Rediscovering The Core Cognitive Processes That Define Scientific Competence.

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ABSTRACT

Scientific competence has largely been portrayed in terms of observable attributes like: observation, classification, experimentation, problem-solving, explanation among others. This conceptualization ignores the cognitive processes involved in the construction and assessment of scientific knowledge. This paper argues that the greater focus should be on the justification of the central cognitive processes if scientific competence is to be the goal of any science curriculum.

Key words: Scientific, competence, core, cognitive, process, construction, assessment.

INTRODUCTION

Great scientists have displayed puzzling mental abilities in contributing to the growth of scientific knowledge. Johannes Kepler systematized the laws of planetary motion; Galileo invented the telescope; Alexander Graham Bell invented the telephone and gramophone; Albert Einstein for example formulated the special theory of relativity (1906) and the general theory of relativity (1916) besides his research in Quantum Physics.

The great scientists had a unique mental focus and demonstrated thinking modes that not only questioned what was known, but also provided new explanatory insights for new knowledge. This paper contends that an insight into the central cognitive processes of their scientific competence may build a good foundation for the science curriculum.

The key question are:

(i) How did great scientists represent knowledge in their minds?
(ii) What logic guided their processing of new information?
(iii) What criteria did they apply to scientific explanations?
(iv) *What methodology can be infused into the science curriculum to develop the core cognitive competences for scientific knowledge?*

We shall take note that Instrumental generic competences across disciplines, Sánchez, A. & Manuel P. Eds. (2008) have been construed to include the following:

1. **Analytical thinking: T**his is the mental behaviour that enables one to distinguish and separate the parts of a whole to arrive at its principles or elements. Analytical thinking is thinking in detail, accurately, Enumerating and distinguishing.

2. **Systemic thinking:** This is the mental behaviour that enables one to organize and integrate interrelated components to form a whole.

3. **Critical thinking:** This is the mental behaviour that questions things and concerns itself with the foundations on which our own and others' ideas, actions and judgements are based.

4. **Creative thinking:** This is the mental behaviour that generates searches to find new and unusual solutions that make sense in different areas of life.

5. **Reflective thinking:** This is the mental behaviour that facilitates the recognition and growth of the modes of thinking that we use in solving problems or performing tasks.

6. **Logical thinking:** This is the mental behaviour that develops ways of thinking that lead to knowledge in general and to scientific knowledge in particular, paying close attention to its structure. It means proceeding in a reasoned, sufficiently argued way.

7. **Practical thinking:** Is the mental behaviour that makes it easier to select the best course of action on the basis of available information and to decide how to proceed to achieve objectives with effectiveness and efficiency. It is the action-oriented way of thinking.

8. **Team thinking:** This is a way of working with other people to arrive at shared views.

9. **Time management**: Is the distributing of time wisely according to priorities, taking into account short-, medium- and long-term personal objectives and the areas of personal and professional life that one spends most time on.

10. **Problem-solving**: identifying, analyzing and defining the significant elements constituting a problem in order to solve it effectively and with good criteria.

11. **Decision making**: choosing the best course of action, following a systematic process and assuming responsibility for the scope and consequences of the option taken.

12. **Planning**: deciding effectively the objectives, priorities, methods and controls for work to be done, by organizing tasks within deadlines and available means.

13. **Computer skills**: utilizing computer skills or information and communication techniques (ICTS) as tools for expression and communication, for accessing information sources, for data and document filing, for presentation.

14. **Data management**: effectively organizing (structuring, gathering, processing and obtaining results from) information in a situation or phenomenon, and making best use of the possibilities afforded by computer systems for database management.

15. **Oral communication**: expressing clearly and opportunely one's ideas, knowledge and feelings in speech, adapting to the audience and situation to ensure good comprehension and attention.

16. **Writing skills**: relating effectively to other persons through clear written expression of what one thinks and/or feels, using graphic support as necessary

The Information Processing Model as a **framework used by cognitive psychologists to explain and describe mental processes** describes representational systems that fall into three basic families:

1. ***Propositional representations***-a set of discrete symbols or propositions equivalent to formal statements.
2. ***Analogical representations- a*** correspondence between the represented world and the representing world as direct as possible in terms of maps, models, images and pictures.
3. ***Procedural representations***- where knowledge is represented in terms of active process or procedures directly interpretable by an action system.

Scientific knowledge on the other hand is generated through five processes:

(I) ***Observation***-making use of the five senses to gain information about the real world.

(II) ***Experimentation***- the systematic process of gathering data in order to test the validity or authenticity of a given hypothesis.

(III) ***Speculation***-the process of going beyond available data in order to anticipate relationships that can be used to make predictions.

(IV) ***Imagery***-the process of constructing images in the mind for representing interactions, mechanisms, processes or structures in the real world.

(V) ***Intuition***-the faculty of mind that generates true knowledge without a clear or immediate explanation.

The concept of Scientific Competence

Ornstein(1986) asserts that, ''the content of our consciousness is a representation of outside reality" and thus consciousness must include a process for constructing a 'representation' or a model of the world; and a mental operating system endowed with acts of creation…. to process, infer, as well as analyze information to arrive at a reliable solution the percept.

Miller (1984) observes that Quantum Physics and Relativity Theory have changed the conception of scientific visualization. Practicing scientists now admit to the use of:

(i) Mental Imagery and Thought experiments as tools for advancement of scientific knowledge;

(ii) Probabilistic/statistical notions in constructing explanations;

(iii) Contextual considerations in constructing an acceptance criteria for scientific explanations.

The cognitive process of science therefore demands higher competences and it may be necessary to review curriculum focus to effectively develop such competences. This task will further require an integration of memory theory and information processing models.
A brief discussion of a model of Scientific Competence by Embeywa (1990) is presented below. In this model three cognitive competences are identified and their interactive nature is discussed. Embeywa (1985) explains that:

A decision on the part of a scientist that an explanation is valid or invalid ……is usually taken after a period of active processing of the input data (p.15).

The active processing is enabled by four competences:

C1: An ability to construct clear representation of events described in scientific language defined as ***visualization competence.***
C2: An ability to discern logical structure in sentences relating to scientific Knowledge called ***logical sensitivity***.
C3: An awareness of the role of logical laws in science called ***logical competence.***
C4: A readiness to subject scientific statements to logical scrutiny referred to as ***logical predisposition.***

In relation to C1, Embeywa (1990) explains three categories of visualization:

(i) ***Pictorial Visualization***- the construction of mental pictures, models and images.
(ii) ***Mechanistic Visualization***- the construction of propositions about the underlying mechanisms of natural events.
(iii) ***Formal Visualization***- the use of known formal/mathematical models relevant to the situation.

The other three competences are prerequisites to ***Mental Manipulation and Explanation-Perception*** and are more energized by ***Imagery, Intuition and Speculation.***
Manipulation involves:

(i) **Logical reasoning**- the recognition of logical structure in discourse and the search for consistency and completeness to avoid errors of implication, tautology and contradiction.
(ii) **Causal reasoning**- reasoning of the type:
A is the cause of B.
A causes B.
A is a causal factor for B.

(iii) **Analogical reasoning**- the transfer of knowledge to new situations by tracing similarities and differences between knowledge representations to enable: pattern completion; pattern extension; or pattern deletion.

Explanation-Perception is the final act of comprehension that involves:

(i) Explanatory **conceptions**.
(ii) Explanatory **models**.
(iii) **Acceptance criteria** for explanations.

Embeywa's model of Scientific Competence.

STRUCTURE

COGNITIVE INTERPRETATION	MANIPULATIVE INFERENCE GENERATION	EVALUATIVE CONCEPT SYNTHESIS

VISUALIZATION → MANIPULATION → EXPLANATION-PERCEPTION

MODELS

IMAGES

PROPOSITIONS

LOGICAL REASONING

CAUSAL REASONING

ANALOGICAL REASONING

JUDGEMENT OF CONCLUSIONS:

TRUTH

ACCEPTABILITY

ADEQUACY

ESSENCE

Some aspects of Scientific Competence in the History of Science.

In 1923, Louis de Broglie, a French physicist, proposed a hypothesis to explain the theory of the atomic structure. By using a series of substitution de Broglie hypothesizes particles to hold properties of waves. Within a few years, de Broglie's hypothesis was tested by scientists shooting electrons and rays of lights through slits. What scientists discovered was the electron stream acted the same was as light proving de Broglie correct.

Although de Broglie was credited for his hypothesis, he had no actual experimental evidence for his conjecture. In 1927, Clinton J. Davisson and Lester H. Germer shot electron particles onto onto a nickel crystal. What they saw was the diffraction of the electron similar to waves diffraction against crystals (x-rays). In the same year, an English physicist, George P. Thomson fired electrons towards thin metal foil providing him with the same results as Davisson and Germer.

Kekule is regarded as one of the principal founders of modern organic chemistry, the chemistry of carbon-based compounds. In 1858 he showed that carbon can link with itself to form long chains. In 1865 he reported his discovery of the benzene ring as the basis for another major group of carbon molecules.

Erwin Schrödinger was awarded the Nobel Prize in Physics in 1933. He is best known for his work regarding quantum theory, particularly about his **thought experiment involving a cat** in order to explain the flawed interpretation of quantum superposition.

Schrödinger's cat is a thought experiment, sometimes described as a paradox, devised by Austrian physicist Erwin Schrödinger in 1935.It illustrates what he saw as the problem of the Copenhagen interpretation of quantum mechanics applied to everyday objects.

In 1957, Hugh Everett formulated the many-worlds interpretation of quantum mechanics, which does not single out observation as a special process. In the many-worlds interpretation, both alive and dead states of the cat persist after the box is opened, but are decoherent from each other. In other words, when the box is opened, the observer and the possibly-dead cat split into an observer looking at a box with a dead cat, and an observer looking at a box with a live cat. But since the dead and alive states are decoherent, there is no effective communication or interaction between them.

Paul Adrien Maurice Dirac was an English theoretical physicist who is regarded as one of the most significant physicists of the 20th century.

Dirac made fundamental contributions to the early development of both quantum mechanics and quantum electrodynamics. Among other discoveries, he formulated the Dirac equation which describes the behaviour of fermions and predicted the existence of antimatter. Dirac shared the 1933 Nobel Prize in Physics with Erwin Schrödinger "for the discovery of new productive forms of atomic theory" He also made significant contributions to the reconciliation of general relativity with quantum mechanics.

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Conclusion

It has been argued that a decision on the part of a scientist that an explanation is valid or invalid ……is usually taken after a period of active processing of the input data (Embeywa , 1985). The active processing is enabled by four competences:

An ability to construct clear representation of events described in Scientific Language defined as ***visualization competence;*** an ability to discern logical structure in sentences relating to scientific Knowledge called ***logical sensitivity***, an awareness of the role of logical laws in science called ***logical competence; and a*** readiness to subject scientific statements to logical scrutiny referred to as ***Logical predisposition.***

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The ***Embeywa Model*** captures the essence of the scientific process of knowledge construction and assessment. It is therefore the conclusion of this paper that Pedagogy in Science needs to use the above discussed competences to guide both the delivery and assessment in Science.