The Alignment Between Teaching and Discovery:
How Do We Teach What We Do Not Know?

Pedagogiskt docenturarbete

Claudio Cantù
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SYNOPSIS

In this brief essay, I wish to consider the role of education and supervision of university students who approach a PhD experience in an experimental scientific discipline. In particular, I will reflect on the pedagogical difficulties that are intrinsically connected to the passage from frontal teaching to the laboratory supervision. The complication is due to the fact that experimentation, the quintessence of scientific subjects, requires standing at the interface between knowledge and discovery. Students meet this phase of their career during their master’s and PhD studies, when they approach a scientifically professional way of learning new things: discovery via experimentation. Here, my goal is to unearth novel thoughts, and perhaps suggest practical solutions, for the inherent dilemma emerging from teaching and supervising students when the final objective of the student’s training process is to discover something new. To lay the ground of my reflection, I will attempt in defining knowledge, and how this concept progressively undergoes metamorphose throughout the phases that accompany the growth of an individual across the academic curriculum. I believe that there is a closing gap between learning and discovering, and that the meaning of learning profoundly changes for students that approach the end of the university path and start their PhD training. No one has the solution for a problem that was never encountered before. Yet, the scope of students at the end of their academic curricula includes solving previously unanswered questions, and this is widely recognized as a genuinely difficult task. My reflection will bear no definitive answer but carries the hope of raising important questions on how we should accompany the students in this difficult transition.

The Catch-22 of the higher education

Improved quality in education is pivotal for both individuals to thrive as well as society as a whole. This narrative implies that quality in education leads society to prosper, and argument that is almost impossible to question (Mufic & Fejes, 2020). Teaching in an institution of higher education is a difficult task. Despite the necessary fact that the students who receive this type of education are in the age where they possess the highest cognitive abilities and psychosomatic strength – from which one could infer the highest capability of learning methods and notions (Nadri et al., 2019) – what is(are) the most effective pedagogical instrument(s) is still arduous to define (Alimuddin et al., 2020). More problematic, in my opinion, becomes the education of the students who wish to undertake a PhD iter.
This is because, in any scientific subject, one of the desired outcomes expected from a PhD student is the production of new knowledge: discover something that no one knew before. Of course, the idea that “If the university is primarily about scientific and philosophical discovery, I do not see why a University should have students” (Newman, 1873), could be briefly defended. I agree in fact that we - as teachers - should realize that, primarily, must provide learning outcomes. Yet, a doctoral student in a scientific experimental subject must also be taught (and motivated) on how to generate discoveries. Therefore, what a first-year university student is supposed to learn, both in terms of content and modality, is radically different from that which is expected from a PhD student in a later stage (Lindén et al., 2013).

I believe that the changing perspective between being an early university student and a PhD trainee exposes a pedagogical dilemma that has been largely overlooked. I refer, in particular, to the quasi-paradoxical realization that a supervisor should teach a PhD student to discover something that he/she (i.e. the supervisor – and anyone else) does not know. And this is the catch-22 of scientific higher education: how could we teach younger scientists something we do not know?

Already Plato was obsessed with the intrinsic difficulty of knowledge generation. In a Socratic dialogue, the character Meno sustains that “Either you know what you are searching for or you do not. If you do know, you already have it, whence inquiry is pointless. And if you do not know, you would not recognize it even if you stumbled on it accidentally; hence, again, inquiry is impossible, pointless.” (Nickles, 1981 p. 89). This is often referred to as Meno’s paradox. According to Peirce, the only way out of the paradox is abduction, a syllogistic way of reasoning that, allowing part of the syllogism rationale to be hypothetical, opens up to new discoveries (Paavola & Hakkarainen, 2005). As we will see, not only a type of reasoning, but rather the exposure to the unknown (via scientific research) could also constitute a partial solution to Meno’s paradox.

What do we teach? A new definition of Knowledge

Knowledge is perhaps the most important outcome of higher-education institutes. Primary for having a clear focus on the problem is spelling out a clearer definition of knowledge. The Oxford Learner’s Dictionaries online defines Knowledge as “the information, understanding and skills that you gain through education or experience” (Knowledge, see References). This definition appropriately entails the raison d’être of universities: that of generating both education and experience. In the words of Bowden and Marton: “the university does not have three aims, it has one. Teaching, research and service are all supposed to yield learning: for the individuals (through knowledge being formed which is new to a particular person), for humanity (through knowledge being formed which is new in an absolute sense) and for communities (through knowledge being formed for specific purposes)”
We could define knowledge as the outcome of an active process that leads to the acquisition and the retention of information from one individual. Knowledge operates by the exchange of “information”, which can represent a fact about the world, a method, or a series of operations (such as in an algorithm), that tells us something we did not know before. The information content is then represented in a symbolic or mathematical language and dynamically exchanged by individuals. Key is also the realization that the source of the information might be dual: new knowledge could be provided A) by a text or an authority figure (e.g. a teacher/supervisor) or B) gathered through experience (e.g. experimentation). In the first method of knowledge acquisition (A), the exchange of information is a directional process that implies the definition of a “donor” and a “recipient” via two complementary processes to which we refer as “teaching” and “learning”, respectively. In a widespread understanding, a classical pedagogical setting sees the supervisor performing one of these actions, the teaching, while the student taking care of the other, the learning. As we will see, the univocal attribution of these two roles might become blurry as time goes by, when the students approach a different phase of their academic curriculum, start an experimental PhD, and switch to the attempt in obtaining knowledge via the second channel (B), experimentation. After this process, the quality and quantity of the information content retained by a student (that is, the knowledge of a student) certainly approaches and often could exceeds that of the supervisor. What is the role of the supervisor at this stage?

It is also important to specify that real knowledge does not refer to knowing the names of things (Feynman & Feynman, 1999). A name is an arbitrary label given to an item to signal its separateness from the environment and allows sharing the information across individuals – at least those speaking the same language; as we all know, “A rose by any other name would smell as sweet” (Shakespeare, 1597). On the face of it, real knowledge must entail the grasp of a mechanistic comprehension of the phenomena under investigation. This must include a temporal and spatial understanding of causes and effects that could be represented in a mathematical or logical model. That is, knowledge is fully present when the individual retaining it is capable of sharing the information content in a manner that transcend any single arbitrary language. As Cato the Elder sentenced: “Rem tene, verba sequentur” - literally “grasp the argument, the words will follow” (Victor, Edition 1980). It is very important therefore that, in building their relationship, supervisor and student must agree on focusing their attention on the right type of knowledge.

The Shifting Student-Supervisor Asymmetry

There is no need of a vast text to persuade the reader that a profound asymmetry exists between a student and a supervisor. The asymmetry precisely lies in the initial retention of knowledge. Moreover,
in a university setting, it is naturally the case that the teacher (professor) experienced both types of knowledge acquisition, via studying (A) and also via discovery by experimentation (B). In this context, it is therefore relatively easy to attribute the roles of knowledge “donor” to the professor/supervisor and knowledge “receiver” to the student/trainee. But what is the scope of the supervisor-trainee relationship in a PhD setting? It is 1) the identification of an open scientific problem and 2) the development of an experimental strategy to address it. In the initial stage, the supervisor should offer a defined set of skills and technologies gathered in years of professional experience. Phase 1 will define the subject of a student’s master’s or the PhD program. Phase 2 is characterized by the construction of a strategy. Here, a close relation between the student and the professionally experienced supervisor is extremely important and instrumental in identifying and selecting a coherent strategy to address the problem. As in all scientific disciplines there might be several routes to one experimental goal; it is important for the supervisor to build early trust in the trainee(s) – and vice versa – so that a consensus on the selected strategy can be achieved. The subsequent actual execution of the experimental plan requires a large amount of supervision. Here, also, the knowledge of technical details and protocols must be massively transferred from the supervisor to the trainee. So far so good.

However, at any point during the PhD itinerary, the shared knowledge between supervisor and student ends. If a PhD is successful, supervisor and trainee must meet – metaphorically – at the borders of the unknown. Therefore, the clear directionality of the teaching and learning actions will be interrupted. How should a supervisor deal with this change? There is no clear answer to this, but the defined teaching-learning process must leave space for a more chaotic and reciprocal exchange. Could we consider, as a diagnostic sign of a functional and successful PhD education, that the students sometimes take the role of teachers providing the possibility for the supervisors to learn new aspects or details of the discipline in which they (the supervisors) deem themselves experts? I believe so. This important switch must occur at the crossroad between two routes. The first marks the directional transfer of knowledge from supervisor to trainee which starts at the onset of a PhD education. The second is traversed when knowledge is generated – via experimentation – and constitutes the output of a professionally functional supervisor-trainee relationship.

The substantive “education” comes from the latin verb *educāre*, which literally means “accompany from”. The etymology is suggestive of the idea of extracting an individual from ignorance or from natural bad proclivities, allowing him or her to autonomously express the positive attributes of the mind. If this is successfully achieved, a trainee is educated in an adult individual in a world of professionals, standing as peer with his/her supervisors. Perhaps, even, it shouldn’t be rare that a trainee, in case the intellectual skills will allow it, surpasses – professionally, his/her supervisor. This outcome is not only plausible but has to be desirable from the point of view of the supervisor.
It is important to mention that the number of doctorates being awarded worldwide has increased exponentially in the last two decades. Within this context, both teachers and PhD students face new challenges, and the very meaning of education is changing. For a rich account of the combination between traditional and innovative pedagogical practices across a range of doctoral systems, including considerations of the relationship between pedagogy and knowledge generation, I refer to the authoritative analysis from Lee & Danby “Reshaping Doctoral Education: International Approaches and Pedagogies” (Lee & Danby, 2012).

**A NEW SUPERVISION TOOLKIT**

Here I will discuss three ideas which could enrich the toolkit of any supervisor. These ideas have the scope of accelerating the process in which the students become self-confident and independent intellectuals and rapidly go over the critical phase in which their tutor might still constitute an important help but is not entirely required for the student to succeed.

I will propose that the teachers should move the focus and develop emphasis on explaining how we know or have discovered what we know, rather than the more diffuse attention to notions and lists of facts that must be remembered. Moreover, I will suggest that, when possible, students of scientific subjects should be encouraged to anticipate their entrance in a professional laboratory.

Finally, perhaps on a more philosophical level, I will suggest that the Supervisor-Trainee relationship should be built on the trust given by the realization that both of them are ignorant when it concerns what really matters: their professional common goal of discovering something new.

*Do not teach what we know but how we know what we know*

From an epistemological perspective, the best we can aspire to achieve in our aim of generating new knowledge is approaching the truth. Epistemological truth (that is, the reality) is elusive, and we always must allow for the possibility that new available evidence will produce a more precise representation of the reality itself. This philosophical concept is widely known, thanks to the work of Karl Popper, under the name of Theory of Falsification, whose central idea is that knowledge is provisional and represents the best we can do in a certain moment (Popper, 1934). Hence, knowledge is not equal to reality. However, it might be widely assumed or expected that, while teaching, the professor provides the students with a careful and faithful representation of reality. This view, I here argue, must be changed in favour of a more careful realization that no one possesses the intuition of a functioning model of the reality which is perfectly fitting the truth. At best, we can possess good tools to judge, on a statistical basis, which models of the reality to provisionally accept and which ones to refute. This very problem is exemplified by a new challenge, emerging in the modern era, for which students have
real-time information retrieval devices at their disposal (Roberts & Rees, 2014). By using these, they are often in the position of identifying pieces of information which could contradict in principle the content of a lecture given by a professor. Are the students right and entitled in doing so? Should the professor defend his/her statement or embrace diversity of opinion?

As previously mentioned, what really counts is not only offering a piece of information; rather, being capable of justifying the reason why we should (not could but should!) trust that piece of information instead of another. In the aforementioned example, the professor could substantiate his/her statement based on empirical evidence available, but also demand a response on what the rationale is for supporting the new assertion(s) put forward by the student. With this attitude, we should hope to let emerging, in the students, the intellectual tools that make them critical and skeptical about any new information they run into. The final lesson is: what matters is the degree of statistical confidence that each of us develops about any news or fact we learn. Methodologically, our reasoning efforts should focus on understanding: how was this information obtained? How did this evidence come available? Who and how discovered it? The content of our teaching sessions, whether it is frontal lectures, problem-based learning groups or laboratory work, should have a heavy component describing how we know each information we are teaching. A good case could be made for cultivating our students in a skeptical approach toward any new information encountered, regardless its source.

An additional powerful logical instrument we should provide the students with is a constitutive bias in asking themselves: what the type of evidence would be needed to disprove this specific fact or tenet I learned? This is a powerful instrument, and I deem it possible even when we are teaching the more robust scientific theories. In a legendary example, the illustrious population geneticist J.B.S. Haldane, when confronted with the question of what would disprove the theory of evolution, famously growled: “Fossil rabbits in the Precambrian” (Dawkins, 2006). No one will find these (emphatically!), but we all know that this is the type of discovery that would render even the Theory of Evolution obsolete.

A good piece of advice comes from a recent article written in the PLOS SciComm online forum which brings this discourse to the extreme, in an attempt of extending the skepticism typical of hardcore scientific subjects to everyday life discussions (Redaelli, 2020). The scientific method in every human discourse will bring about an attitude of referencing to testable predications and facts that will increase our own confidence, and that of those who listen to us, concerning everything we say. And this can be a powerful tool we pass on to our students.

**Start Research Earlier!**

Admittedly, I am passionate of scientific research. Also, as argued above, I personally would encourage the use of scientific methodologies in every human exchange whose objective is the exchange of
information. More importantly here is my discussion on the structural rupture occurring along the academic educational curriculum. Initially students are flooded with tons of information and asked to learn the more they can – often as if this information are revealed by a higher, mystical authority. At some point, we ought to teach them that being “certain” about a certain phenomenon is virtually impossible, and that knowledge could change once new evidence become available (Popper, 1934). Students must start realizing not only that every new discovery is hard to obtain, but also that it is always at peril of being falsified, corrected or improved by future and more robust evidence. 

Here I suggest that this gnoseological schism should occur as early as possible during the academic curriculum. Isn’t the objective of high education institutes to form independent thinkers? It is therefore desirable that the students emancipate themselves by that type of unidirectional exchange of knowledge which represents the prevalent pedagogical method in the first years of university education. One manner to facilitate this process, in my opinion, could be the temporal anticipation of research time along the academic curricula of scientific subjects. This would expose the students – early in their education – to a tangible section of the unknown with the aim of uncovering it. They will realize that what was unknown might be included in the growing set called “knowledge” via a process that combines experimentation, tests and logical thinking – i.e. hard work! Knowledge, in other words, does not appear from the sky or from authority revelation. What better lesson could we conceive for our students?

The laboratory practices will provide and sharpen the intellectual tools for being able to selectively retrieve information in any other field of human knowledge, and weigh the evidence based on the stringent scrutiny of statistical practice. In a traditional setting, university-level science education couples classroom lectures with standardized laboratory courses where students perform experiments with known outcomes. Here I argue that this might not be enough. It has been demonstrated, in fact, that laboratory courses are not the most effective model for educating about the nature of science when compared to inquiry-based or real research-based experiences (Russell & Weaver, 2011). An attempt to improve this model has been described at The University of Texas at Austin, where course-based undergraduate research experiences within faculty research projects provided the benefits of an early research experience to students. In this context, chemistry students benefited of both mandatory and accredited general chemistry lectures and open-ended research experiences. A study describing this example showed that this pedagogical instrument even generated unexpected positive outcomes in scientific curricula, by enabling undergraduates to be productive contributors to new knowledge and scientific discovery at the earliest levels of their academic experience (Ghanem et al., 2018). An additional advantage consists in the rewards and satisfactions obtained in our professional life. Numerous studies have shown that students who become involved early in real research are statistically more likely to enjoy scientific research and to become successful scientists (Russell et al.,
Moreover, strong is the connection between the very act of teaching and that of researching, and the research process is a model of relation between knowing, planning, and learning (Hult, 2001). I strongly believe that the implementation of innovative models of teaching through research should break the paradigmatic view that scientific competencies must be taught with predictable pre-programmed experiments, and will generate more creative, less frustrated, and infinitely more passionate young scientists.

**The blessing of Ignorance: the heart of the Student-Supervisor relationship**

At the core of my reflection is the concept that every form of teaching has to deal with the frontiers of current knowledge by the emphatic distinction between what we know and what we do not. This is all the more relevant during the academic path of a student in scientific subjects, for in this case there must exist an explicit intention of decreasing the second set (unknown) in favour of the first (knowledge). Primary therefore in the establishment of a concrete pedagogical strategy must be the admission of ignorance about a certain phenomenon. Hence, in light of the 2-phase relationship defined before, it appears that ignorance is the leading device for adequate supervision. Not only ignorance is necessary to sketch the borders of the entity which we do not know – but about which we wish to discover new features – but it is a crucial tool to define an honest supervisor-trainee relationship, built on trust and on the agreement on that as a common purpose.

It is responsibility of the teacher to show where the lack of knowledge occurs, and what kind of evidence would be necessary to reduce the uncertainty about that phenomenon. As we have seen, several are the instruments in the hand of a professor. One is the instruction on how we know – rather than what we know – and this precisely allows the generation of parallel strategies to discover something new, by “simply” applying the how on a novel question. The second is the early introduction to research activities for the acquisition of the logical and technological tools required to succeed, such as the attainment of several skills necessary to formulate scientific hypotheses and approach new and existing data in light of the principle of falsifiability.

On the other hand, I wish to reflect on the fact that a teacher should refrain from arranging the future research activity based on series of strategies and tools that need being employed. There exists an intrinsic unpredictability in scientific research for which the establishment of a detailed plan contradicts the very nature of discovery. Perhaps, renouncing the priori acceptance of any single way of supervision could be ideal. That is, in research, having no teaching philosophy might be the best teaching philosophy. This is supported by several lines of evidence, both inherent in the experimental subject, as well as in the heterogeneous nature of the personalities and the spectrum of cognitive abilities of those who subscribe to these institutions for learning. Here I suggest that in teaching,
flexibility and individualisation must be core values. And in the words of the great Richard Feynman: “the best way to teach is to have no philosophy, to be chaotic and confusing, use every possible way of doing it” (Feynman & Feynman, 1999). Science is one of the great achievements of the human mind, and a chaotic, unorganized strategy might leave enough room for creativity - the single most important ingredient for the generation of new knowledge.

**Conclusive Remarks**

This essay is my attempt to expose a difficulty in teaching to the future generation of scientists. There is an intrinsic gap between what we already know and what will be discovered (hence known by future generations), that brings to light a pedagogical fracture: we should hope that those to whom we teach will soon know more than us!

In confronting this challenge, I suggested new tools in the hands of a supervisor of PhD students in experimental scientific subjects:

1) The idea of teaching *how*, rather than *what*: methodologies of learning and discovering (how) are more precious than facts themselves (what), as the how provides a modus operandi generally applicable to future endeavours.

2) Allow young university students to start research earlier, so that they can look out towards the unknown in first person, realizing where the problems that we face, as well as the gaps of knowledge, really are.

3) Embrace ignorance – that is the realization of not knowing – for this is the first step required for learning, constructing strategies to fill gaps in knowledge, and solving problems.

In all this, flexibility and personalization of the teaching philosophy, in dependence of the student personality and cognitive abilities, are keys to the success of a fruitful professor-student relationship.

**References**


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