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TEACHING BY ANALOGIES

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Abstract
The greatest obstacle for a science teacher is to make topics meaningful to students, enhancing their motivation at the same time. Problems usually arise from teacher's and children's different approach to science (in respect of both concepts and competences): teachers often think science as made of abstract and formal models, using a didactic approach based on the transmission of static facts and laws. Students try, on the other hand, to interpret their complex everyday life with approximate, often false, but dynamic models, called conceptions. Correlating results from different fields, as disciplinary didactics (physics, chemistry, biology…), pedagogy and cognitive linguistics; it is possible to look for a teacher-student "common language", made by image schemes. Those image schemes, so often recurring in many elementary science concepts, allow models construction by analogy. Since 2004, in the first level of secondary school (11-14 y/o students) of Canton Ticino (Switzerland), a novel approach to science teaching, finalized to give by analogy accessible explications of common (even if complex) phenomena, has been experimented. In this contribution we discuss this approach and a real school example.

1. Teaching science effectively: a proposal

1.1 Teachers models vs. students' conceptions
Teaching science to 11-14 y/o students requires serious attention. A didactic approach finalized to concepts' transmission only, often results in a tedious sequence of units, knocking down their motivation. Furthermore, students don't recognize the meaning of science concepts taught without connection with their own dynamic and complex everyday experience [1]. In order to train responsible citizens, instead of acquiring only notions, a real meaningful teaching strategy should have as an objective to make students able to trace connections between facts, manipulate relations and find out causal or dynamic interactions [2, 3]. Instead of being taught static models of reality, students should be driven to acquire them dynamically by themselves.
Nevertheless, if teachers practice the "official" science models, the open question is what kind of models an 11 y/o student can build. Child's thought is based indeed on explicative and causal models, usually named conceptions, often abandoned by adults because incomplete, unstructured or incoherent. Even if also teachers construct conceptions, often they cannot recognize those of the students. This occurs because the two use different paradigms, i.e. different concepts, relationships and languages [4,5]; in other words different models. For instance, the teacher can describe a system with models based on a microscopic paradigm (molecules, cells etc.), almost incomprehensible for a young student. For an efficient teaching, science models should be at least expressed in terms of common basic conceptions.

1.2 Image scheme as common basic conceptions
Analogies are supposed to let students describe causative relations starting from an empirical ground, common to teachers. As cognitive linguistics has established, to integrate the observation of novel and recurring events, all humans use "thought structures" called image-schemes, used for instance to represent/express spatial orientations (up-down, in-out), ontological concepts (substance, container), structured experiences or activities (eating,

moving, transferring) [6]. As hypothesized by pioneer works [7], basic image schemes may well be at the core of scientific models. Concepts as substance/quantity (a stock), polarity (a quality difference), path (a transfer or flow) are indeed recurrent in science, so that many complex natural systems can be modeled finding out causative relations for flows of quantities and quality differences (polarity) accounting for observed dynamics [8]. Extended to education, this approach lets students recognize the recurrence of the same image schemes in different situations, allowing analogies between concepts or processes [9, 10].
Such a way of thinking has already proven to be effective in enhancing comprehension of relations between same content domains and cross content domains processes [11-14]. Dealing also with complex systems in a holistic fashion, students are furthermore better motivated [15, 16]. The following paragraph describes an example of this teaching practice based on model analogies identification (concepts, processes etc.).

2. A case study

In a series of units, four parallel 6th grader classes (in total 91 pupils aged 11-12 y/o) discovered model analogies in substance and entropy flows in presence of pressure, density and temperature differences. Pupils discovered convection observing the behavior of two model systems: the first consisted in a red ink deposed on the bottom of a beaker filled with water at room temperature and then put on a hotplate; the second consisted in a beaker filled with room temperature water with floating ice cubes, on top of which some blue ink had been dripped. They identified convection as a process involving mass flow driven by temperature differences in differing parts of a system, i.e. bottom and surface water. After that, students have practiced a heat driven alcohol expansion, relating that behavior with a measurable change of alcohol density triggered by a temperature variation. Comparing the two phenomena, in each system students have established the same causal relations between the local change in the temperature of the liquid, leading to the local change in density, and the relative mass flow. This constitutes the base domain for a process analogy in physics: as a change in an intensive quantity is induced in a system, that change causes a flow of an extensive quantity in the same system. Students didn't know yet the meaning of the terms "in/extensive", nevertheless they observed a local pressure ("density") driven mass flow coupled to a temperature driven heat flow, a fascinating complex process.
The next step has been to transfer by analogy the model observed in a compressible medium, like air, hypothesizing how local air density could affect air flowing. In order to uncover this process, students characterized the dynamic of heat transfer from a heated water bath to the air present in a flask in two conditions: (a) flask sealed (air temperature was measured with an on-line probe [17], Fig. 1); (b) flask with a rubber balloon applied on its rim (not shown; the volume of the balloon was observed qualitatively).

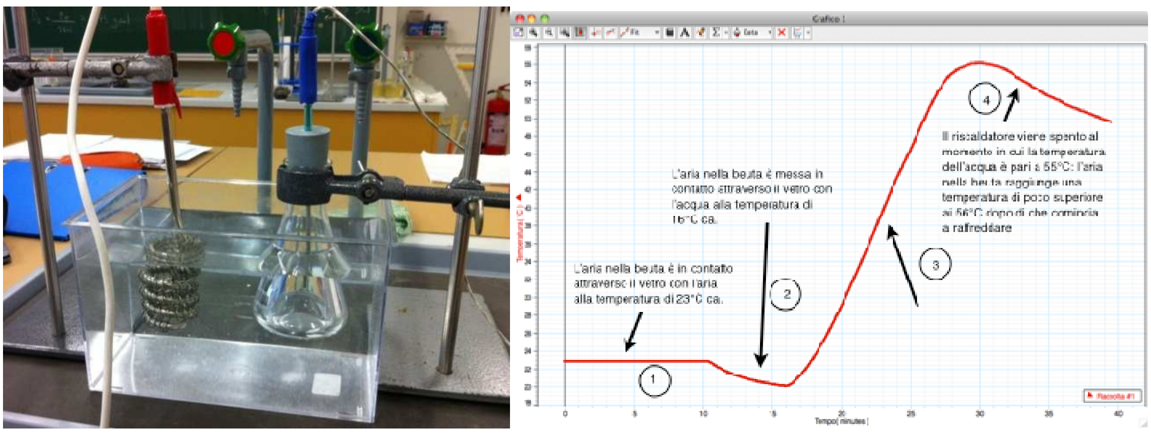

Fig. 1. (left) Experimental setup for a heat transfer from hot water to cool air. (right) Air temperature vs. time, collected with an on-line probe during the experiment [17].

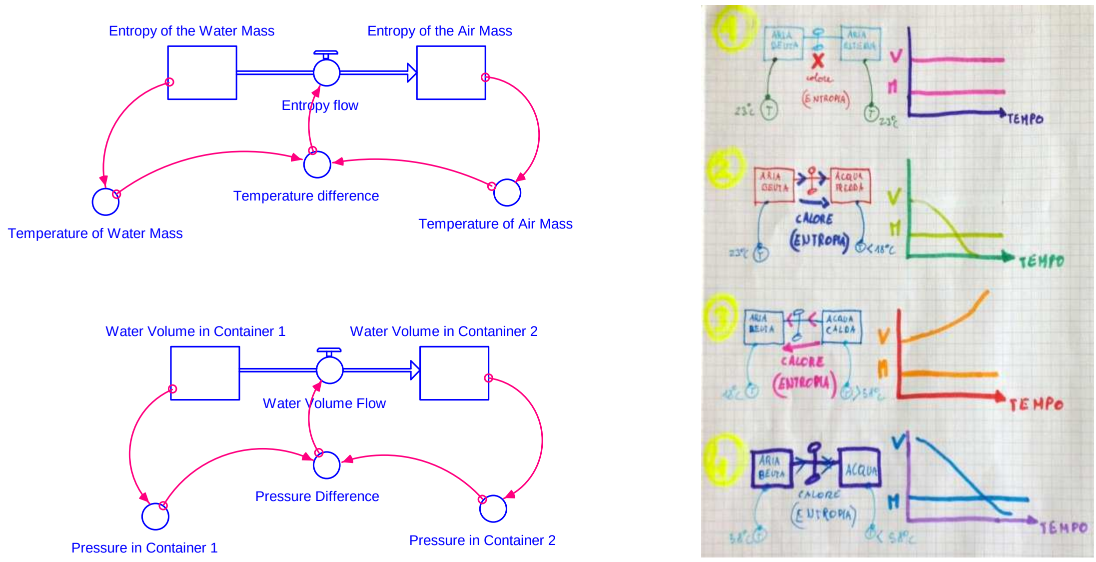

Fig. 2. Stock and flow representation of air heating and cooling processes. On the right, diagrams for the process at constant volume (above) compared with water volume transfer in communicating vessels, where pressure appears [18]. On the left, first discussion about the “balloon case”: entropy flow (arrows between stocks) is correlated with the time behavior of air mass and volume. Students correlated entropy flow with temperature difference, even if they didn’t report it yet in the graphs.

The two cases have been described according to system dynamics concepts. As shown in Fig. 2, heat has been always correlated to the flow (symbolized as a pipe with a faucet) of an extensive quantity defined entropy, stocked in containers (rectangles), triggered by a difference in the intensive quantity temperature (circles) [18]. In the constant volume case, the model behavior has been investigated by analogy using two water containers (as entropy stocks) of the same capacity (for the sake of simplicity) loaded with different masses of water (playing the role of entropy), and therefore with a visible difference of water level (standing for the temperature difference). This way, in cognitive linguistic terms, the analogy between a base domain and a target domain was clearly mapped: as Fig. 2 shows, just as the difference in water level (at this time not yet correlated with pressure) results in a volume flow (from the container with the higher level to that with the lower one), so the difference in temperature between water and air drives the heat flow (from the hot water to the cool air).
To discuss the case in which volume varied, in the following lessons students were introduced to a real situation in which model analogy could be exploited: they were asked to explain the phenomenon of sea and land breeze. After a short discussion, pupils hypothesized at first a temperature difference between the air masses on the land and on the sea. Subsequently, by analogy with previous models, they identified this temperature difference as the cause of a relative difference in local air density, correlated to the airflows. The situation has been sketched to visualize and discuss the process (Fig. 3), comparing it with the constant volume case and reinforcing the concept of “intensive quantity difference as a trigger”. At this point, the concept of pressure in fluids must be introduced.
Since students were familiar with Highs (H) and Lows (L) (from TV weather forecasts), air pressure has been therefore defined as the force exerted by an air column measured on a given surface (at a given altitude). This allowed a further analogy, reinforcing the concept of difference as process driver: differences in local air density, triggered by temperature, determine differences in air pressure. To go further the breeze phenomenon has been again compared with the hydraulic system, where the water level difference determined a pressure one, triggering the water flow.

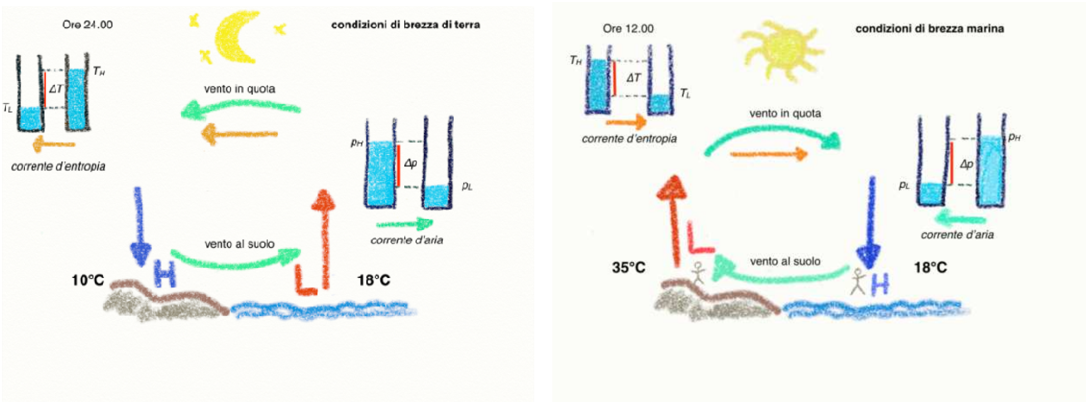

Fig. 3. Sketches of breezes model, made by analogy between hydraulic models of air mass and entropy flows: left, sea breeze, right, land breeze. The concept of pressure has been introduced.

In sea/land breezes, being the air compressible, the new aspect was indeed the coupling between temperature and pressure. Breezes are due to an airflow dependent on air pressure changes induced by temperature: the temperature of the air mass on the sea level is quite constant, whereas the temperature of the air mass on land oscillates, determining an air dynamic. The situation has been modeled qualitatively by students, using a stock and flow diagram (Fig.4, left). Compared with a hydraulic stock and flow diagram (Fig. 4, right), it allowed to visualize process analogies, differences and to hypothesize missing relationships, principally those between temperature, pressure and density (volume) of the air.

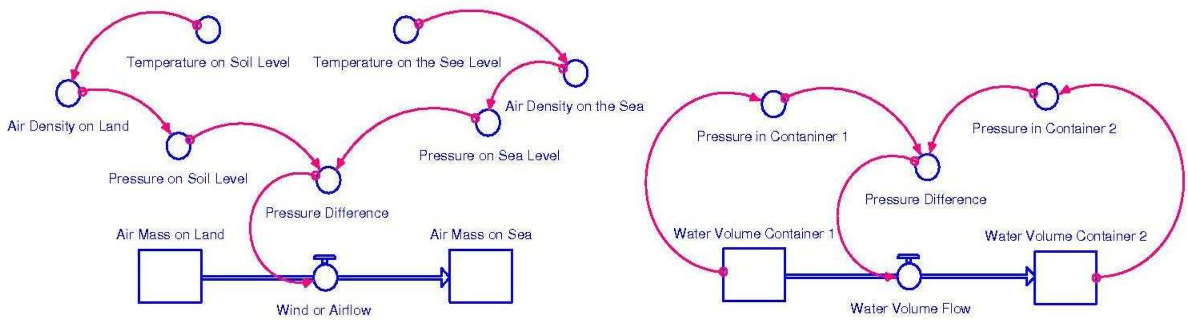

Fig. 4. Breeze (left) and communicating vessels models (right) done by students [18]. While the communicating vessels model is fairly rigorous, in the one for the breezes the relationship between temperature, density (volume) and pressure is still missing. Indeed, pressure difference triggers fluid flows in both cases, but in the breezes case (a convection), pressure and temperature are coupled. As a matter of facts, students followed the path of their discoveries (from temperature to density, from density to fluid level/pressure), discovering *the* problematic point.

3. Discussion and conclusions

This contribution shows how it could be possible to face different scientific topics using analogies between models. Analogy between concepts or processes, carefully discussed, permits indeed to map a base domain (for instance a hydraulic system) to one or more target domains (convection in a liquid, airflows, heat transfer etc.). During the lessons described, students have always recognized when the flow of an extensive quantity was driven by a measurable and observable difference in an intensive property, and they began to investigate or hypothesize complex and missing facts and laws (coupled transfers, gas laws etc.). This same path can be further used to understand by analogy electric, mechanical, chemical phenomena, or population dynamics [8]. Furthermore, this approach has proved very promising because of its intrinsic ability to deal with complex system in an holistic manner, much more close to the natural way of conceptualizing and considering reality rather than a reductionist approach, enhancing students motivation and curiosity [15].

References

[1] A. Giordan, G. De Vecchi, L'enseignement scientifique: comme faire pourquoi "ça marche"?, Delagrave, 2002

[2] E. Morin*, I sette saperi necessari all'educazione del futuro*, Raffaello Cortina, 2001

[3] L. Booth Sweeney, *Learning to connect the dots: developing children system literacy*, Solutions, September-October, 2012

[4] G. De Vecchi, *Aiutare ad apprendere*, La nuova Italia, 1998

[5] E. Roletto, *La scuola dell'apprendimento*, Erickson, 2005

[6] G. Lakoff, M. Johnson, *The metaphorical structure of human conceptual system*, Cognitive Science 4, 1980

[7] H.U. Fuchs, *From Image schemas to Dynamical models in Fluids, Electricity, Heat and Motion*, 2007, https://home.zhaw.ch/~fusa/LITERATURE/Literature.html

[8] H.U. Fuchs, *The dynamics of Heat*, Springer, 2010

[9] AAVV, *Strumenti per l'insegnamento della termodinamica nelle Scienze Sperimentali*, 2011, http://www.scuoladecs.ti.ch/StrIIT2011/scarica/StrIIT_11.pdf

[10] J.W. Forrester, *System Dynamics and Learner-Centered-Learning in Kindergarten through 12th Grade Education*, MIT OpenCourseWare, 1992

[11] S. Christie, D. Gentner, *Where hypotheses come from: Learning new relations by structural alignmen*t, Journal of Cognition and Development, 11, 2010

[12] F. Herrmann*, Le KPK - un cours de physique basé sur des analogies,* BUP**,** 99, 2005

[13] D. Gentner, F.K. Anggoro, R.S. Klibanoff, *Structure-mapping and relational language support children's learning of relational categories*. Child Development, 82, 2011

[14] M.B. Goldwater, A.B. Markman, *Categorizing entities by common role*. Psychonomic Bulletin and Review, 18, 2011

[15] E. P. Odum. *The emergence of ecology as a new integrative discipline*, Science 195, 1977

[16] B. Bollmann-Zuberbühler, P. Kunz. *Ist systemisches Denken lehr- und lernbar ?* In U. Frischknecht-Tobler, U. Nagel, H. Seybold (Hrsg.). *Systemdenken.* Pestalozzianum, 2008

[17] Data were collected using PASCO's Data Studio Software and the PS-2125 temperature sensor (http://pasco.com)

[18] All models not represented by students are made with the software STELLA (http://www.iseesystems.com). Other softwares, as VENSIM (http://vensim.com/) can be considered.