Improving Combinatorial Reasoning through Inquiry-Based Science Learning

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INQUIRY-BASED SCIENCE LEARNING AND DEVELOPMENT OF REASONING SKILLS

Inquiry-based science activities, such as planning and conducting experiments, organising results from observations, reporting findings and building theories require the most systematic forms of reasoning (Adey and Csapó, 2012). Consequently applying inquiry-based methods offer many possibilities to foster students' thinking skills (see Adey and Shayer, 1994; Csapó, 1999). However, in order to exploit their potential, teachers must be aware of the way different reasoning processes are embedded in inquiry-based activities. Furthermore, teachers should be able to identify reasoning skills and to monitor their development. Several previous programs have already utilized science learning for fostering thinking, among these the most well-known is the Cognitive Acceleration through Science Education (CASE) project (see e. g. Adey and Shayer, 1994).

COMBINATORIAL REASONING

Combinatorial reasoning is the process of creating complex constructs out of a set of given elements that satisfy the conditions explicitly given or inferred from the situation (Adey and Csapó, 2012). Combinatorial reasoning plays an important role in many inquiry activities and also has a central position in Piaget's theory of formal reasoning (Inhelder and Piaget, 1958), in creative processes (Simonton, 2010), and in problem solving (Funke, 1991). Former experiments have indicated that combinatorial reasoning is amenable to stimulation, and physics and chemistry learning may easily be enriched with combinatorial exercises (Csapó, 1992, 1999).

THE AIM OF THIS PAPER

In this paper we demonstrate the role of combinatorial reasoning in some inquiry-based science learning tasks. We show how combinatorial reasoning is related to the better known control and manipulation of variables that is prerequisite to designing and evaluating experiments. We present examples that indicate how systematic enumeration of every possible combination of variables or values of variables is essential in organizing knowledge. Distinguishing conceivable and physically realisable combinations contributes to understanding scientific relationships. We demonstrate how learning tasks with similar combinatorial structures but different contents help to generalize reasoning patterns and improve transfer of knowledge.

TASK 1.

The first example shows how we can help to distinguish between the really existing, the possible, and the impossible (but conceivable) combinations of things.

Let us ask students to enumerate the words Sun (A), Earth (B) and Moon (C) in all possible sequences!

Formulating questions:

- Which sequences are possible in reality?
- If the three celestial bodies are in one straight line, in which cases can there be an eclipse of the Moon, and in which cases an eclipse of the Sun?

Implementing and concluding:

The result of the enumeration is the following:

Sun	–	Earth	–	Moon	lunar eclipse
Sun	–	Moon	–	Earth	solar eclipse
Earth	–	Sun	–	Moon	not possible
Earth	–	Moon	–	Sun	solar eclipse
Moon	–	Sun	–	Earth	not possible
Moon	–	Earth	–	Sun	lunar eclipse

Combinatorial structure: permutation without repetition with a set of three elements: {A, B, C}.
Solution: ABC, ACB, BAC, BCA, CAB, CBA.

Applying:

The solution of this task not only requires comprehension of the structure of the solar system but also helps the development of a schema to enumerate all permutations of given elements.

TASK 2.

The following task helps to generate unusual relationships between given concepts. In this way the ability to make remote associations may be developed as well. The textbook that provides the content for devising this tasks lists some possible groupings of materials in an introductory section. The groups of materials introduced there are: sources of energy (A), inflammable materials (B), nutritive materials (C), metals (D), and minerals (E). Students could be asked to combine these aspects in every possible way.

Formulating questions:

- What can we say about these relationships?

Implementing:

The possible pairs of the five groups are:

source of energy	–	inflammable material
source of energy	–	nutritive material
source of energy	–	metal
source of energy	–	mineral
inflammable material	–	nutritive material
inflammable material	–	metal
inflammable material	–	mineral
nutritive material	–	metal
nutritive material	–	mineral
metal	–	mineral

Combinatorial structure: combination without repetition with a set of five elements: {A, B, C, D, E}
Solution: AB, AC, AD, AE, BC, BD, BE, CD, CE, DE.

Concluding and applying:

During the discussion on the connections between these various concepts we can gather together several known facts, for example: numerous sources of energy are inflammable; certain nutritive materials are sources of energy for living organism; salts of certain metals are vital, whereas others are poisonous for living organisms; most of the metals can be found in the form of minerals in Nature, and so on. Practice with these operations makes it possible to increase the consistency of knowledge, as they highlight relationships which might otherwise never appear in the teaching-learning processes.

TASK 3.

Our third task helps students to understand the importance of controlling and manipulating variables in the design and implementation of scientific experiments. The task for students is to examine the effects of different combinations of material's state on the speed of reaction time. A material's states can be solid (A), liquid (B) or gas (C).

Formulating questions:

- Which type of reaction is the fastest? Order the pairs by reaction rate!
- What was your ordering principle?
- Which reaction type can be an exemption? Why?
- What experiments would be needed to test your assumptions?

Implementing:

The possible pairs of the given states are:

solid state	–	liquid state
solid state	–	gas state
solid state	–	solid state
liquid state	–	gas state
liquid state	–	liquid state
gas state	–	gas state

Ordered pairs by reaction time and possible experiments:

gas state	–	gas state	hydrogen (H2) + oxygen (O2)
liquid state	–	gas state	carbon-dioxide CO2 + slaked lime and water [Ca(OH)2]
liquid state	–	liquid state	hydrochloric acid (HCl) + sodium hydroxide (NaOH)
solid state	–	gas state	sodium (Na) + chlorine (Cl)
solid state	–	liquid state	hydrochloride acid (HCl) + limestone [Ca(OH)2]
solid state	–	solid state	iron (Fe) + sulphur (S) + saltpetre (KNO3)

Combinatorial structure: combination with repetition with a set of three elements: {A, B, C}
Solution: AB, AC, AA, BC, BB, CC.

Concluding and applying:

During the solution and discussion phase of this task students can not only understand the effect of a material's state on the speed of reaction but also recognize different variables which can affect the results of chemical reactions in general. It also contributes to deepening their scientific knowledge of the structure of matter.

TASK 4.

The fourth task also helps student to design experiments and to systematically manipulate and control variables. In this pendulum experiment students are provided with a heavy (A) and a light (B) ball that can be put at the end of a short (1), medium (2) or long (3) string.

Let us ask students to determine how the time of the pendulum swing depends upon the weight of the ball and the length of the string.

Formulating questions:

- What defines the time of the pendulum swing: the weight of the ball or the length of the string?

Implementing:

The possible variations of the pendulum from these materials are the following:

heavy ball	–	short string
heavy ball	–	medium string
heavy ball	–	long string
light ball	–	short string
light ball	–	medium string
light ball	–	long string

Combinatorial structure: Cartesian product with the sets of the following elements: {A, B} and {1, 2, 3}
Solution: A1, A2, A3, B1, B2, B3

Concluding and applying:

During this task students can perform the necessary measurements and comparisons between the different constructions, which involves the designing and implementing of experiments, collecting, organizing and explaining data and based on the findings, drawing the conclusions.

DISCUSSION

Our demonstration contributes to the understanding of how combinatorial reasoning skills are embedded in inquiry-based activities and relate to complex thinking skills. The presented tasks require active processing of the material, following the inherent logic of the subject matter, organising the concepts and facts, drawing conclusions from the information given and building relationships between already existing knowledge and newly acquired information. This inquiry-based inclusion of teaching reasoning skills through scientific content leads to meaningful learning which results in coherent understanding of the content and deeper understanding of scientific concepts and phenomena.

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