Students' ideas about energy transfer by heating when explaining thermal regulation of animals

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Abstract. We study how 13-14 years-old students explain three thermal regulation mechanisms in a laboratory workshop developed in Barcelona Science Museum. Based on students' multimodal speech (drawings, writings and verbal) we identify and compare their initial and final models about energy storing and transfer. The results show that most of students move from initial alternative ideas such as that "cold energy enters inside animals' bodies" or "the wool is the source of heat" into more sophisticated models, despite the idea of dynamic thermal equilibrium between animals' bodies and the environment is not completely achieved.

1 Introduction and rationale

Students use mental representations (models) to explain and predict the phenomena they observe in the world [1]. To help students to improve and sophisticate their models, different modeling strategies have been proposed in the literature [2]. Model-based inquiry approach (MBI) proposes building and reconstructing models based on inquiry activities [3].

One of the most challenging models in physics teaching is the energy model and energy-related concepts, since students understanding of these ideas is strongly affected by their alternative conceptions, spontaneous reasoning mechanisms and everyday language [4]. To address this issue, we assume that MBI approach can help students develop and improve their models about energy. In our context, we are specifically interested in the students' energy models used to explain three thermal regulation mechanisms (sheep's wool, rabbit's ears and penguins' grouping).

2 Objectives and methodology

We aim identifying and comparing the initial and final models about energy of the 13 and 14 years old students participating in a laboratory workshop developed in Barcelona Science Museum "*CosmoCaixa*". This workshop follows a 3-hour sequence in which students are first asked to explain (in groups of 3 or 4 students) how sheep, rabbits or penguins regulate their body temperature, and then they develop a brief research using digital thermometers to measure how the temperature decreases in different bottles with hot water. Each bottle represents a different thermal regulation mechanism (wool, ears and grouping). At the end of the workshop students are asked again to explain these regulation mechanisms. For data gathering, we collect the different productions made by students in group (drawings and written text) and their verbal speech and gestures when developing their explanations. These multimodal explanations have been analyzed following a qualitative and interpretative approach, based on the category system (see Table 1).

Table 1. Categorization of students' answers based on 3 dimensions (What, How, Why) and their respective categories

What is exactly the energy flow (that is, what is the nature of the flow)	**Cold flow:** The cold enters inside the animal body
	Heat and cold flow: The cold enters inside the animal body and at the same time the heat gets out the animal body
	Heat flow: The heat gets out the animal body

How the energy transfer surface affects the process (that is, which is the role of the skin or the fur of the animals)	**Active agent:** The surface plays an active role, such as a heating surface, an energy absorbing surface, etc.
	Total barrier: The surface is an energy barrier that does not allow any transfer
	Regulatory barrier: The surface regulates energy transfer by facilitating or hindering energy flow.
Why an energy transfer is produced	**Intentional process:** Energy transfer is produced because the animal decides it (conscious, voluntarily).
	Thermal equilibrium: Energy transfer is produced because the body has higher temperature than the environment, but this internal energy is intrinsic of the body.
	Dynamic energy chain: Energy transfer is produced because the higher temperature than the environment, but this internal energy comes from animal feeding.

3 Results and conclusions

Table 2. Number of groups of students (3-4 students per group) that make an explanation classified according the category system of Table 1. The three columns on the left correspond to the explanation at the beginning of the workshop, and at the three columns on the right corresponds to the end of the workshop). Invalid data means unintelligible answers.

		Initial				Final			
		Sheep	Penguin	Rabbit	T	Sheep	Penguin	Rabbit	T
What	Cold flow	13	5	8	26	1	0	0	1
	Heat and cold flow	2	0	1	3	2	0	0	2
	Heat flow	2	3	1	6	7	6	7	20
	No Answer / Invalid data	5	4	0	9	12	6	4	22
	Heat and cold flows inside	0	0	1	1	0	0	0	0
How	Active agent	7	9	2	18	0	0	0	0
	Total barrier	8	0	1	9	4	2	0	6
	Regulatory barrier	1	1	6	8	7	5	6	18
	No Answer / Invalid data	1	0	1	2	11	5	5	21
	Active agent & Total barrier	5	2	1	8	0	0	0	0
Why	Intentional process	6	8	2	16	4	1	0	5
	Thermal equilibrium	0	1	2	3	4	4	3	11
	Dynamic energy chain	0	0	0	0	1	2	0	3
	No Answer / Invalid data	16	3	7	26	13	5	8	26

Table 2 shows that at the beginning of the workshop most of students use the idea of cold flow as a fluid that "enters" in animals' bodies (for instance, some students explain that "cold enters inside rabbits through the ear holes", and also that energy transfer surface is an active agent of the process or a total barrier (many students draw "cold" (blue) arrows bouncing in the wool of sheep). After the workshop, it is observed that most of students' explanations become more coherent and sophisticated, specially the idea that energy transfer should be understood by a heat and not a cold flow. However, the idea that animals have internal energy because of their feeding seem not to be achieved, probably because they experience with hot water bottles that do not allow them to understand the role of feeding in the energetic chain.

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