

FROM HEURISTICS TO HUMBLE THEORIES IN PHYSICS EDUCATION: THE CASE OF MODELLING PERSONAL APPROPRIATION OF THERMODYNAMICS IN NATURALISTIC SETTINGS

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Abstract

The paper concerns the analysis of a successful classroom experience where secondary school students made evident progress in appropriating thermodynamics according to personal approaches.

The main result of the analysis is the construction of a definition of appropriation which is *operational* in two senses: *i)* it includes the indication of what *observable features* must be searched in students' discourses for recognizing appropriation; *ii)* it is *effective* for recognizing appropriation also in cases where it is not evident.

The study is the first step of an iterative process aimed at developing a "humble theory" for explaining *when, how and why* appropriation is triggered and supported in real classrooms.

1. Introduction

The study concerns an analysis of data collected during the implementation of a teaching proposal on thermodynamics (about 25 school-periods) in a class of 20 students (17 year-olds) of a scientifically-oriented secondary school in Italy (teacher: P. Fantini).

During the activities we observed that something important happened: the students appeared to make evident progress in *appropriating* thermodynamics according to personal approaches, by taking part in the teaching/learning dynamics of the classroom. In other words, most of the students seemed to be able to find a way, that they *feel comfortable with*, for understanding and re-organizing knowledge.

In the light of this evidence we decided to carry out a study in order to answer the following research questions:

RQ1 - How can the word "appropriation" be defined so as to become an operative tool for recognising and evaluating the effectiveness of a teaching/learning experience (*What "appropriation" means*)?

RQ2 - What factors (features of the contents knowledge reconstruction, collective activities, learning environment, mediation action,..) trigger and support individual processes of appropriation (*When, why and how appropriation occurs*)?

2. Methodological framework

Both the selection and formulation of the research questions mirror our choice of referring to Design Studies as methodological framework (Cobb et al. 2003; diSessa & Cobb 2004). Of the Design Studies we considered, in particular:

- the theoretical orientation: "*Design studies are conducted to develop theories, not merely to empirically tune 'what works'.*" (Cobb et al. 2003)
- the "local" (or "humble") character of the theories (diSessa & Cobb 2004; Levrini & diSessa 2008): "*Unlike grand theories or orienting frameworks, they [the theories] aim at being specific enough [local] to do real work for improving instructional design*" (Cobb et al. 2003);
- the iterative design.

A sentence particularly stimulating for the work is: *In order to pursue this intimate relationship between developing theory and improving instruction, the Design Studies indicates that, in collecting and analyzing data, "what works" must be underpinned by a concern for "how, when and why it works, and by a detailed specification of what, exactly, 'it' is"* (Cobb et al 2003).

According to the Design Study, we organized the research as follow.

In order to answer RQ1 ("*What appropriation is*"), we:

- a) overviewed the whole corpus of data in order to select a manageable and significant set of data for providing the first operational definition of appropriation;

b) tested the definition against more complex data [*by enlarging the empirical base up to "theoretical saturation"*, Strauss & Corbin 1990)] in order both to refine it and to evaluate its operative power in making invisible visible.

As far as the RQ2 ("*How, when and why appropriation occurs*") is concerned, we are now working for abstracting, from the specific context, the first hypotheses so as to point out new foci of attention for designing a second level of the experiment within an iterative design.

The last point is in progress and the paper will focus mainly on the work we did for answering RQ1¹.

3. The educational reconstruction of thermodynamics

The teaching proposal was designed so as to shape the learning environment as a *properly complex territory* (Levrini et al. 2010). At the basis of the notion of learning environment as properly complex territory there is the idea that some forms of complexity in physics contents can be transformed into *productive complexities*, i.e. complexities that allow learning environments to be, besides intelligible, rich enough to enable each student to reach deep understanding and to exploit his/her cognitive potential.

The forms of productive complexity, chosen and implemented in the thermodynamics path, are:

- (1) *Multi-perspectiveness*: the same contents (phenomenologies) have been analyzed from different approaches - the macroscopic and microscopic ones - treated consistently as two different models;
- (2) *Multi-dimensionality*: a critical-philosophical reflection has been developed on the peculiarities of the two approaches through specific activities (questionnaire, discussions);
- (3) *Longitudinality*: according to our idea that learning physics is a continuous process of widening, refining, revising knowledge already acquired, the thermodynamics ways of modeling systems, processes, interaction have been systematically compared with the models used in the theories previously studied (classical mechanics and special relativity).

4. Data analysis and results

4.1 Data sources

During the activities we collected data from different sources: written tasks (quantitative and qualitative problems on key concepts, including problems known as puzzling from the research in physics education); audio-recording of lessons; students' notebooks; notes of a Master student (GT, an Author) observing the classroom activities; questionnaires stimulating critical-epistemological reflection; video and audio recording of classroom discussions about the issues raised by the questionnaires; audio-recorded individual interviews to 10 students conducted at the end of the whole work; audio-recorded interview to the teacher and discussions with her. Since we could not complete 2 interviews because of time constraints, only 8 out of 10 have been taken into account for the analysis.

4.2 Working out an operational definition of appropriation

In order to work out an operational definition of appropriation, we focused the analysis on the data related to 5 students: their semi-structured individual interviews; their answers to questionnaires on a critical-epistemological reflection; their contributions to classroom discussions.

The 5 students were chosen on the basis of three criteria: our impression they could represent interesting cases for studying appropriation; the richness of their interviews; their being representative of the class (3 boys, 2 girls, with different levels of performance in physics and different roles within the classroom dynamics).

The data concerning each student were selected and re-arranged so as to draw "the student's profile". In order to make the 5 profiles comparable, all of them were constructed following the same steps: *i*) to pick up the *central idea*, if there is one, around which the student, during the interview, develops her/his discourse; *ii*) to see if and how such an idea is developed along the

¹ A brief description of the work we did for answering RQ2 is reported in Levrini et al. 2011.

interview; *iii*) to reconsider the classroom discussions and the answers to the questionnaire in order to check if there is a relationship between the student's position during the interviews and what appeared in the previous activities.

The profiles' comparability allowed us to get the definition of appropriation out of observable features of students' discourses.

The first main evidence which comes out from the construction and the comparison of the profiles is the variety of the central ideas around which students developed their discourse (see Table 1)².

Table 1: Central ideas around which students' discourse runs

Michele	The Curiosity for "how things work"	"I like Physics because it explains how reality works, so to say, I'm very curious about how objects work and natural events".
Matteo	The pleasure of speculating, in particular on the philosophical distinction between "being and becoming"	"I believe that [...] it is fundamental to build a basis and to speculate on how theories are found, how concepts are elaborated. These concepts will certainly last longer than formulas."
Chiara	The pleasure of understanding by exploring and testing different points of view or perspectives	"It may be more complete to try to analyze a phenomenon, or whatever is around us, from two different points of view rather than from one [...]. It widened my view"
Lorenzo	The need of searching for a unified consistent framework for deep understanding	"One can see that everything is integrated, it is not divided in topics each with its own laws, instead everything can be connected, unified; the argument becomes wider, more uniform"
Caterina	The fascinating search for "not obvious details that are usually taken for granted"	[I like physics since] "obvious things are not taken for granted".[Of thermodynamics I like] "that it made me notice something I had not noticed before."

The other very important evidence is the students' personal way of talking about temperature, since it is evident they focused their attention on those features of temperature more meaningful to them.

Michele, for example, according to his general perspective, focused his attention on the temperature gradient because this is what makes engines work: "Different temperatures are necessary..., only with different bodies with different temperatures we can have a cycle and work".

Matteo, instead, focused his attention on the distinction between ΔT and T , because he saw, in this distinction, the philosophical difference between "being and becoming": [I think that] $Q=mc\Delta T$ is 'becoming' [...]... there is a change. [...] the first relation [$PV=nRT$] is 'being' because [...] [there is] absolute temperature T , that doesn't change."

Thanks to the construction and the comparison of the profiles, the following features of students' discourses can be recognised as signals they did appropriate thermodynamics:

- the discourse is developed, around one key-idea, consistently along the whole interview;
- the key-idea allows the formulation of arguments *on-task*, i.e. arguments which allow aspects of thermodynamics to be selected and meaningfully linked one to the other;
- the keywords, around which each student constructs her/his arguments, reveal personal engagement, by being *genuine* and *emotion-laden*;
- the argumentation is *thick*, i.e. it includes elements belonging to a meta-cognitive and/or epistemological dimension;
- the specific approach to disciplinary knowledge is *not occasional* (it can be traced back to the student reactions in different classroom activities).

The acknowledgment of these features allowed us to formulate an operational definition of appropriation: *A personal process of content knowledge transformation that leads disciplinary*

² The names of the students are invented.

knowledge itself (feature b) to be a consistent (feature a) and personal reconstruction of physics “signed” by the students, where “signed” means that:

- the voice of the teacher is not present (feature c);
- physics content knowledge is assumed within a personal broad path to knowledge that goes far beyond the mere aim of learning thermodynamics (features d, e).

4.3 Testing the definition against complex data

For completing our answer to RQ1 we have, then, tested our definition against 3 interviews that appeared, at a first level of analysis, cases of non-appropriation, because of:

- the lack of an explicit and evident personal idea around which student’s discourse runs;
- the common “flat” sound of their ways of talking about physical concepts (“*In classroom, we have done...*”, “*we have introduced the concept of temperature by...*”, “*I remember that we had...*”, or “*I don’t remember if...*”);
- the same strategy of talking about physics by going over, chronologically, the classroom activities.

Instead, the finer analysis we could carry out by applying the definition of appropriation shows that only one interview is an evident case of non-appropriation. Another interview shows that the student resonated with the global sense of the work, but she seemed to be still inside the process of searching for her own approach to learning. The last interview reveals not only that the student appropriated thermodynamics, but also that appropriation was particularly difficult to be recognized because of a “natural”, spontaneous cognitive resonance of the student with the inner physical language and its formal structure.

As example, we report the results of the analysis of the interview to Paolo, the last one, we carried out by applying the criteria we had pointed out for recognising appropriation.

In the first 30 minutes (out of 37) of the interview, Paolo goes over the whole path for describing where the concept of temperature has been addressed and in what formal relations it appeared.

The language used in the description sounds as an attempt to remember what has been done: “*We have given the initial definition to the temperature...*”, “*Then, we have done the macroscopic approach...*”, “*In between we have seen the laws of Gay-Lussac and Boyle...*”

In his discourse, however, Paolo shows to move within the disciplinary dimension very easy and with self-confidence. In particular, he appears to be very sure both in moving along a formal dimension and in connecting formulas to phenomena or in recognizing the modelling dimension that stays behind formalism.

He also shows a marginal interest for reflections *about* physics or *about* his personal view as the few minutes devoted to the second and third parts of the interview prove (7 minutes).

Paolo may, hence, seem a student who deeply and efficiently understood the contents, without searching for that personal approach needed for transforming disciplinary knowledge into a “signed” knowledge.

Instead, in his discourse all the features we pointed out for recognizing appropriation can be found. In particular, as soon as we re-analysed the interview by applying our criterion of *consistency*, the repetition of a specific point became visible: he stresses several times that, for him, what matters is that physics has the power of reaching the “same result” (“the same formula”) in different ways and that some routes (like the microscopic one) are based on already acquired knowledge (like mechanics). These two aspects make, in his opinion, physics knowledge reliable: *reliability of knowledge* emerges as that key-idea around which his discourse is consistently developed.

This idea can be consistently related to a specific image of physics to which he, implicitly, refers when he says that the boundaries of physical knowledge are clearly demarcated with respect to other forms of knowledge, such as philosophy:

“*The questionnaire has been something interesting but, sincerely, it seems to me that it did not have many implications on thermodynamics... perhaps more on philosophy.*”

His *consistent* and *not occasional* position in looking at physics as reliable and well-demarked knowledge makes us to think that, along the whole interview, he is also implicitly supporting the *objectivity* of physics as another feature that makes physical knowledge reliable. From this perspective, the impersonal way of describing the path in the first part of the interview, seen at a first level of analysis as sign of lack of appropriation, can be acknowledged as the expression of a well-formed epistemological position: *physics is physics*. He was in fact re-constructing the path by

selecting those pieces of knowledge he considered reliable and by cutting off what could sound subjective.

In this sense, we can also infer that Paolo's discourse is *thick*: a precise epistemological dimension can be recognised behind his pure and competent disciplinary (mono-dimensional) discourse.

To sum up, the application of the specific criteria we pointed out for recognising appropriation leads us to conclude that also Paolo's discourse can be acknowledged as a clearly *signed* content knowledge reconstruction. The relative poorness of his philosophical and meta-cognitive language, which made rather complicate to acknowledge signals of appropriation in his words, can be, in our opinion, ascribed to his "natural", spontaneous and authentic cognitive resonance with physics. Because of this natural resonance with physics, a fine and specific analysis has been needed for recognising that the impersonal language used by Paolo was, in fact, *his* personal language.

5. Final remarks... toward a humble theory

Following the Design Studies methodology, data collected during an experiment of thermodynamics have been analysed so as to work out a definition of appropriation. The definition we formulated is *operational* in two senses: *i*) it includes the indication of what *observable features* must be searched in students' discourses for recognizing appropriation; *ii*) it is *effective* for recognizing appropriation also in cases where it is not evident.

In the light of the obtained results, the next important move of our research is the construction of a humble theory able to explain *when*, *how* and *why* collective activities trigger and support personal appropriation. Such a concern is, in our opinion, a fundamental step for disseminating good practices, as well as for making the research results more and more powerful to promote innovation in schools.

In analogy with what happens in the physics of complex systems, the kind of humble theory we have, now, in mind ought to be shaped as a dynamical model comprised of: *i*) boundary conditions, i.e. those context conditions which make the learning environment suitable and fruitful for triggering and supporting appropriation; *ii*) a dynamical mechanism lying at the back of the process, i.e. a mechanism enacted and managed by the teacher in order to make *individual cognition*, *collective dynamics* and the *disciplinary knowledge* resonant with one other (Levrini et al., 2011).

From an operative point of view, we are analysing data coming from 3 further experiences with other 2 teachers (one of them indeed implemented the same proposal, during the same period, in two different classes). What makes these data particularly interesting is that one experience, out of three, was unsuccessful: not only appropriation did not occur (with only few exceptions), but also the forms of complexities seemed to play a counterproductive role in fostering basic understanding. A further element of interest is that the unsuccessful experience is one of the two experiences realised by the same teacher.

This specific situation will allow us to treat the analysis of the boundary conditions somehow independently of the dynamical mechanism of mediation: being, indeed, the teaching proposal and the teacher the same in a successful and in the unsuccessful experience, we expect to find different boundary conditions responsible for the different reaction of the two classes.

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