Considerations on the Education of Prospective Scientists: The Learning and Social Contracts

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***Abstract*— We claim that prospective scientists sign a social contract as part of their training. The social contract naturally addresses matters concerning communication among scientists and the various forms of social recognition. However, probably emerging from social pressure, quality control of the scientific effort is frequently incorporated into the social contract ruling over, and sometimes against, the mastering of metacognitive knowledge in which scientists are supposed to excel.**

This fact influences the formation of prospective scientists and consolidates "bad habits" hiddenly transmitted from their "local community" to students.

I. Introduction

A relevant part of the training of graduate students that will eventually become scientists consists in establishing new learning and working contracts. Undergraduates develop along their studies the successful strategy for graduation. We may call this conditions the *learning contract*. This contract consists among other things in mastering the incorporation of new knowledge and skills, and the ability of resolving excercises in well-determined and controlled environements. However, the strategies to address new problems developed in undergraduate studies have to be transformed into new strategies under graduate studies, useful for addressing open problems in (quite often) fuzzy contexts.

More often than not, the change implies the renegotiation of the learning contract established as undergraduate, into a new contract. The successful undergraduate strategy of trying to reduce a new problem to a contextualized excercise (to be found in a book) becomes insufficient for graduate studies. A scientist is expected to be an expert in discovery and incorporation of new knowledge and skillful in the use of the adequate strategies. They should be excellent in scientific self-control, and scientific rigor, in particullar, they must excel in metacognition [1].

In pararell to the new contract directed towards developing the necessary mastering of "self-monitored learning" and beyond, students are incorporated to a "local group" [2] (which is shaped mostly by the senior scientists) as apprentices that share a common interest and interact in different forms such as: scientific meetings and communications to a particular set of journals in which the senior scientists of the group reciprocally review submitted communications ("peer review"). It is within this context that the meaning of "significant contribution" is established.

In other words, Ph.D. students sign a second contract of a social character. Graduate students learn in an informal way the views of the scientific community they are entering, just by belonging to it, spending time with their advisor, other teachers and other students. We may call this learning process the *social contract*. These views include the evaluation systems, promotion, job opportunities, etc.

The social contract does not reflect the official institutional view of how a sound scientist should work (as stated by the enhanced learning contract) but rather the unwritten rules establishing how scientists frequently *are*. Inasmuch these two things are different –as we claim them to be and show some examples in the coming Sections– the social contract acts *de facto* as a *hidden curriculum* [5].

The matters incorporated to the learning and social contracts are not necessarily disjoint, of particular interest for our study is the quality control, i.e., those points of the contract that address "correcteness". It can be argued that within mathematics and physics, the social contract does not influence correctness, since there is no such thing as "true by consense". We will discuss below empirical evidence from physics supporting the idea that "correctness" belongs in both contracts.

II. Analysis of the problem

We will address two examples where elementary mathematical controls are violated in refereed publications in well-known, high-standard scientific journals, subsequently cited without observations by colleagues in the same field. The chosen examples are special in the sense that the laws violated and the controls that were not performed are accesible to first year undergraduate students of science and engeneering. To identify such examples is a simple exercise for a well trained alert reader *not belonging to the same local community*.

A. Background

A fundamental concept in mathematics is that of equality. No mathematical process can alter the fact that two numbers (quantities, expressions) are equal or not. In particular, equality between different numbers such as 1 and 0 or even worse ∞

(which is not a usual number but a more complicated concept) is impossible.

Heaviside defined the step function to be zero for negative values of the argument and one for positive values. The actual value of this function at $x = 0$ is conventionally taken to be one, but it is usually unimportant in most applications. A fundamental property of this function is the fact that it is discontinuous at $x = 0$ and hence cannot be approximated by polynoms around zero as opposed to e.g., analytic functions which admit a Mac Laurin series.

B. Examples

In [4] the fundamental concept of equality is violated. Compare equations (2.5) and (3.49) for $t = t'$ and $\zeta = \zeta'$ and verify that the first equation yields 1 while the other – which differs from the first one at most in a complex factor of modulus one, according to (3.7)– would take an infinite value.

In [8] a similar violation occurs, where zero or some other constant "equals" unexistent quantities. This explicitly impossible operation is performed by replacing the Heaviside function by the continuous function $f(x) = x$ which has properties that contradict those of the Heaviside function for the purpose of the analysis. This result is cited in other journals and further developed in [3] where the (nonexisting) derivatives of the Heaviside function –as a function– at $x = 0$ are assumed to exist and take a finite value.

C. Interpretation: Social contract and hidden curriculum

How come that elementary mathematical controls such as checking equality are overlooked by researchers, referees and subsequent readers ([3], [8] add up to 97 citations; while [4] presents 32 citations) ?

Somewhere along the way, the natural controls developed by mathematics (i.e., to check that two things are equal in a way which is compatible with standard practice from the moment of their definition and throughout a manuscript, the existence of limits and derivatives, etc.) have to be supressed. The metaconceptual controls have to be (unconsciously) compartimentalized: Such and such procedure is required within the mathematics course, but "in real life" we do something different. This could be the case if one does not strictly follow mathematics and mathematical logic in whichever "real life" application that is considered, but it becomes an unavoidable conflict when scientific conclusions are based upon mathematical procedures and mathematical logic.

The formation of scientists is strongly influenced by the agreement on what is a socially accepted argument for the local community. During graduate studies, the craft (metier) of being a scientist (physicist, biologist or the like) is learned by "apprenticeship", i.e., imbedded in the craft's (sub)culture [2]. This culture constructs the meaning and the rules of use for tools, working strategies, the concept of what is a "finished product" and many other things. It also shapes the social appreciation and approval (the conterpart of examination and promotion in the learning contract) as well as the successful strategies.

The hidden curriculum has at least two elements:

- The evaluation system implies that publication of articles (in reviewed journals) produces satisfaction and relief. The stimulus is placed on publication rather than on understanding (mastering). The examples above show that these things are not always equivalent.
- The meaning of "truth" or "correct" is shifted from "there is a flawless logical chain between what I previously knew and the new result" towards "it is in the book", "it is published", "the argument was accepted by the audience". This is again verified in both examples above.

In other words, the acceptance of an argument ceases to follow from compatibility with our own metaconcepts and with previously accepted and tested knowledge, becoming instead a social behaviour. Successful social behaviours are adopted or dropped as measured by social success.

III. Discussion

The contractual shift can be understood in terms of the use of evaluation methods that sense secondary effects of the principal goals. A goal of research could be "simplified" in the phrase "I understand a new problem and publish a manuscript thereafter". The principal goal is understanding, the (important and necessary) secondary effect is the publication. Measuring the degree of understanding new problems in terms of publications may be misleading since the latter can be produced without the former (see the examples). The measuring method induces an enhancement of the social relevance of publication and a corresponding relevance reduction for "understanding new problems".

The case for the use of citation indexes is even stronger. As shown in the examples, important citations numbers can be achieved with incorrect results as long as the thinking is "socially correct". Citation numbers are to a very large extent a measure of social sucess and are a measure of the fulfillment of the social contract.

We are currently running a questionnaire in order to gain deeper understanding about the processes here discussed.

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