The interplay of domain-specific and domain general processes, skills and abilities in the development of science knowledge

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Overview

- I will present a domain specific theory to describe and explain some of the changes that take place in conceptual organization in the process of learning science.
- I will also argue that these domain specific conceptual changes depend critically on the development of certain domain general abilities or skills such as representational, perspective taking, hypothesis testing and reasoning, and executive function
- This complex interplay between domain specific and domain general abilities may be responsible overtime for the development of the new conceptual structures and new types of processing required for understanding science.

A domain specific theory of science learning: the framework theory approach

- 1. Naïve physics is a ‘framework theory’
- 2. Learning science requires fundamental changes in students’ ontological and epistemological commitments and in their representations
- 3. These changes are slow and gradual and produce fragmentation and synthetic conceptions
- 4. Scientific concepts do not replace naïve ones but co-exist with them

Naïve physics is a framework theory

- Naïve physics does not consist of fragmented observations but forms an explanatory system with some coherence - a framework theory
- A framework theory is a skeletal conceptual structure that grounds our deepest ontological commitments in terms of which we understand the world. It is not an explicit, socially shared and well formed scientific theory
- **We have chosen to call it a 'theory' because it is a principle-based system which is characterized by a distinct ontology and causality and which is generative in that it can give rise to prediction and explanation.**
- **Research with infants shows that they make ontological distinctions, such as the distinction between physical objects and psychological beings. When an entity is categorized as a physical object it inherits all the characteristics of the category.**

Framework theories in physics and psychology

(Ballargeon, 1990, Carey, 1985, Spelke, 1991)

Naïve Physics	Naïve Psychology
Ontology: Physical Object **Causality:** Mechanical	**Ontology:** Psychological Beings **Causality:** Intentional

Instruction-induced conceptual changes in naïve physics

(Vosniadou, 2013)

- By the time they start primary school children have developed a naïve physics that provides intuitive explanations of everyday phenomena
- These early conceptual structures are very different from the scientific concepts to which children are exposed through formal instruction
- Naïve physics needs to be changed in the process of science learning – new concepts, new ontological categories, new representations, must be formed

Naïve and scientific explanations of the day/night cycle

The sun goes behind the mountains and the moon comes up

Earth is flat

stationary

supported by ground, water, etc

Sun and the moon are in the sky and they move

Sun goes down behind the mountains and the moon comes up

Geocentric universe

The earth rotates around itself

Earth is a spherical planet

in space

rotating around itself and revolving around the sun.

Day/night happens because different parts of the Earth face the sun as the Earth rotates around itself

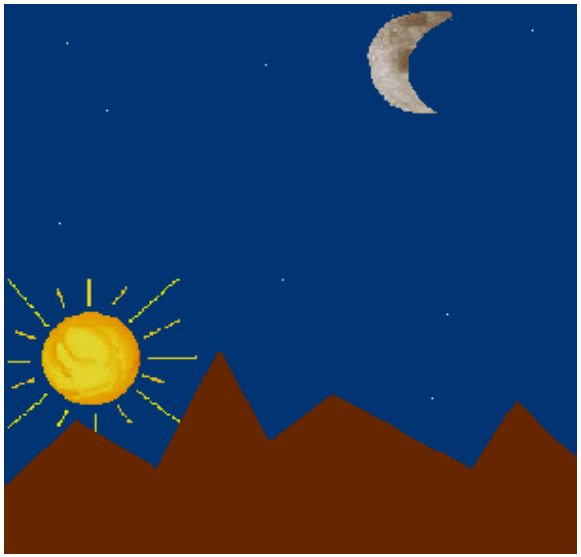
heliocentric solar system

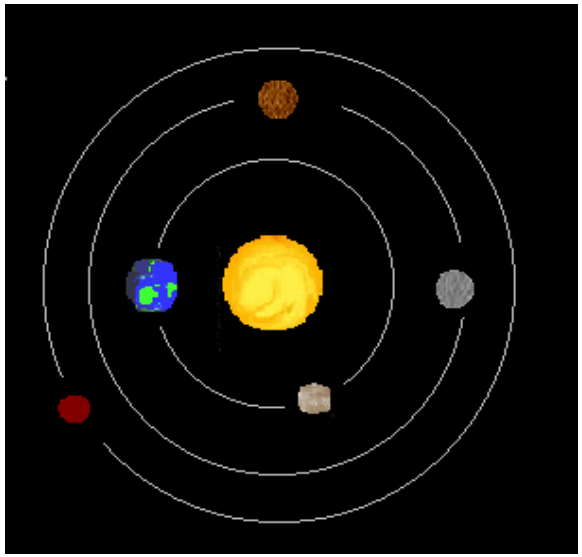
Learning science requires changes in categorization and the formation of new concepts and categories

- Physical Objects vs. Solar Objects
- Earth is a Physical Object – Sun and Moon are Solar Objects

- Physical Objects vs. Astronomical Objects
- Earth, Sun and Moon are Astronomical Objects, etc.
- (Vosniadou & Skopeliti, 2005)

Changes in representation





Changes in personal epistemology

- Explanation based on simple interpretation of sensory evidence vs. hypothetical unobservable entities
  - Development of processes of evidence evaluation, hypothesis testing and problem-solving and reasoning
- Beliefs about knowledge - Nature of knowledge – and the processes of knowing
  - Certainty and objectivity of knowledge vs. tentative and evolving
  - Simplicity vs. complexity of knowledge
  - Knowledge outside the self and transmitted vs. constructed
  - Observation and authority vs. inquiry, evaluation and hypothesis testing

The achievement of these conceptual changes is a slow process during which fragmentation and synthetic conceptions are formed

- Instruction-induced conceptual changes are not sudden, gestalt-types restructurings
- They are slow and gradual and characterized by the creation of fragmentation and misconceptions
- Both fragmentation and misconceptions can be explained if we assume that students use constructivist learning mechanisms to assimilate scientific concepts to their naïve physics

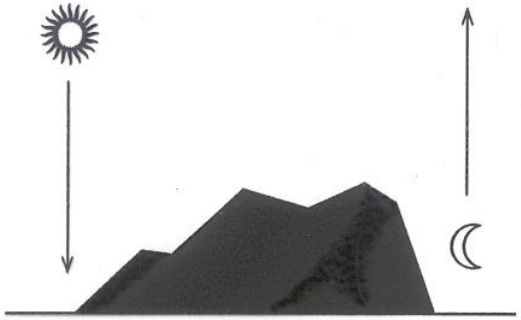
Fragmentation

- Fragmentation can be produced when learners assimilate scientific information to their naïve physics without concern for internal consistency.
- Many children who believe that the day/night cycle is caused because the sun goes behind the mountains simply add the scientific information that the earth turns to their original explanation thus creating an inconsistent response.
- Fragmentation can often be produced as the initial result of instruction

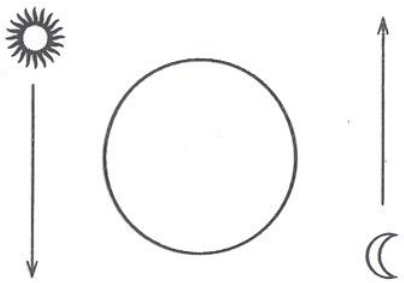
Synthetic conceptions

- Synthetic conceptions are formed when learners assimilate scientific information to their naïve physics but in the process create an alternative explanation that has some internal consistency and explanatory value.
- Synthetic conceptions are incorrect but sometimes creative solutions to the problem of incompatibility between scientific information and initial conceptions

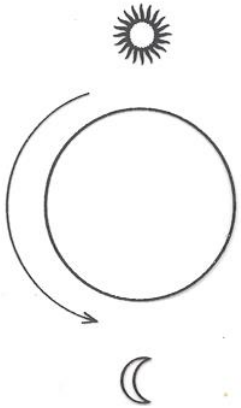
Synthetic models of the Day/Night Cycle (Vosniadou & Brewer, 1994)



1. The sun goes down, on the ground, behind mountains, and the moon comes up.

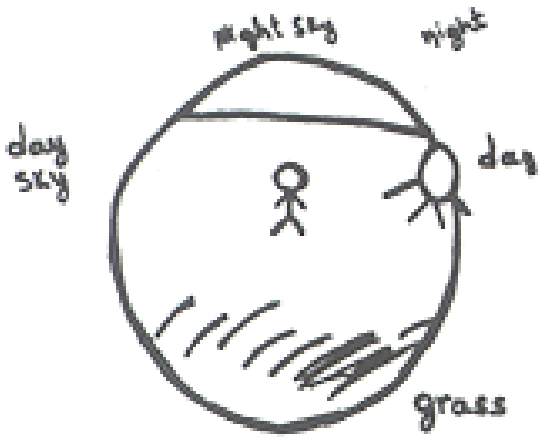


2. The sun goes down, to the other side of the earth, and the moon comes up.



3. The earth rotates in an up/down direction. The moon and sun are located at opposite sides.

4. The earth rotates in an east/west rotation. The sun and moon are located at opposite sides.



Drawing No. 4

4. The sun goes down on/in the ground (and the moon comes up).

Harmony (No. 41, Grade 1)

E: Can you make it day for this person?

C: (see drawing 4 in Figure 4)

E: Now make it night for that person.

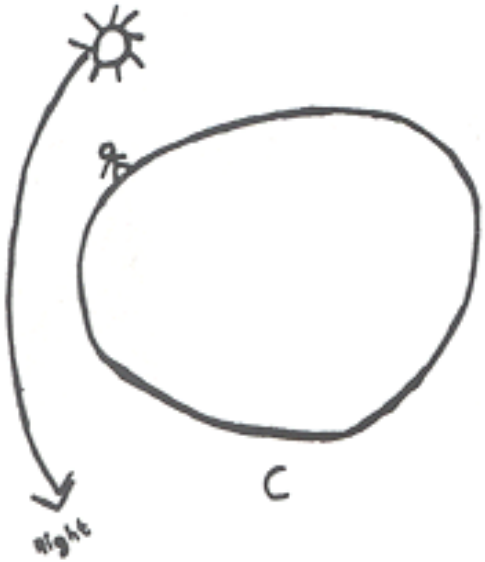
C: To make it night, erase the sun and replace it with the moon.

E: Can you tell me once more how it happens?

C: The sun goes down and the moon comes up, and then the moon goes down and the sun comes up.

E: Where is the moon when the sun is up?

C: The moon is where the sun rests.



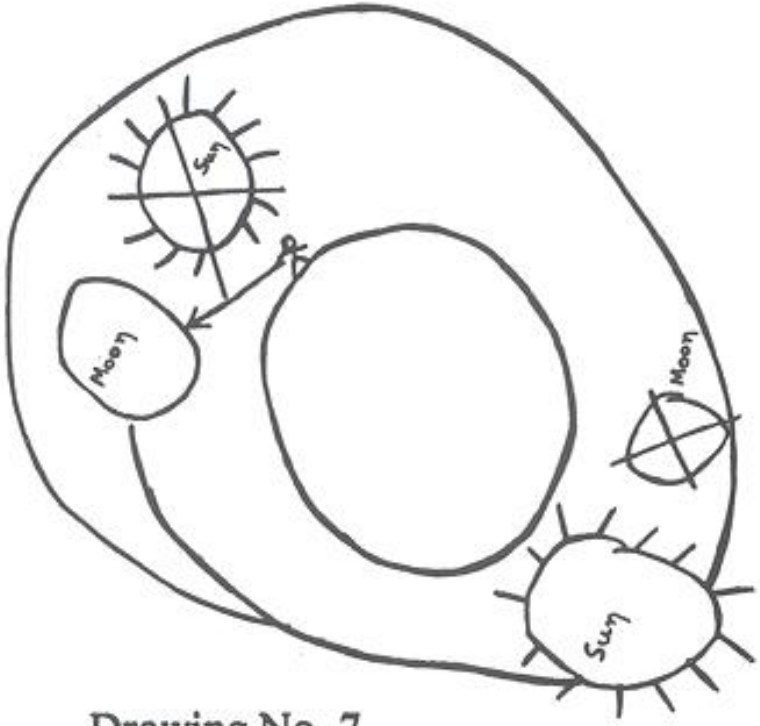
Drawing No. 5

5. The sun goes down to the other side of the earth (and the moon goes up).

Timothy (No. 47, Grade 1)

The child makes the drawings shown in Figure 4.

E: Tell me once more how it happens.
C: When the moon comes up and the sun goes down.
E: Where was the moon before?
C: Under the earth.
E: What time was it when it goes under the earth?
C: Day.



Drawing No. 7

7. The sun and the moon revolve around the earth.

Karen (No. 37, Grade 3)

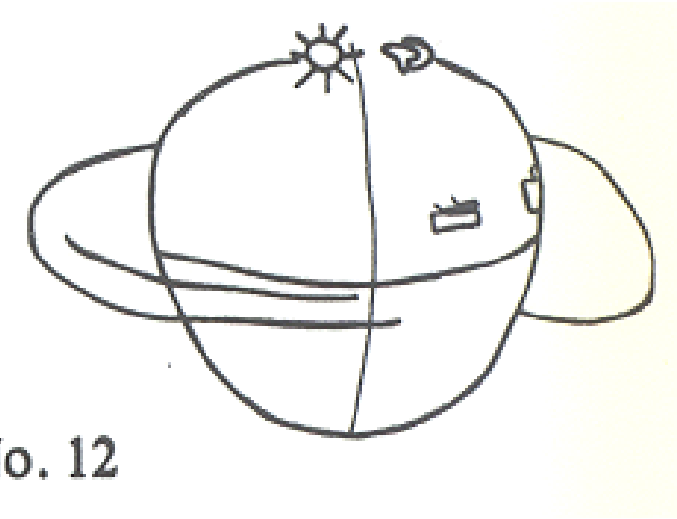
The child makes drawing 7 shown Figure 4.

E: Now make it so it is night.

C: We have to cross out the sun and put it over here.

E: Tell me once more how it happens.

C: Well, the sun vibrates around the earth every 12 hours. And then the moon goes the other direction and vibrates around the earth every 12 hours. So both us and China have the moon and the sun.



Drawing No. 12

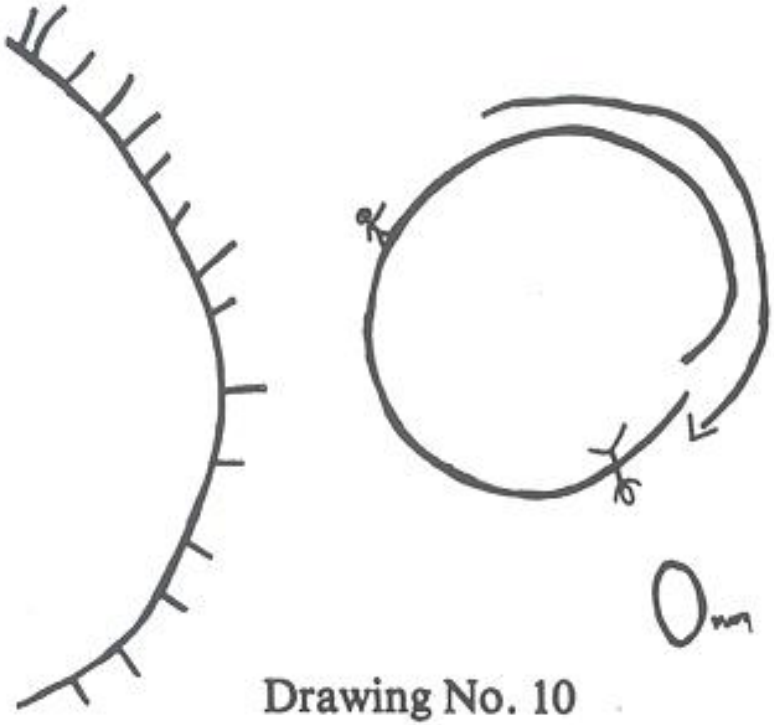
12. The earth rotates left/right and the sun and moon are fixed at opposite sides.

Venika (No. 33, Grade 3)

C: (Child makes drawing 12, Figure 4)

E: Can you tell me how this happens?

C: When the earth turns around its orbit, this side comes day and the other side comes night.



Drawing No. 10

10. The earth rotates up/down and the sun and moon are fixed at opposite sides.

Robert (No. 5, Grade 5)

E: Now make it so it is day for that person.

C: (child makes drawing 10 shown in Figure 4)

E: Now can you make it nighttime?

C: Can I draw him somewhere else? (draws figure at the bottom of the earth)

E: Sure.

C: (Child draws arrows to show how earth spins)

E: Tell me how it happens.

C: When it was daytime, the earth spinned around to the sun. When it was nighttime, the earth turned around to where the moon is.

Frequency of Explanations of the Day/Night Cycle Grade

Types of Explanation	1st Grade	3rd Grade	5th Grade
Sun occluded by clouds or moves down	**7**	2	1
Sun and moon move up/down to the other side of the earth	**6**	0	0
Sun and moon revolve around earth	0	2	0
Earth revolves around sun	1	2	1
Earth rotates (up/down) Sun and Moon fixed	1	4	**10**
Earth turns unspecified	2	2	2
Earth rotates sideways Moon revolves around Earth	0	2	1
Mixed/Undetermined	3	6	5
Total	**20**	**20**	**20**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strawberry.

The role of domain general abilities

- The creation of these new models, concepts, theories depends crucially on the development of certain domain general abilities, such as, representational abilities, the ability to take multiple perspectives, the ability to distinguish appearance from reality, and the understanding that are beliefs are not copies of reality but constructed, hypothetical and subject to hypothesis testing and falsification.
- Learning science depends on the complex interplay between domain specific conceptual changes and domain general processes, abilities or skills.

Summary of the framework theory approach

- Children start the knowledge acquisition process by organizing their everyday experiences into a naïve physics.
- Naïve physics forms a relatively coherent explanatory system - a framework theory.
- Learning science requires revision of existing categories, new concepts and categories to be formed
- Fragmentation and synthetic conceptions can be formed in the process because learners use constructive types of mechanisms to assimilate scientific information into their knowledge base.
- Domain general abilities or skills, such as representational and perspective taking abilities and hypothesis testing and reasoning skills are crucially implicated in making these conceptual changes happen in the process of learning science

Why Do We Need to Posit the Existence of a Framework Theory to Account for Conceptual Change Processes and More Specifically for Ontological Shifts?

- Some researchers argues that many students mistakenly assign concepts such as heat, force, electricity and light, to the ontological category 'Entities' when they should be assigned to the scientifically correct ontological category 'Processes'.
- I agree and go further than describing these changes. **The framework theory uses evidence from cognitive developmental theory to explain why the physical world is originally organized in ontological categories that are different from those accepted by science, and why ontological shifts are difficult (because they are no isolated knowledge pieces but embedded in large and systematic networks of concepts – in naïve theories).**
- **These initial ontological categories are not wrong and misconceived. They are absolutely justified considering our everyday experiences in the physical world.**

Why Does the Framework Theory Claim that Students Always Cohere When the Empirical Evidence Clearly Shows that They Do Not?

- I do not claim that. I accept the presence of fragmentation and inconsistency.
- diSessa argues for a learning process that proceeds from fragmentation to coherence under the influence of instruction. Coherence is triggered top-down, by students' exposure to symbolic and verbal knowledge system as presented via instruction and texts,
- I believe that the need and search for coherence is more an initial condition of the cognitive system and that students are sensitive to issues of coherence from early on (thus the formation of synthetic models), and that fragmentation can often be the product of initial instruction.

The predictive power of the framework theory

- The strength of the framework theory is that it provides an account of the transition process from an initial to scientific concepts. It predicts:
  - A slow and gradual transition
  - The generation of fragmentation and synthetic models
- It also allows us to predict when and where such misconceptions are likely to occur:
  - When there is incompatibility between the new, scientific information and existing beliefs and presuppositions

What happens to naïve concepts when scientific concepts are learned?

- Replacement view
- Conceptual change as some kind of restructuring – scientific concepts replace naïve physics.
- Co-existence of naïve and scientific concepts
- Findings of recent research support the hypothesis that scientific concepts do not replace naïve physics but the two co-exist, and furthermore that naïve physics inhibits access to scientific theories.

- This hypothesis was tested in a set of recent experiments in our lab.

The phenomena explanation task

Vosniadou, Lepenioti, Chountala, Eikospentaki, Papavasiliou, Thanou,2013

- 4 explanations for each phenomenon

Consistent with naïve explanation

- Agree with both naïve and scientific explanations(+/+) - true
- Agree with neither naïve and scientific explanations(-/-) - false

Inconsistent with naïve explanation

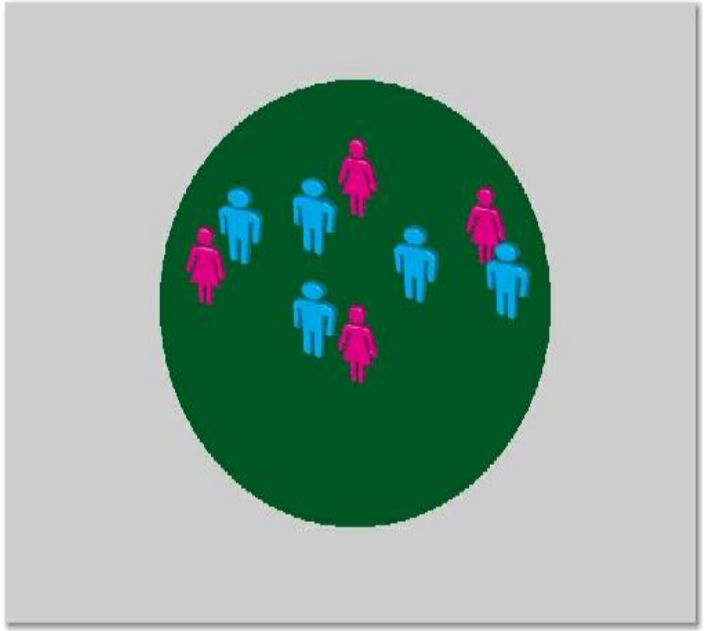
- Agree only with scientific explanation(-/+) - true
- Agree only with naïve explanation(+/-) -false

- (42 phenomena-4 domains, physics, biology, mathematics, epistemology – 104 4th, 5th, 6th graders and 42 undergraduates)

People live of different parts of the Earth

Οι άνθρωποι ζουν

σε διάφορα σημεία πάνω στη γη



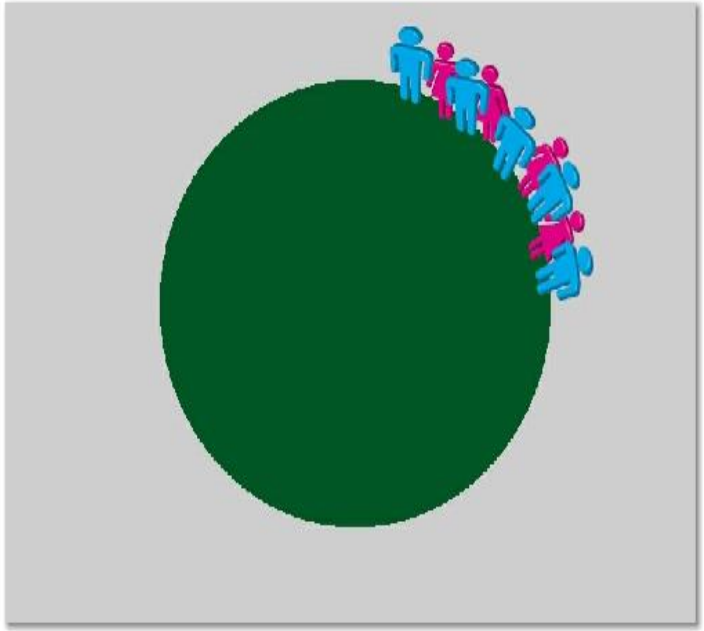
ΝΑΙ

ΟΧΙ

People live only on the right part of the Earth

Οι άνθρωποι ζουν

μόνο στο δεξί μέρος της γης



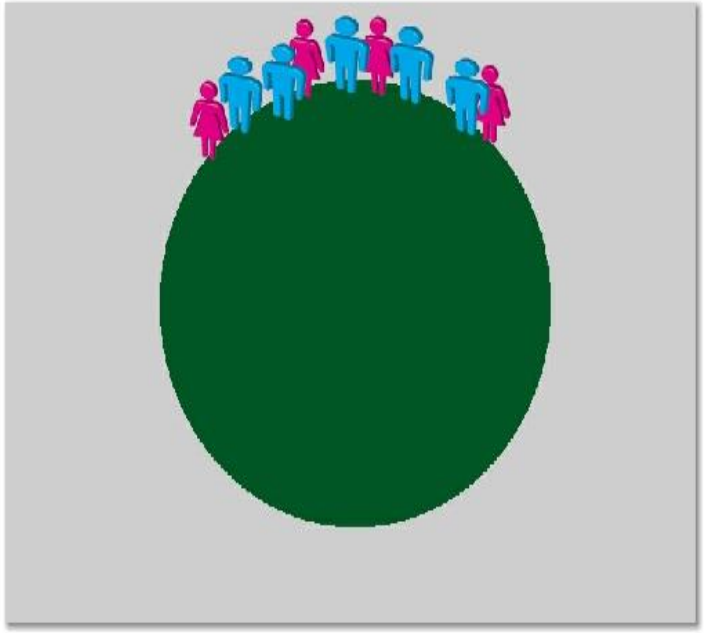
ΝΑΙ

ΟΧΙ

People live only on the top part of the Earth

Οι άνθρωποι ζουν

μόνο στο πάνω μέρος της γης



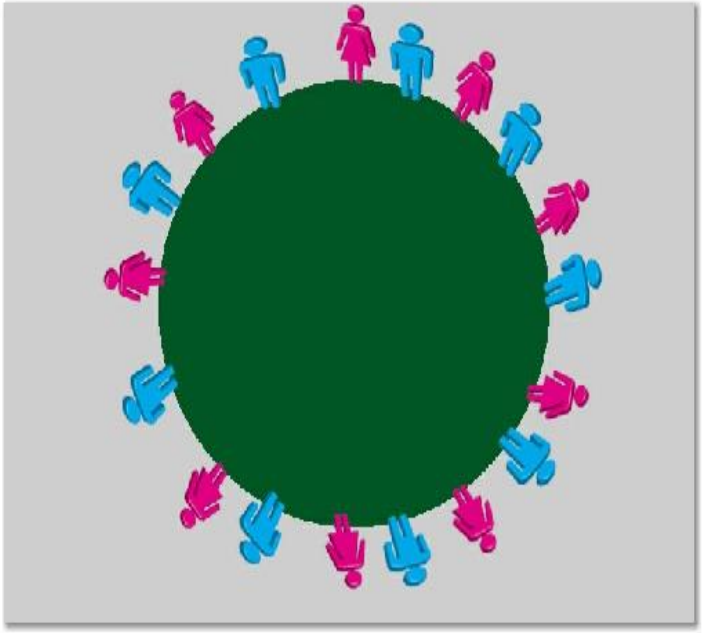
ΝΑΙ

ΟΧΙ

People live also on the bottom part of the Earth

Οι άνθρωποι ζουν

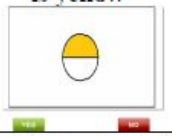
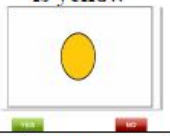
και στο κάτω μέρος της γης



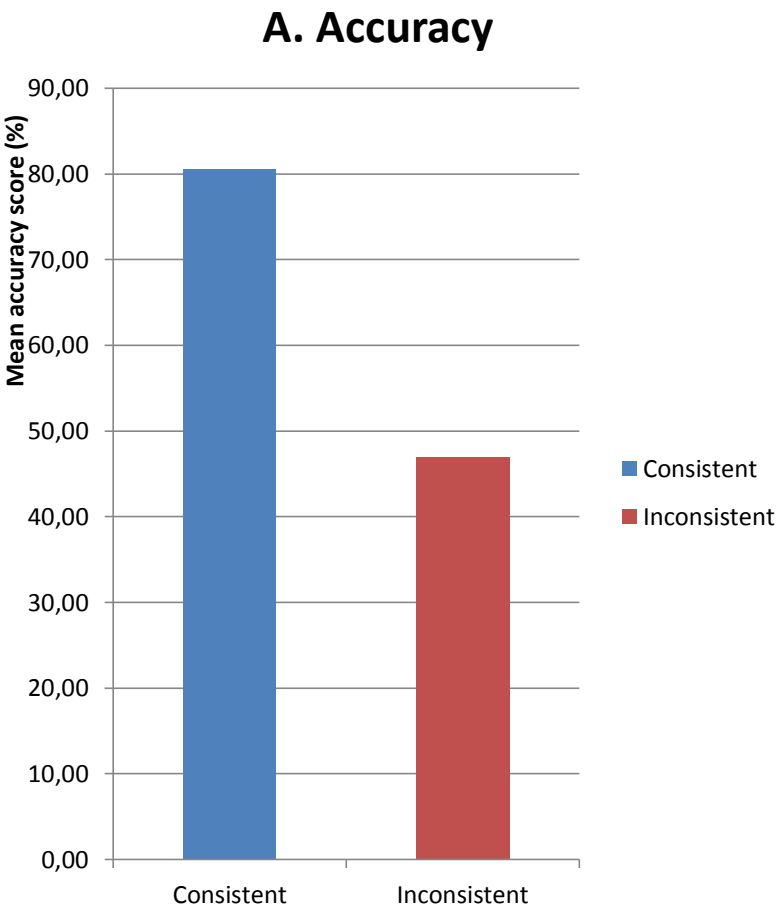
ΝΑΙ

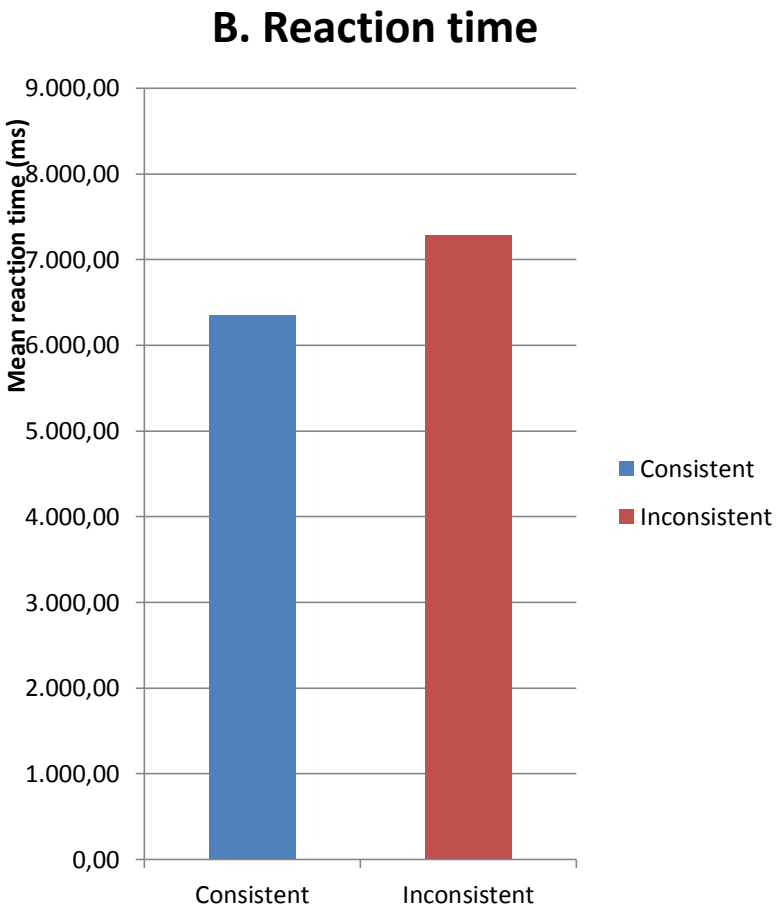
ΟΧΙ

Examples from the PhenEX Task

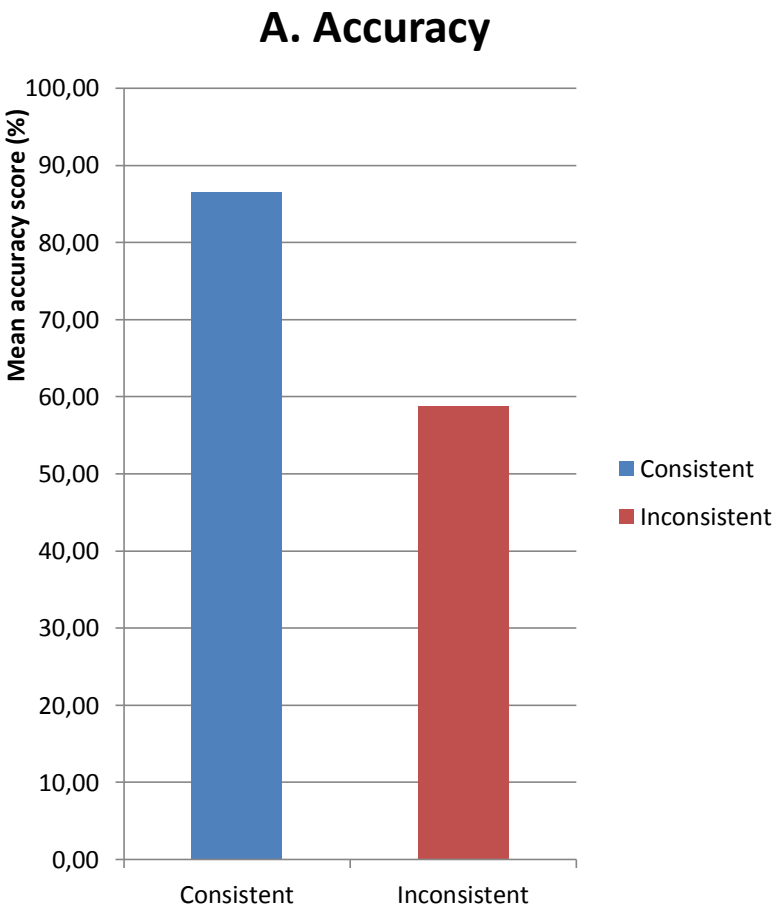
Domain	True Initial/True Scientific	False Initial/False Scientific	True Initial/False Scientific	False Initial/True Scientific
Mechanics	The man exerts force on the spring when he pulls it 	The man exerts force to the spring when he looks at it 	The man exerts force to the spring only when the spring is stretched 	The man exerts force to the spring when the spring is not stretched 
Matter	The room is cold because the window opens 	The room is cold because Costas comes in 	The room is cold because cold gets in 	The room is cold because heat gets out 
Astronomy	If a man travels on the Earth for a long time, he will reach a far place 	If a man travels on the Earth for a long time, he will reach the moon's edge 	If a man travels on the Earth for a long time, he will reach the Earth's end 	If a man travels on the Earth for a long time, he will return where he left from 
Mathematics	½ of the pie is yellow 	1/4 of the pie is yellow 	2/3 of the pie is yellow 	2/8 of the pie is yellow 
Biology	The lion can get sick 	The shoe can get sick 	The throat can get sick 	The tree can get sick 

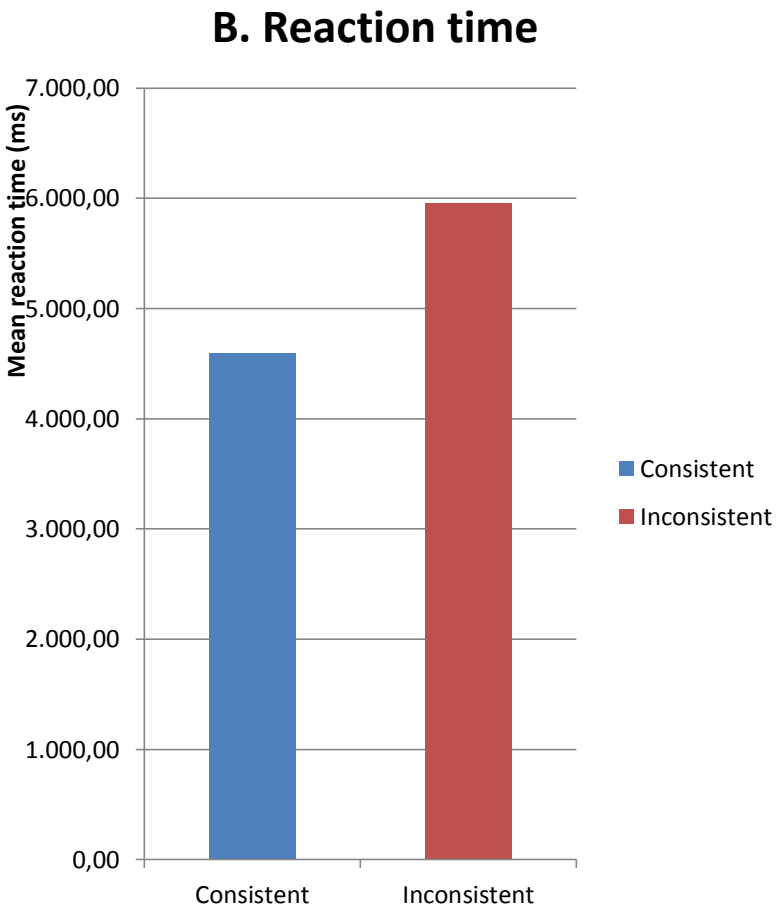
PhenEX Experiment: Accuracy and Reaction Times for Elementary School Students



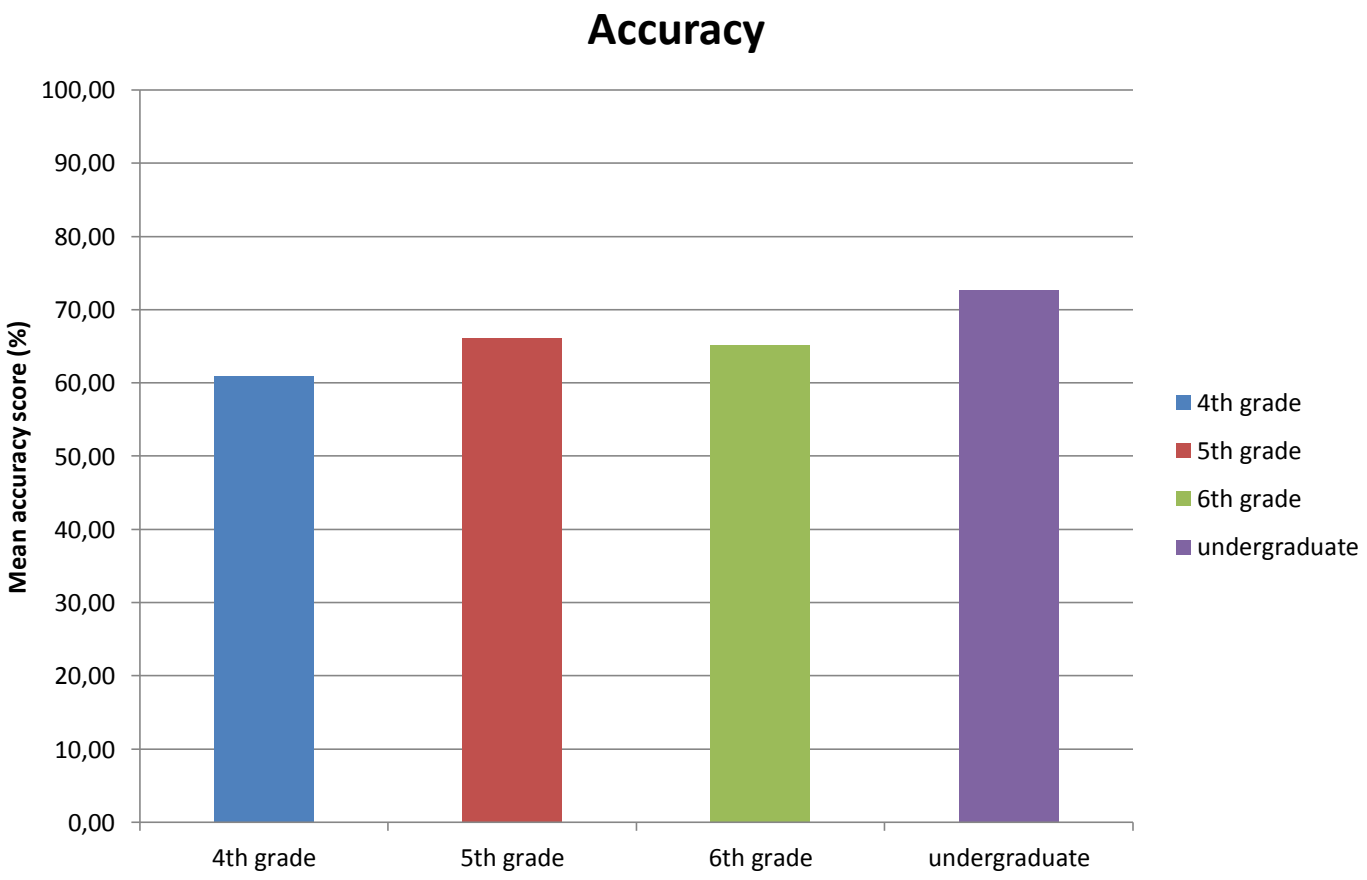


PhenEX Experiment: Accuracy and Reaction Times for Undergraduate University Students





PhenEX Experiment: *Students' mean accuracy score by age*



Summary

- There were significant differences in accuracy and speed between children and adults. The adults were more accurate and faster than the children.
- Regardless of the age differences, all the participants were verified the explanations more accurately and faster when they were consistent with naïve theories than when they were inconsistent with naïve theories
- The results confirm previous findings showing that naïve explanations continue to exist and to influence our thinking

The role of executive function skills in conceptual change

- Reaction time studies show that naïve concepts are more accessible than scientific ones
- If naïve concepts inhibit access to scientific concepts, then scientific thinking requires increased Executive Function skills
- We predicted high correlations in performance in EF tasks and conceptual change tasks like Re-Cat.

Executive Function (EF) Skills

- A set of skills or processes responsible for the regulation and monitoring of complex cognitive tasks that require deliberate planning, impulse control, goal-directed behavior and flexible strategy employment (Baddeley, 1996; Miyake et al., 2000)
- Inhibition, shifting and updating

High correlations between performance in Conceptual Change and EF Inhibition tasks

- We examined the relationships in children's performance in 3 inhibition tasks and 2 conceptual change tasks (such as the Phen-Ex Task)
- One hundred and thirty children (10 to 12 year-olds)
- High correlations were obtained between performance in the inhibition tasks and the categorization task. EF performance predicted performance on the conceptual change tasks.
- The Structural Equation Model had an excellent fit to the data, suggesting that EF is a good predictor of conceptual change
- *(Vosniadou, Chountala, Lepenioti & Eikospentaki, in preparation)*

Connecting Domain Specific Conceptual Changes to Dual Process Theories

- The results presented are consistent with dual process theories.
- Compelling evidence for a two process distinction in the human mind.
- Dual process theories can account for a wide range of phenomena in the reasoning, judgment and decision making literature (Evans, 2007; Kahneman, 2011; Stanovich, 2011).
- Type 1 processing – autonomous processing
- Type 2 processing –cognitive decoupling– the ability to distinguish supposition from belief
- Fundamental requirement for hypothetical thinking that underlies science, mathematics engineering, and many more human activities

Possible developmental path

- Minimal innateness – core knowledge
- Naïve concepts/theories
- Implicit, fast, low working memory load, parallel

---------- type 1 processes

- Scientific concepts are introduced through instruction
- Explicit, deliberate creation of new ontological categories-new ways of thinking. Representational flexibility, hypothetical thinking, epistemological sophistication
- ---------- type 2 processes

- Importance of executive function skills – self-regulation abilities to use the information provided by the culture to create new concepts and representations and new types of reasoning

Take naïve physics seriously
Try to explain not to replace

- Instruction should focus on explaining to learners how scientific explanations can be consistent with their everyday experiences instead of telling them that their ideas are wrong
- – for example, we should not simply tell children that the earth is round, but explain to them how it is possible for the earth to be spherical when we perceive it to be flat and how it is possible for people to live on the earth without falling down.
- The creation of new concepts in turn requires the development of certain domain general skills and abilities, such as perspective taking, representational ability, hypothesis testing, and executive functions.