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Unpacking scientific competence for effective integration in the curriculum design

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Abstract: Educating for Sustainability involves promoting sustainable competences in students. Not in vain, wider societal changes that ensure a balance between economic growth, respect for the environment and social justice must start with individual actions, implying knowledge, capacity and willingness to act. However, and although there is wide consensus that education should promote the development of competences for life, putting this theoretical tenet into may entail more problems. Competence is most often expressed in general terms without a specific definition of the intervening elements (knowledge, skills, values, attitudes), which may collide with the necessity of teachers – as learning planners - concrete entities on which to base their process of design. So that, in this work we propose a series of indicators that serve to characterize the four dimensions of scientific competence – contents of science, contents about science, value of science and utility of science-. Although they are primarily intended to be used to filter multimedia resources in an educational platform, this proposal of indicators can be extrapolated to the management and selection of a variety of resources and activities, and for sharing the objectives and evidences for the acquisition of competencies.

Keywords: scientific competence; competence-based education; educational planning; Education for Sustainable Development; evaluation of digital resources

1. Introduction

1.1. The need for Educating for Sustainable Development

The current ecological crisis is one of the major challenges our generation must face. Unsustainable patterns might even compromise the future of current and future generations [1]. If we want to guarantee our survival as a species, we need to enact a joint action, with concrete actions and compromises, to alleviate or revert the detrimental effects of human activity over the environment ([2–4]. In this context, education appears as one of the priority strategies for involving new generations in the protection of the environment [5]. This is the aim of the Sustainable Development Goals [6]

The term *ecoalfabetization*, coined in the decade of the 90's, points to the necessity of knowing ecological principles to establish a link between society and ecological communities, restoring what they called the web of life (Orr, 1992; Capra, 1996, in [7]). In other words, if we are able to understand the functioning of the natural systems around us, it's more likely we'll respect the limits of those systems, creating communities that work in harmony with the environment. Ecology and ecological science are, in consequence, the discipline that through its structuring concepts supports and substantiates the pedagogical construction of any environmental education program [8].

In this sense, Universities and Education Institutions around the world are trying to incorporate Sustainable Development into their programs, with the aim of ensuring the capacity and enacting personal actions that bring wider societal changes and, lastly, to ensure a balance between economic growth, respect for the environment and social justice [9]. In this line, a key strategy is to increase public awareness and empowering individuals to make informed decisions regarding environmental issues [10]. In other words, taking active part as citizens in sustainability issues imply developing not only knowledge, but also emotions, values, skills and attitudes, whose interactions have the potential to shape individual environmentally responsible behaviours.

This aligns with the claim of Jacques Delors who, on behalf of the European Comission, claimed for an education able to "foster a deeper and more harmonious form of human development and thereby to reduce poverty, exclusion, ignorance, repression and war" [1, p.11]. In this context, is education that needs to equip individuals with the resources to lead an overall successful and responsible life and face present and future challenges. This, together with the notion that decontextualized learning has scarce effect on real life and provoked very weak learning outcomes, created the breeding ground for the emergence of the concept of "competence", which has permeated the educational design since then.

1.2. Towards a definition of "competence"

The introduction of the term competence into the conceptual universe of education meant a significant step forward in the ongoing change of educational paradigm: the traditionally dominant role of conceptual knowledge began to be questioned, as more recognition was given to the development of abilities, skills, values and attitudes. Besides, conceptual contents started to be seen as interconnected pieces - authentic problems in real life are complex, not limited to single areas of the curriculum -, and it became clear the necessity that at all the curricular areas be oriented to the development of competences in students. Competence-based approaches seek to dissociate from the academic logic of disciplines and to promote an educative model in which to integrate the academic, professional and vital perspectives, from a multi and transdisciplinary perspective [12].

Even if there is wide consensus that education should promote the development of competences for life, putting this discourse into practice entails more problems. In fact, one of the obstacles to pursuing competence-based teaching is that the concept can be approached from multiple perspectives [13], so that the term could be too vague and indeterminate for being operatively useful.

The first step towards operationalization should be agreeing upon a minimum set of criteria that are core to the concept. In general terms, competence could be considered as the minimum cultural endowment that citizens need to thrive in life. According to the perspective adopted by the proposer, this could be closer to a conception of competence is a measure of human capital, a predictor of the individual productivity in the labour market, or as empowerment, or ability to transform knowledge into power or social action [14].

Be it one way or the other, there is no doubt that developing competence requires, first of all, **knowledge (Know, or know- what).** That is to say, an underlying cognitive structure, based on theoretical, procedural, methodological and attitudinal knowledge. Complex thinking skills (metacognitive and strategic ones) which arise from this knowledge enable the competent learner to act in a conscious, coordinate, integrated, effective, fast and creative [14]. That cognitive structure is developed through training and experience (**Know- how**), in what constitutes a progressive, endless process of constant updating, which can only take place through action. As a result, competences are only demonstrable in action [15]. In addition to that, the development of competence is linked to personality, a series of characteristics that are intrinsic to the person, including motivation, self-concept, abilities, etc. The **desire to do** and the **know how to be** derive from these personality factors**.** The overall process of competence development enables the learner to play a role efficiently; i.e., to solve problematic questions in complex situations and within given contexts, with autonomy and flexibility [16] (Figure 1).

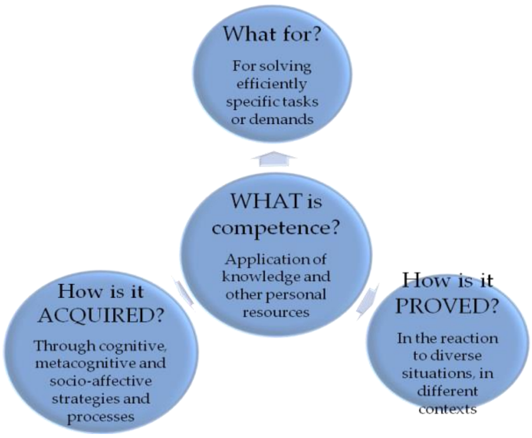

Figure 1. A functional definition of competence.

In other words, competence could be defined as the way by which people mobilize diverse personal resources of their mental structure in an orderly and integrating manner in order to respond satisfactorily, successfully and effectively to specific complex tasks, defined in particular contexts or situations, and under given conditions [17–19]. In this definition, personal resources may encompass concepts, skills, attitudes, expertise, abilities (intellectual, physical and social ones), aptitudes, values, emotions, affections, motivation, etc. [20].

In summary, the competence involves structured knowledge about the activity and the most effective strategy to tackle it; some practical experience; and also the ability to reflect on and assess one's work, and make the corrections that are needed. As McClelland [21] defined them, a sum of knowledge, skills, and aptitudes, which contributes to the capacity of a person to effectively perform the duties and responsibilities of the occupied job; in other words, to be competent.

1.3. *Competence-based teaching*

For the time being, there is not a single theoretical model of competence, complex enough not only for defining clearly the concepts of competence, capability, ability, contents, etc., but also for establishing connections between them [17]. So, elucidating the complex (and not linear) interconnection that exists among all these elements is still a challenge to meet.

Defining learning in terms of competence makes evident the necessity of acquiring knowledge in a way that ensures it can be adequately mobilized for solving complex tasks [15]. Being able to define learning in terms of competence has the advantage of jointly considering the contents and the activities/ contexts, because the competence is a way of mobilizing all the available resources (knowledge, attitudes, and skills) in certain conditions and for a given purpose.

Competences are including concepts, which should encompass and be integrated into the various areas of learning, in such a way that all the areas of the curriculum contribute, from their respective field, in the development of one or more competences. In doing so, the competences must be closely linked to the curricular objectives, so that the achievement of the goals implicitly involves the development of the competences. The selection of contents and methodologies should also serve the development of the competences, while assessing the degree of achievement of the objectives, implicitly report the degree of development of the competences that has been reached [18].

On the other hand, teachers are responsible for substantiating educational policies in the classroom. Every act of educational planning (also competence-based planning), responds to different levels of curricular application. What to teach, how to teach and when to teach it are defined in three nested levels (Figure 2): public administrations (educational policies), schools (Educational Centre Plans, according to particular agendas), and classroom (planning suited to the particular needs and features of the group) [22]

However, these two levels - educational policies aimed to raise competences; curriculum design for the classroom - are difficult to reconcile in practice (Figure 2). On the one hand, competence is most often used as a (rather bold) declaration of intent, which is only expressed in general terms without a specific definition of the intervening elements (knowledge, skills, values, attitudes). Several authors claim that competence, or literacy, are being used non-uniformly (e.g. scientific literacy; [23]), and this is creating ambiguity regarding calls to promote them. On the other hand, teachers, as designers of learning situations and architects of the teaching-learning process, require tangible or concrete entities on which to base their process of design.

In particular, planning for the classroom starts with defining the Learning Objectives (Figure 2), also known as Learning Outcomes or Intended Learning Outcomes (ILOs). Learning objectives are brief and clear statements of what students should know or be able to do at the end of the course that they could not do before. Learning objectives may refer to knowledge, skills or attitudes, and must define or describe an action, be measurable (regarding time, space, amount, and frequency), and be differentiated (i.e., specify levels of achievement). According to competence-based schemes, learning objectives should be referred to the competences, in such a way that the sum of Learning Objectives enables creating the profile of each competence.

Again, the main difficulty that practitioners wishing to incorporate the competences may encounter is the lack of definition of the different frameworks. For example, the PISA and Socioscientific Issues (SSI) approaches are seemingly well aligned when considering general aims. Both approaches emphasize preparing students for life and citizenship, complex reasoning and reflective practices, and robust understandings of the nature of science, particularly as it is practiced in society. However, as the focus of comparison moves from the conceptual to more specific, the connections between PISA and the SSI movement become more tenuous [23]. In absence of specific indicators to develop the general framework, basic competences are, in practice, identified with the curricular areas and substantially reduced to the "know" and "know how" dimensions of the competence, or just used within the context of an non-specific discourse about teaching innovation justifying and accompanying the outburst of active methodologies.

In other words, effectively incorporating the competences to learning and teaching involves, inexcusably, identifying common ground between curriculum and policies designers (top-down direction) and teachers (bottom-up approaches) (Figure 2).

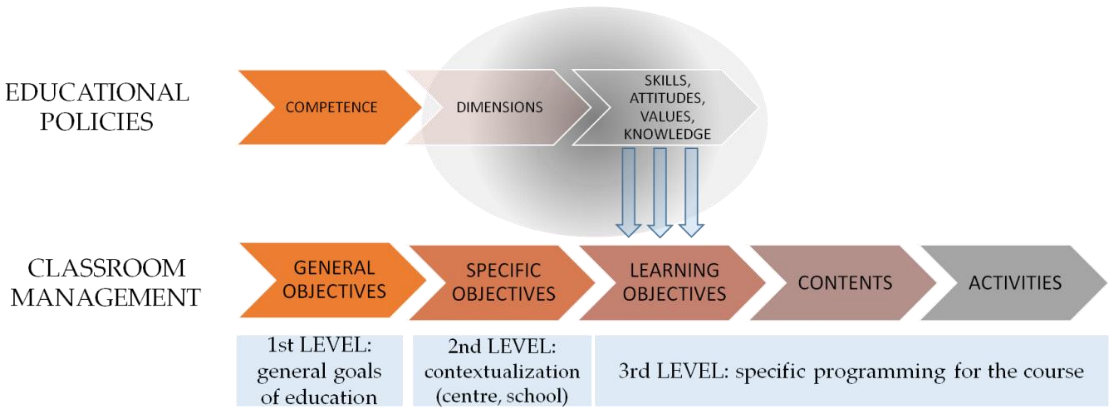

Figure 2. The two levels of educational planning - general policies and specific classroom arrangements - have difficulties in getting together for realizing competence-based teaching.

1.4. An scheme for the evaluation of scientific competence in educational materials

This necessity to develop a reliable method to diagnose the adequacy of published resources to foster competences is further elicited by the increasing availability of online educational resources, and the growing culture of creating networks for collaborative professional development [24].

Teacher networks are often used to share teaching materials and didactical resources, and by doing so they may reinforce collaboration and facilitate the exchange of teaching practices, experiences and methods. Usually, these digital communities of teachers are part of wider digital resource platforms or portals that provide other types of support such as digital learning resources, including informal on-line professional development opportunities and open education resources (OER) [24].

Those materials can include videos or other multimedia materials, classroom activities full lesson plans, games or educational animations or simulations. Whatever the precise resource, it's well documented that, among the dimensions of Teacher Digital Competence, teachers are overall least competent in Resource Creation and Problem Solving [25], which includes selecting the best available tools or sources for given purposes [26]. Moreover, teachers ofter found it difficult to agree on basic aspects such as the cognitive demand of activities and examination items [27], and also when applying competence-based assessment, especially when having to formulate the competence indicators [28].

Taking into account all the above, we are proposing the development of a practical evaluation scheme, based on specific competence indicators, which enable us to analyse the contribution of specific educational resources to the development of the scientific competence. The creation of a system of tags that allowed for marking these resources would, in the last term guide not only teachers but also families and students follow specific formative itineraries and share the objectives and evidences for the acquisition of competencies.

2. Material and methods

This system of tags has been developed with the purpose of filtering and selecting videos that promote the development of scientific competence, and including then in an educational platform (www.zapatoons.info). This platform is intended to offer teaching materials that also fulfill a leisure function, and that are safe and interesting for learning; *i.e.*, a platform that is useful in both formal and informal educational contexts. Although it is primarily intended for evaluation and classification of educational videos, the instrument has characteristics that make it applicable for a variety of resources and formats.

On the one hand, it seeks to offer teachers a practical resource to support the teaching-learning processes, focused on Science (Natural and Social Sciences, with English as the vehicular language) and in the levels of Early Childhood and Primary Education. On the other hand, it is also intended to offer a playful and educational option for use in a family context, as well as for self-consumption by the students themselves. This platform is being developed in the context of collaboration for the transfer of knowledge between university and the industry.

2.1. Structure of the system of tags

In a first step, we will aim to thoroughly characterize *scientific literacy*, in a way that can be translated to other areas of competence. For the definition of this conceptual umbrella, we opt for an understading of competence as *literacy* (read *thorough knowledgeability*) about situations related to science, which derives its meaning from the character of situations with a scientific component, situations that students are likely to encounter as citizens [29].

This vision goes beyond purely technical approaches that are focused on the promotion of scientific concepts and processes and may help students develop robust understandings of scientific findings and formalisms, as well as the skills and processes used within the sciences. We defend instead an approach focused on understandings and use of science in situations, involving personal decision-making about contextually embedded issues [23]. In other words, situations that provide individuals with opportunities for using scientific ideas, processes, and reasoning, and that are thus closer to a holistic view of the competence, understood as knowledge put into action and encompassing the four dimensions (know, know how, know how to be, know to live together) [11].

Accordingly, the indicators, or tags, will be developed as belonging to four main categories, which recall the definition that PISA [30] gives of *scientific literacy*, concerning an individual's:

- Scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomena, and to draw evidence-based conclusions about science-related issues.
- Understanding of the characteristics of science as a form of human knowledge and inquiry.
- Awareness of how science and technology shape our material, intellectual and cultural environments.
- Willingness to engage with science-related issues, and with the ideas of science as a reflective citizen.

Each of the dimensions needs then to be developed into a series of concepts, processes (verbs of action) and contextual factors, which allow establishing links with the Learning Objectives, and the way teaching-learning processes are designed, put into practice and evaluated (Table 3).

Table 3. Indicators *per* dimension of scientific competence.

Dimension	Area	Indicator	Type - *examples*
CONTENTS OF SCIENCE To know science/ to do science	Know Know how	**Science contents**: as defined by the relevant curriculum or document of standards **Scientific skills** (simple and complex).	Nouns *pulleys, living beings* Verbs of action *compare, classify, pose a hypothesis*
CONTENTS ABOUT SCIENCE To know about science	Know Know how Know to be	**Nature of Science**, or epistemology	Adjectives, adjectival phrases *science is verifiable*
CONTEXTS OF SCIENCE To be aware of the importance of science **INTEREST IN SCIENCE** To value science	Know to be, Know to live together	Personal **attitudes, beliefs, values**. Ethical references are guiding scientific practices.	Short phrases *Engage in sustainable behaviour*

Another constraint to be considered is that the indicators must be gradable, or susceptible to be ordered to adjust to a progression: competences are developed through a gradual process that starts in elementary school and continues, both within and outside the school, through elementary and secondary school and even beyond. Thus, the architecture of the system must ensure it allows fitting successive levels of complexity.

2.2. *Literature review*

The proposal of the specific system of tags has been developed following a two-step revision process. In the first step, we performed a systematic literature review. In this search we included articles in scientific databases (WOS, Scopus and Dialnet), published in the last 10 years, which included specific search terms.

This first search allowed us to identify most relevant authors or policy - makers in each of the dimensions, and served as a jump-off point for a heuristic search to identify the most salient indicators in each of them (Table 4).

Table 4. Specific search terms for systematic literature review and referents for heuristic search

	Search terms	Referent authors or policies
Science Contents	Knowledge progression Scientific contents	DF 60/2014 [31] Next Generation Science Standards [32]
Science practices	Science process skills Science processes Scientific practices	M.J. Padilla Science and engineering practices - NSTA [33]
Nature of science	Nature of science Espistemology of science	N.G. Lederman
Attitudes, beliefs and values	Attitudes science Utility science	Earth Charter [34] UN's SDG [6]

Selected references and sources were then combined and critically reviewed to produce a comprehensive list of indicators, designed to reflect the consensus definition of the dimension.

3. Results

3.1. Content progression

We produced a map of the official perceptive curriculum for the region [31]. The map followed a hierarchic structure, progressing from broader encompassing concepts to more specific terms. At the same time, it suggested a progression across courses which allows the algorithm to propose coherent thematic progressions, following coherent strands of increasing sophistication, or suggesting diverse routes within the thematic block (Figure 3).

The proposed final progression included a total of 551 terminal nodes, nested in 7 levels.

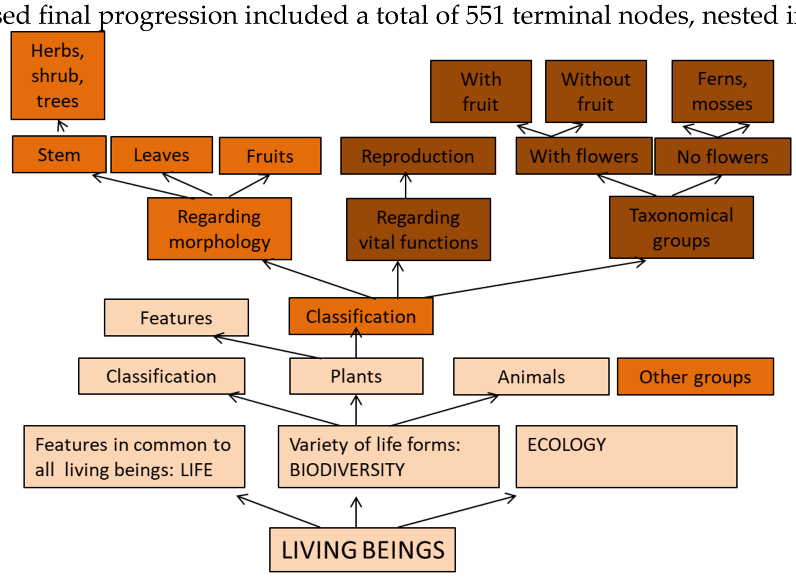

Figure 3. Nested hierarchy of factual concepts (knowledge progression). An example with classification of plants. Colours by grade, gr. 1-2: light; 3-4: medium; 5-6: dark orange.

3.2. Progression in skills or processes

The proposed progression combined the Science and Engineering Practices of the NSTA, also taken over by Bybee [32] with the traditional division by Padilla [35,36] into basic and integrated process skills (Table 5).

The tags are not inherently gradable, but the arrangement into successively inclusive levels facilitates designing ordered progressions.

Table 5. Nested hierarchy of science and technology practices. An example including one basic and one complex science process skill.

1	2	3	4	5
Basic practices	Measuring	Estimating Measuring (with metric units) Comparing measures		
Complex practices	Communicating	Communicating information	Communicating information in written formats	Expressing ideas in texts Combining text and graphic formats
			Communicating information orally	Expressing ideas orally Making oral presentations

3.3. *Nature of science*

A detailed analysis of Norman Lederman's work [37,38], also summarized in the documents of the NSTA [39] allowed us to extract some statements than can be useful to describe the nature of science and scientific practices (Table 6):

Table 6: Statements about the nature of science
Scientific Investigations Use a Variety of Methods
Scientific Knowledge is Based on Empirical Evidence
Scientific Knowledge is Open to Revision in Light of New Evidence
Scientific Models, Laws, Mechanisms, and Theories Explain Natural Phenomena
Science is a Way of Knowing
Scientific Knowledge Assumes an Order and Consistency in Natural Systems
Science is a Human Endeavor
Science Addresses Questions About the Natural and Material World

3.4. *Values, beliefs and attitudes*

As stated above, scientific literacy entails the capacity and will to act to transform the world. In this sense, science should not be understood as the end, but rather a means. The document "Earth Charter", echoing part of the UN's Sustainable Development Goals [6], propose certain underlying ethical concerns that may help frame scientific education of today (Table 7). Earth Charter encourage individuals and nations to "join together to bring forth a sustainable global society founded on respect for nature, universal human rights, economic justice, and a culture of peace. Towards this end, it is imperative that we, the peoples of Earth, declare our responsibility to one another, to the greater community of life, and to future generations" [40].

Table 7: Attitudes, beliefs and values inherent to science education

Knowledge as a value	Science satiates our thirst for knowledge Scientific knowledge make us free to opt and responsible for our actions

	Critical thinking allow us to adopt ethical positions Science leads humanity to excellence through knowledge
Science useful for transforming the world	Science helps us covering basic needs (health and wellbeing) Science may ensure equitable distribution of richness Science can improve life conditions for all and ensure pacific cohabitation Science helps us anticipating problems and adopting best available solutions to achieve sustainability
Ethical framework in which science education must inscribe	
Respect and Care for the Community of Life	Believe in the inherent dignity of all human beings and in the the intellectual, artistic, ethical and spiritual potential of humanity Ensure human rights and fundamental rights Recognize the value of every form of life, regardless of its worth to human beings Bear in mind the need of future generations for Earth's bounty and beauty
Ecological Integrity	Estimulate reduction, reutilization and recycling of materials Work towards increasing reliance on renewable energy sources Behave to avoid severe or very severe environmental damage Preserve the natural heritage
Social and Economic Justice	Strengthen technical cooperation to advance on sustainability Contribute to develop social and economic justice Ensure active participation of women in all aspects of public life Value equitable distribution of wealth
Democracy, Nonviolence, and Peace	Promote a culture of tolerance, non-violence and peace Make possible solidarity and cooperation among nations Engage in resolution of conflicts among people and with the environment Understand the world and act form a "glocal" perspective

4. Discussion and conclusions

SDGs have become common place in conversations about education, both among practitioners and policy –makers. It is with good reason that we say that "*There is no more powerful transformative force than education—to promote human rights and dignity, to eradicate poverty and deepen sustainability, to build a better future for all, founded on equal rights and social justice, respect for cultural diversity, and international solidarity and shared responsibility, all of which are fundamental aspects of our common humanity*." (I. Bokova, cited in [41].

To achieve this goal, it is necessary to start developing capacities since the very first years of formal education. And we say "capacities" because we understand that competence- based teaching must be, first and foremost, empowering. Science education must serve, from the very first year, to understand the world around an how does it work [42], but also what is not working, and how to intervene to alleviate it with the resources at our disposal. And, on top of that, to want to take action. In this sense, values and beliefs are indispensable: [un]sustainable behaviour is not only the result of rational decision-making processes based on specific moral cognitions; emotions of different categories can further account for individual conducts [43]. Rational knowledge requires know-how, capability and desire to do to translate into action.

But, still, concrete actions to enact SDG in coherent and effective ways are still scarce. There are some relevant banks of resources or initiatives offering outstanding materials that, far from focusing on sustainability as a theme, seek also to enable and motion learners to engage in transformative practices [44]: namely, SUSTAIN project (https://www.fondation-lamap.org/en/sustain), or National Geographic Education (https://www.nationalgeographic.org/education/). However, the scarcity of remarkable materials illustrates how difficult is to move further down the road from discourse to action. Unfortunately, legal measures and provisions alone do not guarantee real impact on learners, unless the community of educators take over these directions. And it is at this point where it becomes necessary to establish broad consensus among educators, and develop the tools that will allow these ideas become true. That is to say, practical strategies to share reflections, resources and debate on common grounds, and to be able to enact what they are requested to. I.e., (1) clear formative objectives with clear indicators; (2) guidance on how to integrate them with practice and (3) orientations to evaluate them.

Assuming this responsibility, the major contribution of this proposal is being able to state more accurately the dimensions of the competence, in reference to an explicit higher-order conceptual framework. This, in turn, would provide the concrete entities that ensure educational planning can be made operational, if desired, as based in competences.

The main limitations of this study could, in turn, be related to the lack of theoretical references on which to substantiate a more precise definition of the elements integrating the competence, still in this early stage of the project. This, in turn, determines the way forward in research on the topic. The next steps involve this list going through a 3-step validation process: (1) validation by experts, to check agreement with structuring concepts (big ideas) in science and scientific skills; (2) pilot application to the videos in the platform, to check accuracy (completeness and differentiation); (3) validation with users (teachers) to check comprehensibility and specificity.

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