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Does an Early Physics approach exist?

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Summary. — We engaged some high school Physics teachers in a deep revision of their PCK (*Pedagogical Content Knowledge*) to contrast the trend of a diffuse disaffection and negative attitude of the students towards Physics studies. Starting from the analysis of the Math/Phys interplay prevalent patterns of the teachers, we observed that the application type is the most common, which adversely affects students' learning. For this reason, we suggested that they adopt a new approach, based on conceptual fragmentation and multiple representations reasoning tools. This approach stimulates teachers to adopt different Math/Phys interplay patterns. Here we present the main features of some of the tested activities, which also allowed teachers to better understand and recognise the learning challenges students have to cope with.

1. – Less patterns, less knowledge

In the analysis of Math/Phys interplay patterns, some Physics Education researchers have found a relation between these patterns and the mastery of teaching Physics [1-4]. The four identified patterns (classified in fig. 1) were clearly more recognisable in mastery teachers' PCK (*Pedagogical Content Knowledge*, by the known definition widely accepted for teaching Physics [5-7]) than in other teachers who are not master teachers (less expert). Recently, monitoring an Italian group of high school Physics teachers, we recognised Physics teachers' PCK features and orientations towards teaching by observing their Phys-Maths interplay [8]. We noted that teachers prefer an application pattern, with some weak integration with the construction one. In both patterns, Maths controls the process even in an early Physics learning experience. In Physics lessons, teachers prevalently use maths in the demonstration of physics laws and in their classroom discourses; then they assess students' learning with a great number of maths exercises and problem solving applied to physical phenomena [9]. But all these evaluation tests seem to be mathematically rather than physically oriented [10].

The prevalent adoption of the application pattern produce some relevant nested limits in the building knowledge process (fig. 2):

- epistemological limits;
- linguistic/procedural limits;
- phenomenological limits.

The epistemological limits consist in building knowledge through the definition of physical laws only through mathematical formulas. If it represents the core of the teaching process, this leads to the construction of knowledge by precluding the possibility

Patterns	Teaching goal	Teaching practices
A. Exploration	To demonstrate how Phys-Math is used to explore the behavior of physical systems	Exploring within Math ramifications for the physical system: limits (of validity, of approximation), extreme cases, etc.
B. Construction	To demonstrate how Phys-Math is used in constructing a model for physical systems	Constructing and developing (from experiments or from first principles) mathematical tools to describe and analyze physical phenomena.
C. Broadening	To demonstrate how Phys-Math can be used in broadening the scope of a physical context	Adopting a bird's-eye view and employing general laws of physics, symmetries, similarities and analogies
D. Application	To demonstrate how Phys-Math provides aid in problem solving	Employing already known laws and mathematical representations in problem solving

Fig. 1. – Phys-Math patterns, teaching goals and teaching practices from Lehavi *et al.* [1], in close relation to Etkina and Magnusson [5, 6] PCK model.

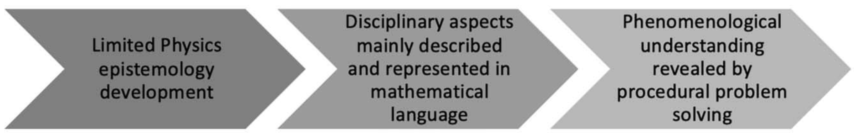

Fig. 2. – Limits of a prevalent adoption of application pattern in Math/Phys interplay teacher's PCK.

of investigating phenomenological aspects through disciplinary languages other than the purely mathematical one. Students think they understand a phenomenon only if they are able to solve related problems, in the framework of formulas' application. If teachers would be more aware of the limits due to the use of this pattern, they would surely change their PCK towards a wider and deeper Math/Phys interplay supported by a disciplinary languages' integration.

Furthermore, there is a close link between this epistemological limits, caused by the prevalent use of the application pattern, and students' development of argumentation skills [11, 12].

If students are engaged in the process of applying formulas to explain physical phenomena, they will not explore the limits of validity, verify the model used, or try to test hypotheses and ideas also through conceptual experiments. This happens because argumentation skills support epistemological building [11].

Improvements in the epistemological building occur by integrating the development of argumentative skills into learning processes.

This integration is possible only if teachers revise their PCK of Math/Phys interplay, adopting all patterns, and if they include an epistemological building based on argumentation skills.

The advantage of this integration covers two very important aspects in the learning process and the activation of learning skills:

- thinking like a scientist (in the framework of the epistemological building [13]);
- critically thinking, as the argumentation skills enact [14].

School year	Teachers/classes/students
2020-2021	6 / 7 / ~ 150
2021-2022	8 / 10 / ~ 250

Hours per class		
Planning, Building activities and assessments	Lessons activities	Revision
~ 25	~ 10 - 15	~ 5 - 10

Fig. 3. – Detailed information about the *Early Physics* project [9].

2. – More representations, more integration

In order to overcome the identified limits, we engaged some high school Physics teachers in a deep revision of their PCK (see fig. 3 ([1])) and we guided them through the adoption of a teaching approach with two main features:

1) knowledge fragmentation through the so called *knowledge segments* [15];

2) use of multiple representations [14, 16].

Conceptual knowledge fragmentation consists of content management to simplify concept building and to emphasise disciplinary languages. The use of multiple representations is the way for deep conceptual insights, manipulation and consolidation. It improves the teacher's process exploration of more Math/Phys interplay patterns. These two elements should characterise every lesson step: it is not the methodology of chunked lessons that operates in the lesson timing.

This approach consists in exploiting and explaining all those aspects which become unclear through the mathematical formalism they are constrained to during the process of conceptual building, partly losing their physical meaning. What is clear to teachers in terms of mathematical language description and conceptualisation [2, 3] is unclear to most of the students [17].

They need more representations, in different disciplinary languages to activate the process of building physical knowledge [14]. By describing and representing Physics phenomena in multiple manners, students are led to develop their scientific abilities [18]. The different representations give them a "conceptual place" where they could build their reasoning and start to argue. This conducts their learning process to raise towards an epistemological knowledge building.

3. – Conclusions and perspectives

When teachers improve their PCK with a revision of their Math/Phys interplay, they adopt teaching approaches that better target the development of students' argumentation skills. We are trying to guide some teachers in applying a new approach based on knowledge fragmentation and multiple representations in the first curricular Physics classes in secondary school. These features differ from other teaching/learning Physics approaches for secondary school. For this reason, we call it *Early Physics*, by analogy with a similar approach in Math Education [17].

([1]) We reported more details concerning the *Early Physics* project activities during one seminar session in GIREP WEBINAR 2021 and one in WCPE 2021.

We are confident that this kind of approach will improve students' attitude toward Physics [19, 20]. The project is still ongoing, and we plan to conclude our classroom testing and teaching revision during the school year 2021–2022.

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