Research in Marine Sciences
Volume 8-Issue 4- 2023
Pages 300-315

Conceptual discussion scientific paper

Philosophical thoughts about the specialization phenomenon in natural sciences

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Received: 2023-09-26 *Accepted: 2023-11-22*

Abstract

This paper is a philosophical attitude about the phenomenon of specialization with focus on the natural sciences such as marine biology. At first, a briefly pointing out the context in which the phenomenon of specialization begins to become notable, which is linked to the process of professionalization that occurred in science in the second half of the 19th century. Then, it will be indicated how the phenomenon of specialization can be conceptualized, for which the concept of hierarchy will be used, that is, a hierarchical ordering of the taxonomy of sciences. Some of the advantages and limitations of this way of thinking about specialization, as well as some alternatives, are discussed. Next, the problem of the reliability of specialists are analyzed, which determines the way in which the specialist in general and the scientist in particular are socially perceived. The other problem that will be analyzed refers to the way in which scientific knowledge is imparted when it is part of a specialization process. Here, the key concept to understand the teaching process is training. Finally, some negative consequences of the process of specialization will be emphasized.

Keywords: Specialization; Natural sciences; Marine biology; Hierarchy concept; Philosophical attitude.

1. Introduction

1.1. The beginnings of specialization

The phenomenon of increasing specialization exhibited by science contemporary is closely linked, in its origins, to the process of professionalization that occurred in this activity as a result of the reform of the university in the 18th and 19th centuries. Just as an illustration of the recentness of this process of professionalization, it is enough to remember that in

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1834 the English magazine Quarterly Review raised the difficulties that the British Association for the Advancement of Science faced by not having a generic term to refer to all the scholars from different scientific disciplines. To remedy this problem, in an article, the use of the term “scientist” was proposed by analogy with the term “artist”. This proposal was spread by the naturalist and philosopher William Whewell, who in 1840, in his book The philosophy of the inductive science, proposed the use of the term “scientist” to refer to those who were dedicated to research in the various fields of science.

Despite their differences, the new university models that were established in the 18th and 19th centuries promoted specialization. In 1794, under the government of Napoleon, the École Polytechnique de France and the Muséum National d'Histoire Naturelle were founded, which constituted the first modern research institutes. In these institutions, teaching combined with research appeared for the first time, that is, the scientist and the teacher merged, which meant that the knowledge that was taught was that which resulted from the experimental research that was produced in the laboratories. However, this attempt was hindered by the imposition of the Napoleonic model of university that was organized from special or professional schools, with an education characterized by a practical conception of life, and whose fundamental objective was to train doctors, lawyers and teachers. These professional schools were called faculties and had the function of training professionals to serve the empire. The focus shifted to teaching rather than “science production,” which caused its graduates to become high-ranking public officials rather than scientific researchers. Furthermore, the university became an instrument of the state, since it depended completely on a ministry that was responsible for establishing teaching subjects and the appointment of professors. Later, the reform of the university led by Wilhelm von Humboldt in Berlin, in 1809, established a model different from the Napoleonic one, in which scientific research effectively became an integral part of the needs of these study centers. This meant that the university had to set itself the goal of creating knowledge and not limit itself to possessing and transmitting it. This reform introduced modern science to the university and promoted the creation of departments that multiplied as new sciences emerged.

This process of professionalization made research become an exclusive activity of prepared and formally qualified people, who were clearly distinguished from other types of professionals. This first division was quickly followed by a whole series of new divisions within science, as scientific disciplines emerged and took root throughout the 20th century. As a consequence, physicists, chemists, astronomers, geologists, mathematicians, historians, sociologists, philosophers, and many others, were recognized as being part of distinct occupational groups, each with special training, formal qualifications, societies, publications and with all the other characteristics of a developed profession. Since that time, specialization has continued to advance rapidly, so that, although the scientific discipline remains the basic unit for teaching purposes, the specialty, or even the subspecialty within it, frequently constitutes the most important professional reference point for every scientist (Balzer *et al.*, 2012).

2. How to conceptualize the phenomenon of specialization?

The philosophical thoughts in specific phenomena in natural sciences is that they play a crucial role in understanding and interpreting these phenomena. Philosophical point of views helps scientists to answer the questions and analyze the underlying assumptions, methodologies, and implications of their research. They provide a framework for critical thinking, ethical considerations, and epistemological reflections. One of the ways to conceptualize the phenomenon of specialization is using the concept of hierarchy, whose analogy corresponds to the shape of an inverted tree (Darwin, 1982). Virtually all the authors who wrote on the subject from the mid-19th century (Comte, Whewell, Mill, Spencer, Peirce) proposed a hierarchical ordering of the taxonomy of sciences, characterized by a sequence in which fields are differentiated, branches, specialties, subspecialties and problem areas.

In the 1969 Epilogue, Thomas S. Kuhn, referring to the problem of the criteria necessary to identify scientific communities and differentiate them from the concept of paradigm, suggests an ordering of the different disciplines following an organization in levels. Although Kuhn does not delve into the matter, it could be said that he subscribes to a hierarchical organization of the sciences (Kuhn, 2004).

Comte (1984) proposed a hierarchical organization of the sciences based on a conception about the historical development of human knowledge, which he called the law of the three states: theological, metaphysical and positive. All human knowledge is obliged to go through these three theoretical states, which correspond to three different ways of explaining the phenomena of nature: in the theological state, it is resorted to the divinities, here the human mind invents; in the metaphysical state, abstractions are resorted to, at this point the human mind abstracts; and finally, in the positive state, scientific methods such as observation and experimentation are used, here the human mind submits to positive fact.

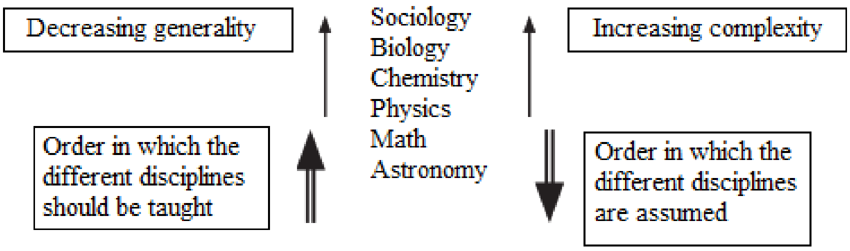


Figure 1. Comte idea to propose the hierarchical ordering of the sciences

The law of the three states provides a criterion of a historical nature that allows explaining the reasons why a discipline occupies a certain place in the hierarchy. This criterion reveals the passage of the particular sciences to the positive state. Mathematics was the first discipline to move to the positive state, which occurred in ancient Greece. Physics left the metaphysical state to move to the positive state in the 17th century. In the 18th century, chemistry entered the positive state, and in the 19th century, the same thing happened with biology. Comte (1984) hoped that the same would happen with sociology, that is, that it would become a positive science. In addition to the previous criterion, there is one of a logical type that Comte called dogmatic, which establishes that the hierarchy begins with the science that has the simplest object (mathematics) and ends with the one that has the most complex object (sociology). In addition to the above, in the hierarchy there is a decreasing order of generality that goes from mathematics, which is the most general discipline, to sociology, which is the least general discipline (see Figure 1).

Pedagogical consequences emerge from this ordering, given that Comte points out that the sciences should be taught in the same order in which their historical genesis occurred, which means starting from the most general to ending with the least general, and simplest to most complex. On the other hand, in the hierarchy presented by Comte, the most complex sciences presuppose the simplest ones, which does not mean that the higher sciences, in the hierarchy, can be reduced to the lower ones.

Regarding the ordering suggested by Comte (1984) for the sciences, it is worth pointing out a distinction, as in the case of Comte, of a hierarchical order applied to a set of disciplines such as those included in Figure 1. It can be applied hierarchical ordering to the specialization process that occurs within a particular discipline, for example, in the case of biology and their subfields such as marine biology. In more technical terms it would be what is called in philosophy of science intertheoretical relations (for the first case) and intratheoretical relations (for the second case).

Now, in the task of specifying the concept of hierarchy, it must be pointed out that this is built from successive additions governed by the relationship of systematic inclusion that consists of the containment of something within a systematic whole as a constituent element of it. This systematic inclusion generally proceeds through the concrete supplementation of a new specification of a thematic focus. The additions that occur in this super-addition of new thematic elements come, mainly, from the introduction of new thematic restrictions. This idea can be represented by the Figure 2 (Rescher, 1981):

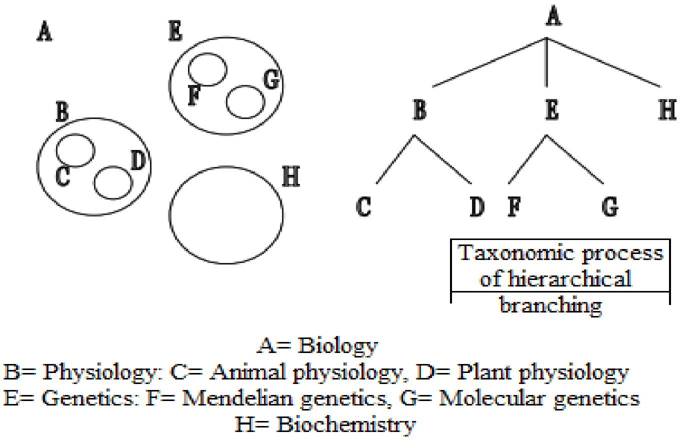


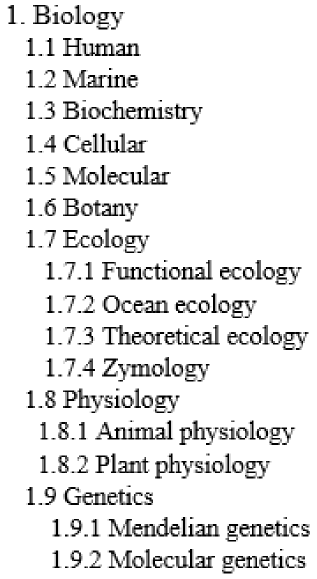
Figure 2. Systematic supplementation of new thematic elements (Rescher, 1981)

As can be seen in Figure 2, this is a narrowing of the thematic focus that produces a subdivision of the theme. As descending in the taxonomy of knowledge represents the hierarchical structure, it is shown how cognitive systems are divided into subsystems at each level of the process of increasing specialization. This taxonomic process of hierarchical branching admits, in principle, endless refinements.

The specialization process occurs in two directions: one called fission – a process of multiplication of the number of taxonomic elements –, as for example, when in the 19th century chemistry was divided into organic and inorganic. The other that could be called fusion – a process that reduces the number of taxonomic elements in question – which can be illustrated with the framework provided by Newton's theory of gravitation that allowed the theory of terrestrial fall to be combined with ballistics, etc. with the theory of planetary motion; or when Maxwell's field theory merged with the theory of light and electromagnetism.

This overspecialization has caused a complementary phenomenon, which can be called interdisciplinary synthesis, and which gives rise to a whole series of new sciences with a double name: astrophysics, biochemistry, mathematical chemistry, biophysics, physical-chemistry, etc. It is interesting to observe how this attempt to counteract fragmentation, through disciplinary synthesis, produces new fragments, since these syntheses constitute new specialties.

If you look at the evolution process of any discipline, you can note that fusion tends to occur at the higher levels of the hierarchy, which are characterized by increasing generality or abstraction, this results in the union of previously separated branches. On the contrary, at the lower levels of the hierarchy fission predominates, causing in a tendency towards qualitative growth. The concept of hierarchy allows us to schematize the growth in geometric progression of the branches of science, which constitutes one of the most characteristic features of the evolution of modern science, considering the example of the taxonomic structure of biology. Furthermore, it can be assumed a taxonomy of three strata: the field as a whole (biology), its specialties (human, marine, biochemistry, etc.) and the subspecialties (functional ecology, animal physiology, etc.). This taxonomy can be represented in the scientific way:



1. Biology
  1.1 Human
  1.2 Marine
  1.3 Biochemistry
  1.4 Cellular
  1.5 Molecular
  1.6 Botany
  1.7 Ecology
    1.7.1 Functional ecology
    1.7.2 Ocean ecology
    1.7.3 Theoretical ecology
    1.7.4 Zymology
  1.8 Physiology
    1.8.1 Animal physiology
    1.8.2 Plant physiology
  1.9 Genetics
    1.9.1 Mendelian genetics
    1.9.2 Molecular genetics

In general terms, the same image appears in all fields of the sciences. The emergence of new fields, specialties and subspecialties is manifested throughout its evolution. However, when the systematic inclusion scheme includes overlaps, it is no longer possible to achieve a hierarchical ordering as it is seen in Figure 3 (Rescher, 1981).

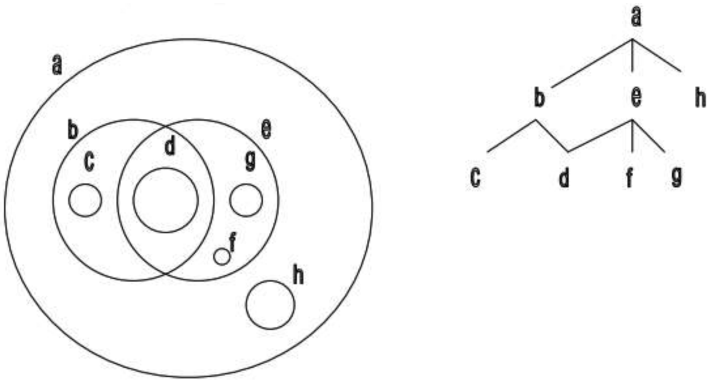


Figure 3. An example of the case indicated in different disciplines (Rescher, 1981)

An example of the case indicated in Figure 3 can be found in the physics and chemistry, disciplines that share quantum theory as a common background, a theory that these sciences complement in quite different ways, giving rise to different systems that are based on different thematic focuses. So, it can be concluded that hierarchical ordering is insufficient to account for the issue of specialization, with Nicholas Rescher's quote (1981):

> “The results regarding our initial question regarding the adequacy of a hierarchical model of the taxonomy of science in general is, then, negative. The general structure of a natural science is not that of a hierarchy. Without a doubt, in the descending order of successive subdivision of the taxonomic split always remains within a hierarchical scheme. But in the ascending order of associative relationship will obtain the complexity of an interweaving mesh network”.

Rescher's quote refers to another type of ordering or possible relationships between the various specialties of science, without ruling out hierarchical ordering. It is a “network interweaving” that refers to a reticular model, which conceives the set of specialties of a given discipline as linked through a network of connections. This reticular model of theoretical systematization corresponds to coherentism. What is relevant to the problem that have been discussing is that the hierarchical model and the reticular model are not exclusive. The reticular model can incorporate locally, as a sub-system, a hierarchical structure that is called a lattice model or network model (Figure 4).

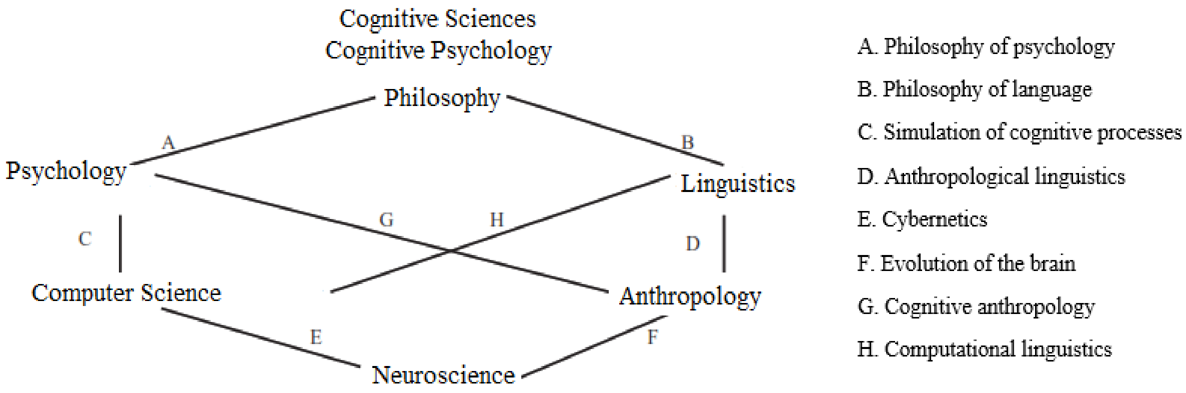


Figure 4. An example of a lattice model (Rescher, 1981)

Another alternative to conceptualize the phenomenon of specialization, has to do that specialization can be considered in the broader framework of the problem of intertheoretical relations, particularly of intratheoretical relations, that is, not only of the relations that They occur between theories but also those that occur within a theory. As Diez and Moulines (1997) say:

> “Each theory of the various scientific disciplines is found in more or less close and diverse relationships with other theories, often from the same discipline, but sometimes also from quite different disciplines. A mechanical theory, for example, cannot be understood and applied without taking into consideration its relationship with physical geometry. The relationships of thermodynamics with chemistry are essential to both disciplines; it is really unidentified what genetics says about living beings if it does not take into account essential concepts of taxonomy, etc. It is very doubtful that, in the current state of empirical science, there exists a single theory, however elementary, that does not carry empirically and conceptually significant relationships with various other theories. In many cases, these relations are even absolutely essential to the theory in question in the sense that it cannot be identified that theory or fully determined what it is about. For example, the relationship of mechanics with physical geometry is essential for the first (although not for the second): if the grasping link of some of its basic concepts with concepts coming from geometry cannot be done, it will not be understood the essence of a mechanical theory.”

If a semantic conception of theories is adopted, in which a theory is defined as model-theoretical structures, some relationships such as: specialization, theorization, reduction and equivalence can be considered.

3. The reliability of the specialists

In this section, the problem of the reliability of specialists will be addressed. The phenomenon of specialization determines the way in which the specialist in general and the scientist in particular are socially perceived. One aspect of this perception has to do with a problem that can be raised from the following question: What is the authority of specialists based on? Living in a society where the experts are actually reliable and in which almost all the decisions to the judgment of experts are directed, from the most trivial ones such as, increasing the capacity of the computers; to the most transcendental ones such as, building a new world order.

One of the criteria with valuation the contribution of specialists to society and with which they value each other has to do with the reliability and effectiveness of the knowledge they possess. Greater authority is always given to the opinions of those experts that can be considered as best qualified on a given topic. However, in this matter, moving between a scientific position that maintains that science is the only legitimate way of knowing, which is characterized by being disinterested and maintaining a certain distance from society; and a skeptical position that questions the trustworthiness of the knowledge on which experts' judgments are founded (Wallerstein, 2005).

For example, it can be thought that reliability depends on the training that specialists receive and the objectivity that characterizes them. In this sense, it could be argued that specialized knowledge requires prolonged and rigorous training, which is obtained in formal institutions whose reliability can be evaluated. On the other hand, being objective, experts would not respond to personal interests, and would always be willing to defend the truth from any attempt to distort it or at least, among their fundamental objectives would be the search for the truth. This scientific conception tends to offer an idealized image of how scientists work.

Precisely, the analyzes of some philosophers, sociologists and historians of science have pointed out the difficulties that characterize this scientistic vision. For example, Feyerabend (1985) is particularly radical about the role that experts play and should play in contemporary societies. When wondering about “the narrow-mindedness” that resides, precisely, in something similar to what it is called scientism: “This myth could persist as long as science seems like perfect knowledge.” and free of errors, if the deviations were insignificant and the necessary improvements were minimal, on condition that there was no serious failure”.

The myth that Feyerabend (1985) refers to in this quote has to do with the conviction that the progress and success of science is the result of the existence of special scientific methods. Feyerabend leans towards one of the extremes that have been pointed out before adopting a skeptical and relativist position. Relativizing the trustworthiness and effectiveness of the knowledge on which specialists base their authority. Actually, the science does not have any privileged epistemological status compared to other forms of knowledge, and that, therefore, specialists cannot claim any advantaged status in society when making decisions that affect its development. Based on this criticism, Feyerabend advises specialists to free themselves from the “narrow-mindedness” that characterizes them.

Some scientists are aware of the complex social and intellectual interactions that affect them as specialists. Watson (2009) recounted the events surrounding the process of discovering the structure of the DNA molecule. Certain statements by Watson show the competition that had been generated with the North American team, led by Linus Pauling, who was also in search of the same objective.

Merton (1984) said that the theme runs through Watson's book is that of the “race for priority” and all the consequences that flow from it: competition for scientific discoveries; the race to obtain the highest tributes (the Nobel Prize); the desire to obtain fundamental data or to hide basic information from the competition and etc. It usually happens that in some specialties the number of scientists working on cutting-edge problems is much greater, which results in the intensification of competition that in many cases, promotes competitive behaviors that escape or violate the current norms of the science.

On the other hand, if the issue of objectivity is considered, one could object that this is not based on the impartiality of the scientist, as assumed by the scientistic conception, which means recognizing that the scientist, like any person, is subject to a series of prejudices or the lack of a "critical spirit" regarding his own convictions, and that on many occasions the way wherein observations are made transforms the objects of research. Popper (2020) stated that the only way to avoid the aforementioned prejudices stands on what is called the social aspect of the scientific method.

On some occasions, the knowledge of experts is used for a technical-instrumental purpose, in which consequences occur immediately and visibly, which allows verification of its reliability in terms of effectiveness. For example, in the case of the engineer who builds a bridge, its reliability through the object is being judged that has been produced from a certain knowledge. In this sense, the knowledge involved here can be considered as a means to achieve a certain end. This means that the success of the activity carried out by this class of experts lies in part, in the effectiveness of the means to achieve the projected end.

But in other cases, it is more difficult to assess the effectiveness of the knowledge wielded by experts. For example, in the case of courts of law that use the knowledge of psychiatrists and forensic doctors, there are not an objective that becomes effective, like the technical object in the previous example, to which it can be applied quantifiable criteria that allow persons to judge its effectiveness. This does not mean that in these specialties there are no criteria to establish efficiency, but rather that these criteria are more subject to discussion and controversy. In the case of courts, there is always the possibility of challenging the experts' judgment.

However, by consulting the opinion of these experts the courts legitimize their decisions, based on the assumption that they have acted in accordance with the most authoritative opinions possible. However, to confront the limitations of the scientistic conception of the reliability of experts, it is not necessary to reach a position as extreme as that held by Feyerabend (1985). During the 20th century, specifically after World War II, science found itself involved in scenarios different from those with which it had traditionally been related. One of them originated from being increasingly complicated in public policies, which produced the appearance of a scientific activity with particular characteristics, which has been called in various ways: trans-science, regulatory science, post-normal science (López Cerezo and Luján, 2002).

This type of science raises the problem of interactions between science and society, particularly the role that experts play in contemporary societies. In addition, it plays an important role in government offices and in industry, although due to the innovation policies that are being implemented, its presence in universities is increasing. Traditionally, it has been thought that while experts provide the means, for example to develop supersonic trips, politicians or someone representative of society decides the purposes, for what and how to use these space trips. However, this image of the role of experts and politicians is very simplistic, because when it comes to issues involving decisions about public affairs, means and ends are not clearly separated.

Regulatory science, has several characteristics that distinguish it from the science that is developed in academic settings. Unlike the latter, regulatory science is guided by practical objectives and criteria (Bowker, 1991):

1) Its fundamental objective is to produce knowledge that can be used for the formulation of policies that allow business decisions to be made regarding the location of resources and in the implementation of public projects. This type of science produces reports that are often not published (López Cerezo and Luján, 2002). Examples of administrative decisions in which this type of scientific activity intervenes are: the assessment of the impact of new technologies, the toxicity of chemical substances, of acceptable levels of exposure to certain chemical or radioactive substances, among others (López and Luján, 2000). The regulatory individuals that are responsible for authorizing certain products (chemical substances, medicines, foods, etc.), and which today tend to be more or less independent agencies of the state such as: The European Food Safety Agency (EFSA), the United States Agency Food and Drug Administration (FDA), or the US Environmental Agency (EPA) (Jasanoff, 1990).
2) Regulatory science has a significant social impact since the decisions made based on its analyzes have consequences which can affect the health and safety of citizens. This explains, on many occasions, why it makes decisions that unleash controversies that reach the level of a public debate (Todt *et al*., 2010).
3) From an epistemological point of view, the empirical data with which regulatory science works are scarce and have little reliability, or are compatible with mutually incompatible hypotheses. This has the consequence that the interpretation of these data can generate discussions, because they are controversial cases and, furthermore, because the scientists who produce data for regulatory decision-making are under pressure from a variety of interested groups that feel affected in different ways, by these decisions; consumers, politicians, businessmen, members of non-governmental organizations, etc.

Other reasons of why the data handled in regulatory science are unreliable is that experts normally have little time to produce relevant data. This prevents generating all the data necessary in a given case, with a sufficient level of detail, which makes it difficult to obtain broad consensus among experts. A good example is the probability of extremely improbable events. For instance, to determine catastrophic accidents in nuclear reactors, trees of plausible accidents are constructed, each of whose branches is made up of possible failures of a specific component. Statistics are obtained on the reliability of each component, which means that some of these modules; ion chamber, transistors, orientation of the control rods, etc., have to be tested. But there are two reasons why these calculations are doubtful. First, the total probabilities obtained by such estimates are very small (10^7 /reactor/year). Second, there is no proof that every conceivable flaw has been identified. Because the probability is so small, there is no practical possibility of determining failure rates directly, unless it is build a thousand reactors, let them operate for ten thousand years, and tabulate their operating history (Weinberg, 1974).

4. Knowledge in a specialized context

In this part, the problem of how scientific knowledge is imparted when it is part of a specialization process are analyzed. The expertise has an important component of implicit knowledge that is maintained. While, the dominant model, which is called technical rationality, maintains that theory has preeminence in professional knowledge. An alternative conception, defended by many authors such as Kuhn (2004), Barnes (1987) and Polanyi (1968), has emphasized the important role played by the knowing how the training processes of scientists and professionals are, a process that leads them to the acquisition of expert and, therefore, specialized knowledge.

The technical rationality model (Schön, 1998) maintains that “professional knowledge”, the same that experts acquire in their training process, can be defined as: “the resolution of instrumental problems that have been made rigorous by the application of scientific theory and technique” (Schön, 1998). It is a model that has had a decisive influence on our conception of experts and the way they relate to research and education.

As stated earlier, it was in the 19th century that the process of professionalization of science began and then the specialization was rapidly developed. But the Second World War was the event that strengthened the model of technical rationality, particularly the idea that scientific research constitutes the foundation of professional practices.

In the United States, the first research center was created and large-scale development, the National Research and Development Corporation. During this time, the increase in the rate of expenditure allocated to research was unparalleled by any other country in the world. All research institutions that emerged at this time were based on the assumption that the generation of new scientific knowledge was the guarantee for the production of wealth, “achieving national objectives, improving human life and solving social problems.” The field of medicine was the area in which the greatest investment of resources was made and in which the results became most visible. The medical research center was organized around a medical school and a teaching hospital. This organization assumes the existence of a solid base of basic science, a field of applied clinical science and a profession prepared for the application of the results of the research process, which is constantly evolving (Schön, 1998).

In light of the technical rationality model, professional knowledge has three components (Schein, 1973):

1) An underlying discipline or basic science component upon which the practice rests, or from which it is developed.
2) An applied science, or “engineering” component, from which many of the everyday diagnostic procedures and solutions to problems are derived.
3) A component of skill or attitude that concerns the actual execution of services to the client using the underlying basic and applied knowledge” (Schön, 1998).

When talking about applied science, in this quote, it is assumed that the professional practice and the knowledge involved therein is subordinated to the corresponding basic sciences. Therefore, it is a hierarchical conception of professional knowledge, in which the general principles (theory) are located in the base place and the specific solution to the problems (practice), in a subordinate place. As can be seen, basic science constitutes the fundamental factor of the components of professional knowledge. Applied science is the result of the application of basic science. In turn, applied science provides techniques for diagnosing and solving problems that can be applied to the actual provision of services. And as it was stated former, referring to the hierarchy of professional knowledge, the applied science is founded on basic sciences. Therefore, in this sense, the higher status of the profession is in direct proportion to the greater generality of the basic knowledge.

The model of technical rationality intervenes in the institutional context through the presence it exerts in research and in the normative curricula of professional education. Regarding research, and responding to the aforementioned hierarchy, research and practice are separated from the institutional point of view. From this perspective, researchers are responsible for producing basic and applied science with which the necessary techniques for diagnosing and solving problems in practice are obtained. On the other hand, professionals who represent the practical level provide researchers with the problems that are the object of study and certify the usefulness of the research results. Generally, the researcher is considered superior to the professional. This situation can be exemplified in professions such as medicine in which there is a division of labor between people dedicated to theory and others dedicated to practice. The biologist who decides to work in a biology research center, or the one who decides to dedicate himself to private practice.

In this section, the preeminence given to theory over practice, particularly with regard to the normative curriculum of the professions are considered. From the point of view of the technical rationality model, real knowledge is found in the theories and techniques of basic and applied science. For this reason, from a course opinion, basic science should come first in the training process. “Skills” in using theory and technique to solve specific problems should be given subsequent to training in the relevant science. All of the above for two reasons: “first, because you cannot learn application skills until you have learned applicable knowledge, and second because skills are an ambiguous and secondary type of knowledge" (Schön, 1998). One of the greatest difficulties of the technical rationality model is, precisely, the way of conceiving the training process. Assuming that the training process fundamentally passes through theory, leaving the learning of skills as a type of knowledge totally dependent on the theory.

One of the problems with the technical rationality model is that it is based on the distinction between pure science and applied science. This conception of science and technology assumes the existence of a type of science whose fundamental objective is the search for knowledge in itself, and of a technique that expects science to produce knowledge validated by experience and then use it for practical purposes. Although it contains some truth, this conception oversimplifies the existing relationships between science and technology. Furthermore, this interpretation of the technique prevents us from thinking of it as a knowledge-producing activity in itself. Here it is pertinent to take into account the words of Ryle and Tanney (2009) when he refers it to the intellectualist legend.

The intellectualist legend assumes that in performing a skill, first it must be recognized a certain set of rules about how to perform such actions and then actually perform them. It is precisely the preeminence of theory over practice that Ryle wants to criticize with his reference to the intellectualist legend, and which, as it has been already pointed out, is reflected in the normative curriculum of the professions. Since from the attitude of the intellectualist legend, real knowledge is found in theories, basic or pure science comes first in the training process, while skills in the use of theory and techniques to solve Specific problems come later, as expressed in the three components that characterize the model of technical rationality. The reasons for this hierarchy are precisely those that Ryle and Tanney (2009) pointed out as an intellectualist legend; First, skills cannot be learned until applicable knowledge has been learned; and, second, skills are an ambiguous and secondary kind of knowledge.

As it was stated at the beginning of this section, there is another vision of learning and teaching a science that questions the technical rationality model, particularly the supremacy of theory over practice, redefining the function of theory and practice. This vision of learning science supposes a change of epistemological horizon, in the sense that it does not exclusively involve knowing what, but also knowing how. In other words, it not only involves learning a body of theory, but also the development of a set of fundamental skills and competencies, which imply knowing how.

Several authors, such as Kuhn (2004), Barnes (1987) and Polanyi (1968), compared the sciences with trades that involve a series of skills. More precisely, thinking about the training process was carried out in a science using the learning of a technique as an analogy. Here, the key concept to understand the highest levels of teaching in science is training.

As happens with the learning of a technique, the student of a science spends a significant time of subordination with his teacher (Polanyi, 1968), with the purpose of acquiring an adequate level of competence, which is only achieved by assimilating the knowledge that is imparted. and the skills, techniques, methods and competencies in specific forms of manipulation, experimentation and calculation. This will allow the apprentice to master a limited field of knowledge that will constitute, throughout his life, his field of research and expertise. It is, then, a teaching, to a certain extent, dogmatic and authoritarian, where the critical examination of scientific knowledge and reflection on its foundations is suspended, at least for the moment. In this regard, Polanyi pointed out: “To learn by routine is to submit to authority. You follow your teacher because you trust his way of doing things even when you cannot analyze and account in detail for its effectiveness”.

In the natural sciences, the apprentices of these disciplines have to spend many hours in the laboratory to learn to manipulate instruments and to understand the appropriate methods of analysis and the interpretation of results. Students of a given scientific discipline must spend a long time solving countless problems, so that the concepts and symbols are understood in use, and mathematical procedures and techniques are not acquired in an abstract way, as series of symbols that must be memorized, but in a concrete way, that is, as elements that have an application (Kuhn, 2004). The paradigms in their sense of exemplars, that is, concrete problems that the scientist's apprentice has to solve, and that almost always appear at the end of physics textbooks, for example. To justify this idea Kuhn offers an argument similar to that proposed by Ryle and Tanney (2009) about the intellectualist legend. Traditionally, philosophers of science have thought that when science students face tangible representative problems, they must first have learned the theory and some rules for its application. Therefore, expertise is not achieved only by learning a theory, but by developing skills from the solution of the concrete problems.

5. Some negative consequences of specialization

An author like Adam Smith, in his book The Wealth of Nations, published in 1776, was already aware of the importance of specialization for the advancement of science. This author understands the division of labor as the specialization and cooperation of workforces in different tasks and roles, with the aim of improving efficiency. However, today the perspective is offered by distance in time to assess the negative consequences that arise from excess specialization.

A first negative aspect has to do with the pressures to adapt teaching and research to the economic, technical and administrative demands of the moment and conform to the latest methods and recipes on the market. History has shown that over-adaptation has not been a sign of vitality but, on the contrary, an announcement of aging and death, due to the loss of inventive and creative capacity. Precisely, the loss of inventiveness and creativity, as a negative sign of the excesses of specialization, has direct effects on the individuals. Preparation in a discipline makes many of the procedures that characterize it mechanical, which puts the specialist at risk of losing the ability to appreciate aspects that go beyond the skills that have been mechanized, and that can be vital for development. of the discipline in question. To draw attention to this problem, Pacey (1990) used the expression “tunnel vision”, for example in engineering. The training that specialists receive has the consequence of restricting the scope of the problems that professionals and scientists face. For example, on many occasions specialists in the fields of engineering tend to reduce their focus on issues related to technical problems, thinking that the enormous capabilities of modern technology can always lead us to an “appropriate solution.” This approach extends to a varied number of problems: military security, pollution, curing diseases, etc.

In terms of the consequences for society, specialization, by increasing an individual's ability and aptitude with respect to a small number of tasks, also entails a loss of aptitude with respect to other tasks. In this sense, if individuals are compared with more primitive societies, it can be seen that the person live in a society in which completely depended on others, the specialists, much more than in those societies of the past.

There is also the possibility that over-specialization generates widespread political empathy, by distancing citizens from the knowledge that informs key political decisions and legitimizes them once they have been made. Of course, this is not about suppressing scientific specialization, but about pointing out the need for scientific knowledge to be culturally linked to the rest of society. In a society that relies heavily on science, the largest possible percentage of the population must be encouraged to have a general understanding of science. On the other hand, scientific specialists must not only be scientifically prepared, but must also have a broad general culture, so that they can communicate with the rest of society and be sensitive to their needs and attitudes.

Conclusions

In natural sciences, philosophical thoughts help scientists to explore the nature of reality, causality, and the relationship between observation and theory. They also aid in understanding the limits of scientific knowledge and the potential biases or limitations that may arise from human perception or interpretation. In marine sciences specifically, philosophical thoughts can address questions related to the nature of water systems, biodiversity, ecological interactions, and human impacts on marine environments. They can also delve into ethical considerations regarding conservation efforts, sustainable practices, and the rights of non-human organisms.

Overall, philosophical thoughts in natural sciences contribute to a deeper understanding of these fields by encouraging critical thinking, questioning assumptions, considering ethical implications, and exploring the broader philosophical implications of scientific research.

As a solution learning process is an important step to manipulate instruments and to understand the appropriate methods of analysis and the explanation of results. Junior experts in a given scientific discipline must spend a long time solving countless problems so that the concepts and symbols are understood in use, and mathematical procedures and techniques must be memorized, but in an actual way.

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