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How knowledge about the historical background of physics affects students perceived learning outcome

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To be or not to be a *good-enough* physicist -that is the question addressed in the general physics curriculum from the Niels Bohr Institute (Københavns Universitet, 2010). The *formal* curriculum consists of the courses, lessons, and learning activities students participate in, as well as the knowledge and skills educators intentionally teach to students. Besides the formal curriculum, there is a *hidden* curriculum that consists of the unspoken or implicit academic, social, and cultural messages that are communicated to students. One example is the epistemology of physics: i) of how a physicist produce knowledge, and ii) what kind of questions that drive physics research; as formulated by Barnett and Kjeldsen (2016).

The formal physics curriculum for the MS level (Københavns Universitet, 2010) states a list of intended learning outcomes (ILO) common for all physicists. The ILOs are divided into the categories “knowledge about”, “skills in/to”, and “competences in/to”. Here I only consider the first category:

“Knowledge about:

1. The basic physical laws in all classical physics disciplines, i.e. classical mechanics, thermodynamics, electromagnetism, quantum mechanics, and their interrelationships.
2. The construction of materials at both macro- and micro-level, and the fundamental principles for the various forces that operate on each scale of longitude.
3. Quantification methodology.

4. Up-to-date, specialist knowledge of a given field of research, built up through research based teaching and the thesis.
5. Mathematical methods for solving a wide range of problems, both linear and nonlinear.
6. Numerical methods for data processing and solving mathematical models.
7. The historical background to physics and science."

ILO 1 is directly covered by the mandatory courses at the bachelor's level, ILO 3, 5 and 6 describes the mathematical methods, and ILO 4 is related to the writing of the master's thesis. The last, ILO 7, seems to stand out and it is not further explained how knowledge about the historical background should be obtained. With this project, I investigating a possible intervention to give students the knowledge and there are two obvious available approaches i) implicitly by *doing* physics or ii) by creating an explicit-reflective framework. The later is to help students to reflect upon the *nature* of science from within an epistemological framework (Abd-El-Khalick, 2013). In other words, either the historical knowledge is part of the more or less hidden curriculum or it is taught explicitly. Here I investigate the possibility of creating an explicit-reflective framework to obtain *alignment* between the formal curriculum and the students' perceived learning outcome (PLO).

As a possible intervention, I consider the course History of Physics (HoP) offered at the Niels Bohr Institute. I investigate the students' PLO and whether they have an impression of deep understanding of the *nature* of physics?

Course design

History of Physics is a 7.5 ECTS points master's course held at the Niels Bohr Institute as collaboration between Assoc. Prof. Ricardo A. S. Karam, Department of Science Education, KU (PhD in Physics and Mathematics education) and Prof. Helge Kragh, Niels Bohr Archive, KU. The course consists of 12 modules that in chronological order cover the history of physics from Newton's laws of mechanics to modern cosmology. As stated in the course description, an important ILO is: "they shall be able to use the history of physics as a background for reflections on philosophical and

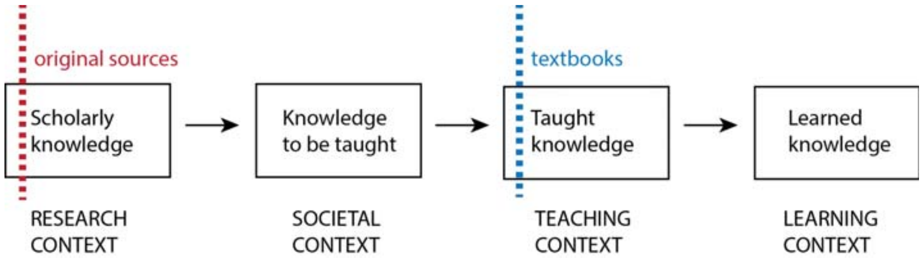

Fig. 3.1: Diagram of the didactic transition, reproduced from Ben-zvi (2014), Achiam (2014). The diagram sketches the transposition in time from the scholarly knowledge to the actual learned knowledge of a given group of students. In my interpretation, this scheme includes the transposition from original sources (red) to textbooks (blue).

sociological questions of this science" (Karam & Kragh, 2017). The course has run for the first time in block 4 2016/2017 and 10 students signed up but only 5 completed the course.

When designing a history course, one needs to be aware that the history of physics, or any other discipline, is neither cumulative nor straightforward. Instead, it is affected by the cultural and scientific context, including prejudices, religion etc. Thus, teaching the historical evolution can be approached in many ways and in my reading of the HoP curriculum, the course is based on critical reading of original sources, as described by Tzanakis and Thomaidis (2000). The outcome of critical reading should result in the following knowledge about i) general conceptual framework and the associated questions, ii) evolvement of not only the content but also the form of science, and iii) difficulties related to solving the problems that brought the research forward. Structuring the course based on primary literature presupposes a high-level of student participation. Students are required to spend many hours of preparation, as the terminology and mathematical framework is very unfamiliar to the student. Furthermore, this approach is complemented with the motivation of students to understand why a specific theory is required to answer a question that remained unanswered for some time in history. Every module corresponds to a specific crossroad in history where problems arose that brought the research forward. Hence, the focus is not only on deciphering the original terminology but also on reconstructing history in a modern context.

To understand how HoP can create an explicit-reflective framework, we relate it to the *didactic transposition*. The process of didactic transposition refers to the transformations an object or a body of knowledge undergoes from the moment it is produced, put into use, selected, and designed to be taught until it is actually taught in a given educational institution. The scheme was introduced in the field of didactics of mathematics by Chevallard and Mary-alberte (2005). Here I present a simplified interpretation of the didactic transposition (fig. 1), where I place the primary literature within the *scholarly knowledge* and textbooks within the *taught knowledge*. Hence, the didactic transposition shows the transposition in time, educational levels, and institutions of research papers over curriculum to *learned knowledge* (Achiam, 2014). Thus, the *knowledge to be taught* must be reflected in the ILOs and the *learned knowledge* in the PLOs. This means, to establish an explicit-reflective framework the students are presented to the original source. This abstraction from the *taught knowledge* and focus on the *scholarly knowledge* will constitute an awareness of the didactic transposition and, hence, create this explicit-reflective framework.

Study design

I followed module 10 on the original formulation of quantum mechanics and thereafter I had 1 hour of focus group interview. The group consisted of 3 students from the course: 2 males physic students and 1 female physic/philosophy student. I aimed at letting the group lead the interview by posing generic question pointed at the students' PLOs. The interview plan with questions can be found in Jauffred (2017). It was clear from the interviews that the PLOs was the result of students creation of links between the new information, taught in the course, and his/hers existing framework. After the interviews, I extracted, what I found to be, the most interesting themes: the physics and mathematics relation and identification (with the heroes of physics). Surprisingly, these PLOs were all related to the epistemology of physics (Barnett & Kjeldsen, 2016) or the, more or less, hidden curriculum.

The relation between physics and mathematics

The students brought up this theme and they emphasized that they found this to be an important PLO. The students gave different examples of how they became aware of this this complex interplay and I will discuss two of these in the following.

The first dealt with the idea of *pure* physics, which I understood as physics that was not mediated through mathematics. Their example from HoP was a text by Faraday, who is the originally proposed the idea of *fields*, a concept that is widely used within physics, e.g., electromagnetic and gravitational fields. However, Faraday proposed this fundamental concept of physics without any formulation of the implied mathematical framework. Instead, the mathematical description, e.g., vector fields, was developed much later: ”det var ikke matematisk til at starte med det var et rent fysisk koncept”[1]. It is very difficult to extract modern physics from its mathematical formulation but by reading the primary text written by Faraday, the students made the abstraction of physics as an isolated object. They also expressed that this was a development in time: ”Vi læste noget som nærmest var en mellemting mellem filosofi og fysik [. . .] pludselig kommer matematikken ind i det og det hele bliver meget mindre metafysisk og nu skriver vi det hele ned i ligninger” [2]. This is closely related to the focus of HoP module 8, namely Maxwell´s path from mechanical models to the abstract notion of field and its mathematical formulation. Thus, HoP pushed the students to reconsider this relation between physics, metaphysics, and mathematics.

Another important idea discussed by the students, was the choice of mathematical formalism. For instance, Newton used geometrical diagrams and Euclidian mathematics even if he had the possibility to use algebra. In other words, he had the two different notations available but he chose the one that was costume at the time for physicists, i.e., astronomers.

The students also reconsidered the course of Electromagnetism they completed at the bachelor’s level: ”det var svært konceptuelt at få det hele til at passe sammen”[3]. One HoP module focused on how electromagnetism is a merge of galvanism and electrostatics and, thus, two different mathematical formalisms. The module covering this thus provided the students with a retrospective understanding of why the formalism of electromagnetism is as it is. They emphasized this as an important PLO.

Being an excellent physicist is tightly related to a deep understanding of the mathematics employed. Most often theories of physics are bound to

[1] Translation: It wasn’t mathematical from the beginning [instead] it was a purely physical concept.

[2] Translation: We read [texts] that almost was a merge of philosophy and physics. Suddenly, mathematics replaced metaphysics and now we write everything as formulas.

[3] Translation: It was, conceptually, difficult to get everything to match.

a specific mathematical formalism, e.g., algebra and geometry, with which they must be coherent. However, physicists often present mathematical notation as a useful tool and approach mathematics prosaically, thus, eroding the strict structure by which it was developed (Dunn & Barbanel, 2000). Nevertheless, physics is not simply a domain of applied mathematics. Instead, mathematics is a tool of reasoning and the two fields have evolved in complex interplay. The awareness of this intertwined relation; gave the students the impression of deeper understanding of the physics curriculum.

Identification

The second theme I retracted from the interviews is the satisfaction that arose from the humanization of the heroes of physics. Through reading of the primary sources and the revelation of the struggles they went through to develop their theories, the students felt a strong identification. They, particularly, pointed out that it was skills and competences that got them that far: ”De var dygtige håndværkere snarere end guddommeligt inspireret eller geniale”[4]. Furthermore, the students recognized the obstacles that appeared historically and that may reappear in the learning process and at different points during the interview, they drew comparisons to their own thesis work. In other words, they found comfort in: ”Vi står på skuldrene af giganter [...] men de havde heller ikke den fjerneste ide om hvad der foregik”[5].

Discussion

To present the students to the primary literature forced them to consider the didactic transposition prior to the formulations of the laws of physics that we all know from textbooks. In that sense, HoP provided this explicit-reflective framework. The students reported reflections about how physicists produce and validate knowledge, and what kind of questions that drive research; they had the impression of insights into *authentic* research practices. Even though, the themes that came up during the interview is not directly mentioned in the course description they are covered by the ILO,

[4] Translation: They were good artisans rather than divinely inspired or genius.

[5] Translation: We are standing on the shoulders of giants [...] but they did not have any idea of what was going on.

mentioned earlier: "they shall be able to use the history of physics as a background for reflections on philosophical and sociological questions of this science" (Karam & Kragh, 2017). Hence, there is alignment between the ILO of the course and the PLOs of students.

The analysis presented here, is suggestive of the view that students, working with the history of physics, can develop knowledge related to the hidden curriculum as well as a direct fulfillment of the ILO: "Knowledge about the historical background to physics and science". Therefore, my conclusion is that HoP is a very appropriate intervention to obtain alignment with the ILOs of the curriculum. However, the question is whether the course should become a mandatory part of the curriculum? The students, I interviewed, all had their own motivations to choose this course, e.g., interest in outreach or philosophy of science, but they all had a special interest in the history of physics. When I asked them whether this course should be mandatory, they answered that the found it relevant for all physics students and much more relevant than the mandatory bachelor course Theory of Science and Ethics for Physics. Nevertheless, it is not obvious that this course should be for all physics students. Instead there are two other possibilities: i) it is taught implicitly when students are *doing* physics or ii) this explicit-reflective framework could be established by embedding small elements of HoP in other physics courses. I do not know which of these approaches was intended from the Study Board.

I am not planning any similar course nor a minor one related to my field of research, biophysics. However, I am considering using the history as an element to clarify the relation between physics and mathematics. I anticipate this will help the students understand how the use of a specific mathematical terminology relies on the historical development of the field. This can be used in all physics courses, especially in my own Cell Mechanics and Single Molecule Biophysics. In this cross-interdisciplinary course, I could introduce some modules with a brief sketch of the history that led to a given relation between the biological object and its mathematical/physical interpretation. I think that the awareness of how the field has developed in an interplay between experiments, mathematical modeling, and the available computer power will help the students to a deeper understanding of the forces and limitations.

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