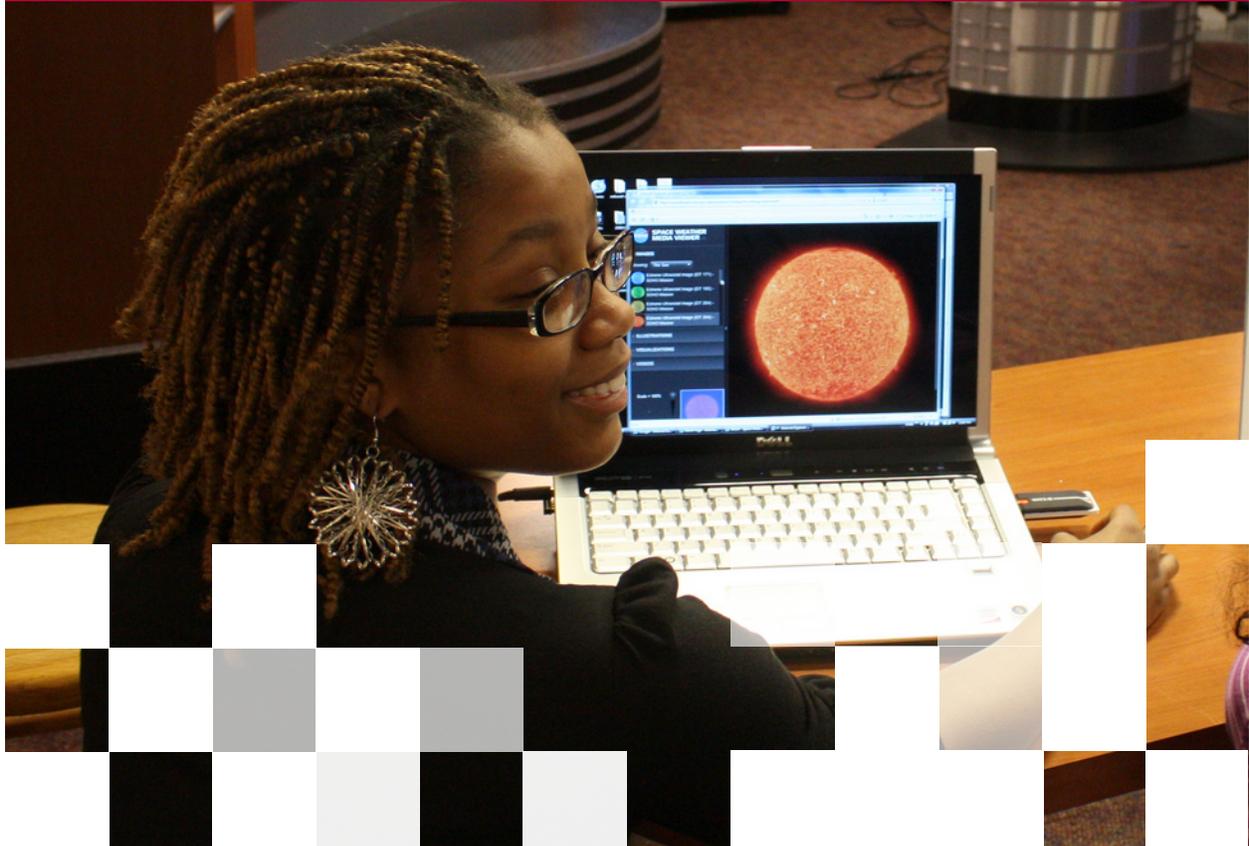


Types of Changes That Occur as Declarative Knowledge Increases



Albert Oosterhof

May 2012



Center for Advancement of Learning and Assessment

Florida State University, Tallahassee, FL
www.cala.fsu.edu



Types of Changes That Occur as Declarative Knowledge Increases

Albert Oosterhof

Center for Advancement of Learning and Assessment
210-B Sliger Building
2035 E. Paul Dirac Drive
Florida State University
Tallahassee, FL 32306-2801
aoosterhof@cala.fsu.edu

Acknowledgments

The work reported in this paper is supported through a grant from Education Research Programs at the Institute of Education Sciences (IES), award number R305A110121, administered by the U.S. Department of Education. Faranak Rohani is the principal investigator for this research. Related information is available at <http://www.cala.fsu.edu/ies/>. Findings and opinions do not reflect the positions or policies of IES or the U.S. Department of Education.

Copyright © 2012 by the Center for Advancement of Learning and Assessment, Florida State University. All rights reserved.

Cover photo by "NASA Goddard Space Flight Center"



Types of Changes That Occur as Declarative Knowledge Increases

In “Upgrading High-Stakes Assessments,” Oosterhof (2011) describes a research project at the Center for Advancement of Learning and Assessment (CALA) that is examining an alternative approach to large-scale assessment programs. In essence, the research investigates an option that may help expand the range of skills evaluated by statewide assessments while adding a significant formative aspect to these assessments. Because of the number of students involved, the typical approach to large-scale assessment programs is to use test formats that are highly efficient with regard to administration and scoring. This approach influences the formats that can be used and consequently constrains the types of competencies that can be assessed. This increased importance given to students’ performance on assessments motivates teachers to emphasize the types of knowledge and skills that can be measured by these tests.

Working from Florida’s Grade 7 science benchmarks, CALA identified competencies implicit in the curriculum standards that are beyond the reach of the statewide tests used in traditional assessment programs (Gilmer, Sherdan, Oosterhof, Rohani, & Rouby, 2011). Here are examples of these competencies:

Student can create a plan for carrying out a scientific investigation, including what, when, and how to measure variables.

Student can organize data by creating a table, chart, or other representation to facilitate interpretation.

Student can explain the difference between theories and laws. Student can provide examples of evidence that support a scientific theory.

Student can explain complex relationships between biotic and abiotic factors in an ecosystem.

As part of the research effort, a number of specifications are being developed, each defining a set of parallel tasks for students to complete. A particular task within each set is intended to provide evidence of a student’s proficiency with a given competency. Each competency emphasizes a particular type of knowledge: declarative knowledge, procedural knowledge, or problem solving. Among the four competencies listed above, the first focuses on procedural knowledge, the second on problem solving, and the last two on declarative knowledge.

Establishing a predominant type of knowledge when devising a task is relevant because different types of student performance provide particularly useful indicators for the respective types of knowledge. For instance, tasks related to declarative knowledge will involve students in some way stating or explaining what they know. Tasks related to procedural knowledge will involve students performing an operation that requires

application of a procedure, generally with the task presenting a specific operation that is novel to and not selected by the student.

Declarative knowledge, which is the focus of this paper, involves knowing that something is the case. This includes the recall of factual information. Declarative knowledge also involves being able to state and explain characteristics, terminologies, properties, phenomena, concepts, principles, and techniques, and can be quite complex. Chi and Ohlsson (2005) characterize it as the dominant form of knowledge, stating that human beings “have a lot of it.” They explain that declarative knowledge does not involve isolated units but rather is organized as semantic networks, theories, schemas, or some combination of these. They propose seven types of changes that occur as declarative knowledge increases: larger size, denser connectedness, increased consistency, finer grain of representation, greater complexity, higher level of abstraction, and shifted vantage point.

Within its examination of an alternative approach to large-scale assessments, CALA is using the Chi and Ohlsson (2005) framework when devising our specifications and tasks related to declarative knowledge. Therefore, as we devise these tasks and interpret students’ performance on them, it is important to be aware of the types of changes that Chi and Ohlsson propose will occur as declarative knowledge increases. Here we look briefly at each of the types. Following this review, a table provides a summary and additional example of each type of change.

- **Larger size.** Chi and Ohlsson (2005) note that the size of declarative knowledge increases over time, as illustrated by older children having more experience and knowledge than younger children. For instance, the number of characteristics that children (and adults) know about the neighborhood in which they live accumulates over time, such as knowing the characteristics of the people, houses, shops, businesses, and weather, among other things. As indicated earlier, declarative knowledge does not exist in isolation. As the number of known characteristics increases, each is learned as it relates to something. For example, characteristics of a grocery store may be known in the context of obtaining food, while characteristics of a house may be known in the context of knowing who lives there.

Most any declarative knowledge can increase in size and this increase can involve, for instance, knowledge of properties, phenomena, and techniques. In science, it includes learning the characteristics of more plants and animals, the difference between a law and a theory, what a spectroscope is and a purpose of its use, and how distillation works.

- **Denser connectedness.** Although declarative knowledge always involves a relationship, connectedness pertains to the density of these relations. For instance, a relationship exists between monarch butterflies and milkweed because monarch larvae eat milkweed. Denser connectedness includes knowing that the larvae absorb cardenolides in the milkweed, which are bitter and toxic to most animals but not

to the larvae. Thus, a monarch larva becomes a butterfly that is similarly toxic to other animals, with cardenolides protecting the butterflies as well as the milkweed. In meteorology, an example of connectedness is knowing that barometric pressure is associated with the amount of precipitation. A denser connectedness involves knowing the multiple links between higher pressure and vertical convection in the atmosphere, which, when inhibited, restricts cloud formation. Increased connectedness improves the likelihood that previously learned declarative knowledge would be applied in settings different from that in which it was learned.

- **Increased consistency.** Consistency deals with compatible beliefs across different situations or settings that involve or rely upon the same principle. Chi and Ohlsson state that a person who declares the earth is round is inconsistent should the person refuse to sail on the ocean for fear of falling over the edge. In astronomy, an example of consistency involves a principle known as redshift, which pertains to light waves. Light waves stretch out if the object emitting the light is rapidly moving away from the observer. Stretched-out light waves shift toward the red end of the color spectrum; therefore, a star that is moving away from the observer will look more reddish than a similar star moving toward the observer (i.e., the color of the star is observed to have shifted toward red if the star is moving rapidly away). Consistency also is involved when an astronomer views a spiral galaxy edge on and observes that the color of the stars on one side of the galaxy are more reddish than those on the other side. The astronomer uses this information to establish that the stars are spinning around the galactic center. Stars on one side are moving away and stars on the other side are moving toward the astronomer.

Inconsistency (lack of consistency), which often occurs, suggests that particular knowledge is incomplete. For example, stars far from the center of a galaxy would be expected to have less redshift than stars close to the galactic center. This would be the case if the orbital speeds of stars within galaxies were consistent with the orbital speeds of planets in our solar system around the sun. Like planets, the orbital speed of stars further from the center of their orbits would be expected to be lower than the orbital speed of stars near the center of a galaxy. However, astronomers have not observed this occurrence, which suggests an unknown variable that produces the inconsistency.

- **Finer grain of representation.** Fineness of grain involves increasing the details known about something by learning its relevant subcomponents or subparts, including their relationships. For example, one might know about the working components of a sailboat, such as the sail that powers the boat, the running lines used to trim the sails to proper angles relative to the wind, and the steering mechanism that controls the direction of the boat through the water. Further fineness of grain might address components of the steering mechanism, such as a tiller that provides the leverage needed to move and control the angle of the rudder

in the water, the rudder that makes contact with and uses the water to change or maintain the direction in which the boat is sailing, and the pintle and gudgeon that act as a hinge while attaching the rudder to the transom of the boat.

Chi and Ohlsson (2005) use knowledge of the human circulatory system as an illustration of fineness of grain. At a basic level, one may know how the circulatory system works relative to the function of the heart, lungs, blood, and blood vessels. This knowledge would include awareness that contractions of the heart send blood with oxygen from the lungs throughout the body. Chi and Ohlsson state that a finer grain of representation would include knowing how parts of the heart function, the properties of contractive muscle fiber, and so on. Additional learning can result in an even finer grain of representation, such as knowing how individual muscle fibers contract.

- **Greater complexity.** Complexity involves creating a more complex representation of phenomena by integrating what otherwise appears to represent distinct principles or relationships. Chi and Ohlsson illustrate this type of change from a historical perspective, using the development of the theory of evolution by natural selection as an example. They note that prior to the development of this theory, biologists were aware of inheritance, knew that variations within species existed, and understood that many species produced more offspring than survived long enough to reproduce. The theory of evolution created a more complex representation of these phenomena, combining three schemas into a new, more complex schema. Another example of complexity would be a student seeing parallels between how different simple machines provide mechanical advantage, for instance, between an inclined plane, screw, and wedge. Although each machine applies force in different ways, a common principle applicable to all three involves the use of a slope to produce a high level of force.
- **Higher level of abstraction.** Abstraction involves the representation of components of a phenomenon into a more compact and efficient abstract representation of the problem. Chi and Ohlsson note that the concept of abstraction is unsettled with respect to the source or derivation of an abstraction. When employing a procedure or solving a complex problem, an expert typically will perceive the process as a holistic abstraction, whereas a novice typically will require more mental effort, representing the process in the context of its multiple, more concrete components. For instance, Chi, Feltovich, and Glaser (1981) compared eight physics experts (doctoral students in physics) to eight physics novices (undergraduates who completed one relevant course with a high course grade). When asked to sort physics problems based on the similarities of the solutions, the novices grouped the problems based on what the solution looked like (i.e., the solution involves pulleys or inclined planes). In contrast, the experts grouped the problems by the physics principle

necessary to solve the problems, such as the conservation of energy or Newton's second law.

- **Shifted vantage point.** A vantage point pertains to the perspective from which something is known or understood. Increasing declarative knowledge can involve learning multiple vantage points, thereby perceiving or understanding something from multiple perspectives. Chi and Ohlsson cite research by Shatz and Gelman (1973), who found that two-year-olds could not adjust their speech to the age of the listener whereas four-year-olds adjusted their speech in response to talking to their peers versus talking to adults. Another illustration of shifted vantage point is understanding an issue from the perspective of individuals associated with a different culture, for example, as it relates to the modesty of women. Having an ability to understand a particular phenomenon or principle from another vantage point is not equivalent to accepting a particular perspective or idea as desirable or preferable, but it does involve more than being able to recite an alternate point of view. Learning multiple vantage points facilitates problem solving.

Learning to shift vantage point as declarative knowledge increases is relevant to science education. For instance, the process of evaporation can be learned from its opposite perspective: condensation. Water removes heat when it evaporates, which is the reason the skin is cooled when wind evaporates sweat. Water adds heat when it condenses. From this perspective, water condensing on a cold glass is adding heat to the glass and making its contents warmer. From still another perspective, water similarly condenses into clouds, making them warmer and contributing to air thermals and the puffy clouds associated with thunderstorms. In hurricanes, the huge amount of condensation that is present creates enormous amounts of heat, which is the energy source that powers these strong storms.

The following table summarizes the seven types of change that Chi and Ohlsson associate with increased declarative knowledge. An increase in particular declarative knowledge does not necessarily result in changes of all seven types, although as declarative knowledge is learned, change likely occurs within more than just one of the seven areas.

When selecting or developing tasks, the validity of assessments of declarative knowledge likewise benefits from taking into account the types of changes associated with increased declarative knowledge. The summary provided is intended to facilitate this choice of tasks. The table names each type of change, provides a brief description of the qualities involved in that change, and then offers an example. To facilitate contrast, each example relates to declarative knowledge from one content area—characteristics of our solar system.

Table. Qualities involved and examples of types of changes that occur as declarative knowledge increases

Type of Change	Qualities Involved	Example
Larger Size	Involves bringing in additional information. This information is added to an existing structure of knowledge, without changing previously learned knowledge and possibly without changing the structure or relationships that bind together elements of this prior knowledge.	If one knows that Earth, Mars, Jupiter, and Saturn are planets, an example of <i>larger size</i> is learning that Mercury, Venus, Uranus, and Neptune are also planets. If one knows that Earth and Mars are rocky planets and that Jupiter and Saturn are gaseous planets, an example of <i>larger size</i> is learning that Mercury and Venus are also rocky planets and that Uranus and Neptune are also gaseous planets.
Denser Connectedness	Involves increasing the number of relationships between elements of knowledge, often improving the quality or richness of existing relationships.	If one knows that Mercury, Venus, Earth, and Mars are rocky rather than gaseous planets, an example of <i>denser connectedness</i> is learning that these four rocky planets are smaller than the gaseous planets and have orbits closer to the sun than the gaseous planets.
Increased Consistency	Involves compatible beliefs across different situations or settings that involve or rely upon the same principle. Inconsistency, however, often occurs and should be tolerated as the complexities of knowledge are being learned.	One learns that the motion of the moon across the sky is due to its orbit around Earth, in addition to Earth's rotation on its axis. An example of <i>increased consistency</i> is knowing that the same phenomena are associated with the motion of the International Space Station across the sky. However, apparent <i>inconsistency</i> initially might be experienced to understand that the sun's observed motion across the sky does not mean it is orbiting Earth.

(table continued on page 10)

Type of Change	Qualities Involved	Example
Finer Grain of Representation	Involves increasing the details known about something by learning its relevant subcomponents or subparts.	If one is aware of the general appearance of the moon's surface, an example of a <i>finer grain of representation</i> is knowing that the surface includes many craters. An even <i>finer grain of representation</i> would be knowing that these craters typically have a perimeter that rises steeply from the crater floor.
Greater Complexity	Involves creating a more complex representation of phenomena by integrating what otherwise appears to represent distinct principles or relationships; analogous to creating a larger box into which existing smaller boxes fit well.	Ocean tides involve a periodic rise and fall of the sea level associated with the position of the moon and sun relative to Earth. Tidal force, which is relevant to ocean tides, is an example of <i>greater complexity</i> because it integrates an explanation of ocean tides with that of other phenomena, such as the breakup of Comet Shoemaker-Levy when it passed close to Jupiter. Tidal force is a secondary effect of gravity and states that gravitational force is weaker for objects that are a greater distance apart. For example, ocean water on the side of Earth nearest the moon is more strongly affected by the moon's gravitational pull than the rest of Earth's oceans, resulting in a high tide on that side of Earth. Likewise, tidal force caused Comet Shoemaker-Levy to break apart because Jupiter's strong gravitational force was sufficiently different on the comet's near and far sides to pull it apart. (See http://bit.ly/d2makm for a photograph of Comet Shoemaker-Levy after its breakup and other illustrations of tidal force.)

(table continued on page 11)

Type of Change	Qualities Involved	Example
Higher Level of Abstraction	<p>Involves representation of components of a phenomenon into a more compact and efficient abstract representation of the problem. When employing a complex procedure or solving a complex problem, an expert typically will perceive the process as a holistic abstraction, whereas a novice typically will require more mental effort, representing the process in the context of its multiple more concrete components. Abstractions allow more compact and efficient representations of relationships and principles.</p>	<p>The motion of planets across the night sky is complex because we observe them moving within their orbits from Earth's changing position within its orbit. Greeks referred to the observable planets as <i>asters planetasi</i> (ἀστέρες πλανῆται), which means "wandering stars." The observed planets generally move from west to east relative to the "fixed stars," but then move from east to west for a few weeks followed by a return to their normal motion. Planets in orbits closer to the sun than Earth's (Mercury and Venus) never move in the sky far from the sun, becoming regular morning or evening stars. The other planets move much more widely across the sky, and, unlike Mercury and Venus, can be overhead at midnight. Mars, being in an orbit closer to the sun, changes its position in the sky more rapidly than Jupiter and Saturn.</p> <p>Although this narrative involves abstractions, expert astronomers would often explain this planetary motion at a <i>higher level of abstraction</i>, using the Copernican model expressed as an equation. These astronomers cannot only use an equation to determine observed planet location, they also can understand observed planetary motion fully and efficiently through mathematics. (An interesting illustration of the Copernican model is available at http://faculty.fullerton.edu/cmconnell/Planets.html).</p>
Shifted Vantage Point	<p>Involves the ability to perceive a property or idea from a different point of view, thus allowing for a more complete representation of the knowledge.</p>	<p>From Earth, our moon moves slowly across the sky, always with its same side facing Earth. An example of <i>shifted vantage point</i> would be knowing what the corresponding view of Earth looks like from the moon. (From the moon, Earth appears to stay at the same place in the sky, rotating slowly on its axis.)</p>

References

- Chi, M. T. H., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science*, 5, 121–152.
- Chi, M. T., & Ohlsson, S. (2005). Complex declarative learning. In *Cambridge handbook of thinking and reasoning*. Cambridge University Press.
- Gilmer, P. J., Sherdan, D. M., Oosterhof, A., Rohani, F., & Rouby, A. (2011). *Science competencies that go unassessed*. Available online at http://www.cala.fsu.edu/files/unassessed_competencies.pdf
- Oosterhof, A. (2011). Upgrading high-stakes assessments. *Better: Evidence-based Education*, 3(3), 20–21.
- Shatz, M., & Gelman, R. (1973). The development of communication skills: Modifications in the speech of young children as a function of listener. *Monographs of the Society for Research in Child Development*, 38(5, Serial No. 152).

