P-SPICE

Physics for Systemic, Praxis Immersive, Convergence Education

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Abstract

Disciplinary convergence is increasingly becoming a necessity in the workplace and many other aspects of life. Such convergence is about bringing knowledge from different disciplines, especially scientific disciplines, to tackle life related issues in innovative ways. Education of all levels should then endeavor for convergence education among traditionally distinct disciplines through appropriate convergence lenses the most realistic and efficacious of which are systemic, differential lenses, and under appropriate pedagogical frameworks that foster experiential learning, particularly in the form of praxis that brings theory and practice together in real life contexts. Model-laden physics is mostly suited to lay the grounds for systemic, praxis immersive, convergence education (SPICE) at all grade levels. Physics teachers are then mostly concerned with leading educational reform that brings about such convergence and empowers students for excellence in life and not for merely passing high stakes exams.

Keywords

Convergence education, crossdisciplinarity, model, modeling, paradigm, pattern, praxis, system, Systemic Cognition and Education, systemic reform, systemic thinking, transdisciplinarity.

The digital revolution of our era was made possible thanks to a major paradigm* shift in industry that implicated similar paradigm shifts in other sectors of society and various aspects of life. New paradigms are marked primarily by a convergence among traditionally distinct disciplines within and among different fields beginning with science, technology, engineering, and mathematics (STEM), and extending to arts, humanities, social sciences and other fields. Meanwhile, general K-12 education in Lebanon and other parts of the world is still governed by outdated paradigms that: (a) mandate numerous unsubstantiated and erroneous pedagogical myths, (b) maintain rigid barriers among various academic fields and disciplines, and between these and vocational and technical fields, and (c) bring about graduates often encumbered with compartmentalized, loose knowledge they develop mostly by rote for the sole purpose of passing high stakes and exit exams rather than empowered with potent profiles for success, rather excellence in life.

This paper proposes a paradigm shift in education that meets the realities of the 21st century and which physics teachers can significantly contribute to bringing around, should they take advantage of what physics is really about. The new paradigm calls for *systemic convergence education* that relies on mind and brain based pedagogy to help students bring together traditionally distinct disciplines systematically and meaningfully through systemic convergence lenses, and that engages them into *praxis* for bringing theory and practice together to tackle real life issues in innovative ways. Physics is primarily about constructing, validating, and deploying scientific models mapped unto structural and functional patterns in real world systems. As such, physics is best situated to allow systems-based convergence among STEM and other fields in various sectors of society, and particularly in the education sector.

The paper comes in four sections that draw primarily on works by this author on modeling theory in physics and science education and on systemic convergence education. It begins with an outline of systemic convergence education, and follows with a discussion of how model-based physics education can facilitate such convergence beginning with STEM fields. In the third section, praxis is introduced as a major aspect of hands-on, minds-on, experiential learning that brings together general education and technical and vocational education for tackling real life issues with optimal systemic convergence. Physics teachers are then invited in the last section to lead the paradigm shift called for in education by making the best of what physics is really about, and by helping to put in place the infrastructure needed to bring about the systemic reform implied by such paradigm shift.

1. Systemic convergence education

Along with the digital revolution came unprecedented and often revolutionary changes in the job market and various other aspects of life which educational systems in Lebanon and other parts of the world did not keep up with. Most if not all innovations that we have witnessed in the last few decades, and that will continue to surge in the near and distant future, came about, and will continue to do so, as the result of *convergence* of a variety of communities of practice (CoPs). CoPs that used to work almost independently of each other increasingly come together from even traditionally distant fields like natural sciences and social sciences to tackle emergent issues that neither community could address alone, defy new challenges like the CoViD-19 pandemic, and even to frame and solve new and unforeseen problems and come out with innovative ideas and products that are beyond the widest imagination of most people. Some educational systems around the globe have already embarked on one form or another of convergence in their structure and curricula at all educational levels, bringing about what we call *convergence education* of specific modalities. Most other systems are contemplating such convergence or still struggling to find their way in this direction, while the few others, like the Lebanese system, are turning the blind eye on what goes on around them, mostly because education is not yet for them a public good that should be made at the disposal of all their young citizens with the highest quality standards possible and in ways to meet the realities of the 21st century (Halloun, 2018a).

Educational curricula in K-12 general education have traditionally been disciplinary or discipline-based. A given curriculum is designed and implemented around a particular academic discipline like physics, and teachers, especially at the secondary school level, are trained to handle individual disciplines independently of each other. Disciplinary education has been often practiced in ways that led students to develop by rote loose and incoherent knowledge, even within the same branch and discipline (e.g., the branches of classical mechanics and electricity in physics). The plethora of educational research continues to show that student disciplinary knowledge is compartmentalized to the extent that they are unable to transfer what they learn in one course to another, even in one part of a given course to another (Halloun 2020a). This evidently leads to students' failure to take enough advantage of their disciplinary knowledge in everyday life and eventually in the workplace when they get there.

Realistic and feasible convergence modalities need to be adopted in education so as to accommodate two contrasting, even opposite, realms: (a) the realm of the 21st century the realities of which outside the educational sector increasingly bring disciplines into convergence from the same and different fields, and (b) the realm of the educational sector where disciplinary education still prevails in most parts of the world. Such convergence modalities should take place with appropriate pedagogy that gives away outdated and unsubstantiated tenets of the past two centuries and that benefits from latest developments in cognitive science and particularly neuroscience about how the human mind and brain are and work (Halloun, 2018a). We hereby propose to adopt in our curricula *differential convergence* modalities under systemic pedagogical frameworks, thus bringing about *systemic convergence education* that can be afforded by all teachers and an entire educational system still geared towards disciplinary education.

Different convergence modalities may be distinguished across CoPs, and subsequently in education, based on the conceptual lens that brings together many disciplines from the same and/or different academic and non-academic fields to answer particular questions, solve particular problems, or come about with totally new and innovative ideas and products. We distinguish five modalities based primarily on: (a) the framework in which a given modality is achieved, (b) how professionals from different disciplines (or disciplinary branches) work together, (c) convergence processes, (d) the extent to which different disciplines and respective paradigms preserve their identities or, alternatively, are integrated or fused together, and (e) the scope and nature of the outcomes brought about. Modalities are: pluridisciplinarity, multidisciplinarity, interdisciplinarity, crossdisciplinarity, and transdisciplinarity. The conceptual and procedural complexity of distinguished modalities gradually increases from pluri- to trans-disciplinarity, and so do the extent of convergence and integration of implicated disciplines and the level of innovation in developed conceptual and physical products (Halloun, 2020b).

The first three convergence modalities, pluri-, multi-, and inter-disciplinarity, are the most conservative modalities in the sense that that they entirely preserve all foundational and practical aspects of converged disciplines and, except for some semantic and syntactical refinements that infuse some harmony into existing disciplinary conceptions and procedures, the three modalities bring no new significant conceptual or procedural component to any of the disciplines in question. These modalities are mostly suitable for elementary and intermediate education (primary and middle schools).

Crossdisciplinarity and transdisciplinarity, at the other end of the spectrum, are the optimal convergence modalities for secondary and tertiary education respectively. *Crossdisciplinarity* brings together different disciplines under an *emergent* framework that draws on common and concurrent aspects of the disciplines' distinctive paradigms and incorporates new paradigmatic aspects. *Transdisciplinarity* transcends in its framework all existing paradigms and can lead to the development of a totally new discipline that may cut across existing fields or lay the ground for a completely new field. Emergent and transcendent frameworks open the door to tackling in *innovative* ways old and entirely new questions, problems, and issues. The digital revolution of our era, the breakthroughs in neuroscience, especially cognitive neuroscience, which education may benefit of most, and the many new careers that keep emerging in the job market and that could not have been foreseen or even imagined just a decade ago, are all compelling testimonies in favor of crossdisciplinarity and transdisciplinarity (*ibid*).

Convergence we are calling for in education, especially in K-12 general education and a little beyond, is *differential*. It preserves the sovereignty of individual disciplines with their distinctive paradigms as well as the integrity of their episteme and methodology. However, it works over and around disciplinary barriers and boundaries and allows for episteme and methodology to seep through from one discipline to another. Differential convergence blends conceptions and processes from different disciplines and may somehow integrate them if necessary. It brings about, particularly in higher education, emergent conceptions and processes that may transcend the original disciplines. Differential convergence education in K-12 may gradually work its way through feasible modalities up to crossdisciplinarity, though this modality may be only partially realized at the pre-college level. More importantly, differential convergence education may be significantly afforded in the context of traditional disciplinary curricula (*ibid*).

In the latter respect, and until differential convergence education finds its way formally and systematically in a given educational system and corresponding curricula, teachers of discipline-based courses may get together to coordinate their efforts for helping their common students carry out life related projects that require convergence of their respective disciplines under convenient modalities within the constraints of their traditional disciplinary settings (Halloun, 2020c).

Convergence in education, whether differential or not, is best achieved through systemic conceptual lenses (Fig. 1) under systemic pedagogical frameworks. Any academic or non-academic discipline is then conceived in any curriculum, whether independently of, or interdependently with other disciplines, around a limited set of conceptual and physical systems, and all knowledge construction and deployment processes, problem solving of all sorts included, are carried out as systemic processes.

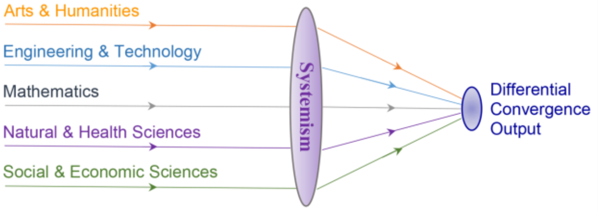

Figure 1. Convergence of disciplines, especially from different fields, is optimized when carried out through systemic lenses.

Unless elementary, i.e., consisting of a single component, a system may be defined in simple terms as an ordered unity or totality of physical or conceptual elements that interact or are connected together within well-defined boundaries and that serve specific purposes, or perform specific functions, within a given environment and under particular conditions. Properties and functions of a given system are due only in part to its individual constituents. Most importantly, a system, as a whole, has *emergent* properties and *synergetic* functions that cannot be attributed to any of its constituents independently of all other constituents, and that offer new functional possibilities that cannot be conceived and materialized by putting these constituents together in any non-systemic structure. Systemic thinking, i.e., carrying out our thoughts in the context of systems, and all conceptual and physical processes as systemic processes (Fig. 2) allow us to systematize, and infuse order in, our everlasting quest to make sense of the world around us and develop and deploy our knowledge about this world in meaningful and productive ways. It also helps us optimize our engagement with others, and bring about processes and products that none of us can produce on her/his own independently of others. (*ibid*).

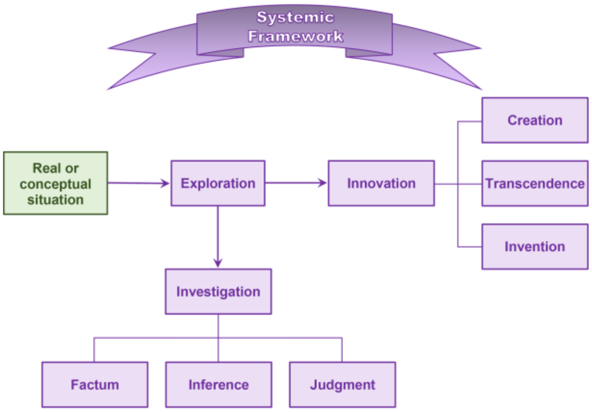

Figure 2. Systemic processes.
Systemic processes are about system identification and delimitation or system construction, system validation or corroboration, and system deployment for various purposes that may be exploratory, investigative, and/or innovative (cf. Halloun, 2022, for details).

Systemic Cognition and Education (SCE) offers a generic pedagogical framework for student and teacher education that is well suited for systemic, differential convergence education (Halloun, 2022). *SCE* is grounded in reliable research in education, and especially in cognitive sciences and neuroscience, and in the history and philosophy of science.

According to SCE, our *experiential* knowledge about the physical world, i.e., knowledge that results from direct experience with physical realities (objects and events), emerges from continuous transaction with this world. The transaction consists primarily of realist-cognitive exchange or negotiations between a given person and a given physical reality exposed to the person senses. The transaction is most efficient at any age and any educational level, and the emerging knowledge most meaningful and productive, when all entities involved, including the mind and brain of the person engaged in the experience, are treated as interacting dynamic systems or parts of systems (Halloun, 2017, 2019, 2022).

2. Modeling in physics for systemic convergence

Systemic transaction with physical realities is particularly important in physics where experiential learning can take place in the most meaningful ways possible. For like, and a little more systematically than, other sciences, physics is primarily concerned with the construction and deployment of scientific models (conceptual systems) that represent particular patterns in the real world, and these patterns are best revealed when the universe is looked at with a systemic worldview (Halloun, 2001, 2004/6, 2007, 2018b, 2020d).

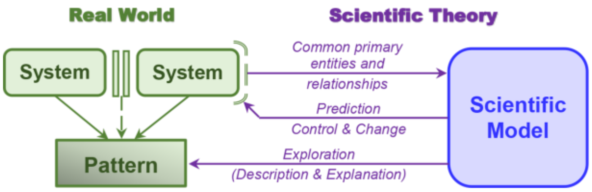

Figure 3. Systemic transaction via a scientific model with many physical systems manifesting a particular pattern. Evaluation and regulation take place continuously throughout all processes by correspondence to individual systems and pattern (Halloun 2018b and 2020d).

Patterns predominate in the universe at all levels, from the subatomic scale to the galactic scale, including the human mind, brain, and body. Patterns, like those in the structure of atoms and solar systems or the day-and-night and seasons cycles on Earth, are morphological (structural) or phenomenological (behavioral) regularities that are repeatedly manifested throughout space and time in the state of physical realities of all sorts and scale. Physical patterns are best revealed through systemic transaction whereby we look at physical realities not individually and in isolation from each other, but in relation to each other in well-delineated physical systems (*ibid*). Pattern referents, i.e., physical systems manifesting the pattern, would then all be in a similar *state* (or change of state), from morphological and/or phenomenological perspectives, and bring about similar outputs. Science, and particularly physics, describes and explains this state with a scientific model that represents the corresponding pattern (Fig. 3).

Simply put, a *scientific model* is a conceptual system, a humanly conceived abstract system, that partially represents, in specific respects and to a certain extent, a morphological and/or phenomenological pattern in the real world. Each model is constructed in the framework of an appropriate scientific theory with the exclusive function of describing and/or explaining, in specific respects and to a certain level of approximation or precision, a particular pattern in the real world. The model is constantly evaluated and regulated in the framework of the sustaining theory. The model is evaluated primarily by deploying it for the prediction of specific aspects it is supposed to be about in the state (or change of state) of its referents. It is accepted and inducted in the corresponding scientific theory only if it is duly corroborated by allowing repeatedly good predictions at the set levels of approximation and precision. Otherwise, the model is regulated (modified or replaced altogether) and then evaluated as before. Once corroborated to a satisfactory level and inducted in the theory, the model may be used for carrying out all systemic processes shown in Figure 2 as *modeling* processes, while it continues to be constantly evaluated and regulated. The model may then be deployed to describe, explain, predict, and carry out other investigative processes with its referents, control them and change them in creative ways, extrapolate them, and transcend them if necessary to derive or implicate new models, for the discovery and invention of entirely new referents (Halloun, 2018b).

Let us take for example the case of Newtonian theory in classical mechanics. Two scientific models, the “free particle” model and the “uniformly accelerated particle” model, are most crucial for students to develop all Newtonian conceptions of translational motion, from state, kinematical concepts to Newton’s laws of dynamics, and related processes (Halloun, 2001, 2004/6, 2007). The first model is a conceptual system that represents physical objects moving with constant velocity (constant speed in a straight line) under no net external force. The second model is a conceptual system that represents physical objects moving with constant acceleration, i.e., with a velocity that varies with constant increments during equal time intervals. Once students meaningfully understand all Newtonian conceptions and processes these two systems require, they become ready to gradually develop more complex particle models (say the particle in uniform and uniformly accelerated circular motion and the simple harmonic oscillator).

Galileo was the first to develop the two aforementioned particle models of translational motion that continue to be part of classical mechanics. Galileo conceived these models, along with others, to make the point about the necessity to transcend our senses in order to develop a valid and reliable picture of the real world. For, according to Galileo, our senses (and our common sense) may deceive us in exploring and investigating physical realities, just like they do when they lead us to think, as many people still do, that the Sun "turns around" the Earth. To grasp the "reality" of things, we need then to imagine how they could possibly exist in ways not exposed to our senses, and represent them with appropriate models that we need to process and corroborate as indicated above. Galileo developed the two models in question primarily to discredit the misconception that has prevailed at all times, and that continues to do so, that the shape, size, and mass of physical objects determine how gravity makes them fall near the surface of the Earth. He argued that these properties, and especially shape and size, affect air resistance not gravity, and that in the absence of this resistance, all objects would fall with the same acceleration. Under such circumstances, like in the absence of any other dissipative force like friction in any translational motion, he continued that shape and size of physical objects become secondary not primary properties, and that they can thus be ignored. The motion of such objects, according to Galileo, can then be described and explained by representing them with particle models, i.e., with geometric points of no shape and size, points that stand for their referents without being part of these referents, particularly not their centers of mass as many physics textbooks continue to hold mistakenly! Galileo processed these models mathematically and came out with the basic laws of classical kinematics that we keep using until our present days, along with most basic laws of classical dynamics which Newton refined later and put in the shape we have now.

With his work in what is nowadays part of classical physics, Galileo laid the foundations of modern science, particularly in relation to the pivotal role of scientific models and modeling. Physics education should follow Galileo's footsteps by having such conceptual systems and systemic processes at the core of all physics courses, thus making them serve as pedagogical tools and processes to students of all levels as much as they serve as research means and methods to scientists, whether for meaningful understanding of any scientific theory in any given scientific discipline like physics, or for systemic convergence among different STEM disciplines, and between these and non-scientific disciplines (Halloun, 2020d). Physics models and modeling actually lend themselves readily to convergence, and especially to systemic differential convergence among various disciplines, beginning with STEM disciplines. Physics deals more than any other discipline with physical systems and patterns that pertain to everyday life and that make the object of different disciplines within and outside STEM all the way to arts and literature. Take the very simple examples of day and night cycle and the change of seasons at any spot on our globe. These patterns have long made the object of physics and, say, geography, to mention a few, as well as many literary and artistic works.

3. Praxis for meaningful convergence education

Experiential learning that is about hands-on, minds-on, transaction with physical objects and phenomena is particularly crucial in physics. Such learning becomes most meaningful and self-fulfilling in physics, STEM, and other fields when students put what they learn into practice for developing conceptual and physical products to deal with life related matters which they deem worth investing their efforts in, at the personal and collective levels. This is what praxis is about and what makes convergence education gain its full significance.

Praxis in CoPs is about bringing theory and practice together in order to evaluate and regulate every CoP paradigm, and particularly to bring its episteme and methodology in consonance with each other, and to ensure that various elements of the epistemic corpus (scientific theory or theories in physics and other sciences) and related processes and products (practice) viably correspond to what the theory is about in the real world and fulfill the function set for the theory. Praxis in education is meant to help students appreciate and take advantage of CoP professional paradigms in both theoretical and practical respects. To this end, experiential learning should come, whenever possible, as close as possible to CoP praxis and turn into what we call "education praxis". Education praxis would then then have two complementary aspects: praxis education and praxis for education. Praxis education is about learning how professionals engage in praxis within their own CoPs to bring their theory and practice into consonance with each other and continuously enhance them in the framework of their professional paradigms. Praxis for education serves to help students evaluate their own profiles, their own paradigms, and regulate them insightfully to make them inherently coherent, consistent, and viable in theoretical and practical respects, and, especially, to bring them into consonance with professional paradigms. In both respects, education praxis needs to take place in authentic CoP settings, or related real world settings, including the job market, community service, or any other real life setting that students can directly relate to and that provides them with the opportunity to put what they learn about professional paradigms into practice within the natural scope of each paradigm, appreciate what these paradigms can offer at the personal and collective levels, and subsequently take full advantage of them whenever and wherever they fit in their daily lives (Halloun, 2021 and 2022).

Education praxis (praxis for short hereafter) is particularly crucial for convergence education. It may take place on-campus or off-campus, during regular class hours and after school, provided that it always brings about physical and/or conceptual products that carry added value to experiential learning and that students can directly benefit of, and benefit others from, in theoretical and practical respects. Praxis may take place on-campus in dedicated makerspaces or in traditional facilities, like laboratories and computer, arts, or technology workshops, provided that these facilities be run with the spirit of makerspaces. A *makerspace* simulates an authentic CoP field of work, whether it pertains to a single CoP or a number of CoPs converging to work on issues of mutual interest. It provides students with actual CoP tools and with the opportunity of working collectively, hands-on, minds-on, to design and realize CoP conceptual and physical products following systemic rules and processes that characterize the community(ies) in question. Makerspaces are run by teachers and/or qualified technicians or mentors who treat students like apprentices in need to master the "rules and tools of the trade", but especially to think outside the box, try out their own ideas, and produce things to the highest, and most reasonable, professional standards possible. As such, makerspaces are dedicated not only to praxis in the limited sense of bringing theory and practice into consonance, but to all sorts of productive and innovative experiential learning, particularly under systemic differential convergence education.

Praxis becomes most productive when it engages students from different schools and different educational levels, along with members from concerned CoPs. This may be best achieved when praxis takes place off-campus in actual CoP settings and facilities, and, if feasible, in dedicated makerspaces there.

In the latter event, makerspaces may be open to the general public, and not only to school students, to exchange and try out some innovative ideas, which, as it has actually been sometimes the case, turn makerspaces into incubators of inventions and new business startups that are particularly successful when involving crossdisciplinarity and especially transdisciplinarity. Off-campus praxis requires that the curriculum be designed to accommodate such endeavor, and that both school and the surrounding community be prepared to manage things as specified in the curriculum and under terms and conditions mutually agreed upon by the school and the hosting professional facilities. No matter where and how it is carried out, praxis always requires that concerned teachers and CoP supervisors be qualified to serve as mentors for students of specific age and background.

4. Physics teachers as reform leaders

Systemic, praxis immersive, convergence education (SPICE) necessitates a major paradigm shift in curriculum design and implementation, as well as in the structure and governance of educational systems. Such paradigm shift requires agents of change, rather reform leaders from within a given system, that are competent and determined enough to bring it around in a gradual but steadfast way, and to overcome all hurdles that may come across particularly as a consequence of the deep rooted, centuries old, inertia of disciplinary education. Going back to the Galilean roots of modern science, to scientific modeling in STEM disciplines, should help break that inertia, and physics teachers are naturally the most concerned to push forward in this direction.

For the desired paradigm shift to take place on solid grounds, physics teachers should take the lead in setting a number of measures for systemic change including the following:

1. Institute educational communities of practice (CoPs), at the core of which would be teacher organizations like the Lebanese Association of Physics Teachers, that bring together teachers from different disciplinary background, from different educational levels, university professors included, and from general education and technical and vocational education, to serve as hubs for bringing about SPICE and sustaining it in the most efficient ways and to the highest quality standards possible.
2. Turn K-12 teaching into a true, worthy, and highly esteemed and compensated profession that attracts dedicated and qualified people, and institute in-service training programs to bring at first all teachers to speed on latest developments in cognition, neuroscience, technology, and education, particularly in relation to SPICE, and subsequently to sustain continuous professional development (CPD). Programs may span from formal regular courses and workshops given by “master teachers” at local universities, adult education centers, and/or local school campuses, to professional learning communities (PLCs) that bring teachers together within a given vicinity in order to share ideas and best practices about disciplinary and SPICE matters.
3. Work in partnership with local universities and various sectors of society to bring about SPICE and sustain it on solid grounds that meet the actual needs and aspirations of society, particularly the job market at large.
4. Institute digital platforms to connect various CoPs, PLCs, and other organisms and their members, sustain continuous and fruitful communication among them, and allow for timely and efficacious support to be provided to any of them whenever needed.
5. Work for true systemic changes in the structure and governance of the entire Lebanese educational system, beginning with the institution of the *National Education Council*. The council would “serve the primary function of upholding formal

education as a high quality public good and a significant national investment for the 21st century and beyond", and ensure that all entities in the educational system "serve a clear educational vision for the entire country and fulfill a broad national policy for education and development" and that they bring about and sustain all necessary systemic changes (Halloun, Nahas, et al., 2019a). Among others, and particularly important for SPICE, dichotomy would be transcended between general education and vocational and technical education, as well as between the public sector and the private sector, and new concepts would be brought along of student, teacher, curriculum, school, etc., so as to meet the realities of the 21st century (Halloun 1018a; Halloun, Nahas, et al., 2019b). Systemic changes would then extend all the way to the nature and very foundations of intermediate and secondary school diplomas and of state exit exams based upon which diplomas are granted (Halloun, 2016a & b).

Footnote

*Every professional community (Community of Practice or CoP), and especially every academic community, is characterized by one particular *paradigm* (or a couple of complementary paradigms, like the classical and modern paradigms of physics and natural sciences). The paradigm consists then primarily of:

- ontological, epistemological, methodological, and axiological (ethics and value system included) tenets of axiomatic nature, corroborated principles, and other foundational propositions commonly accepted by all members of the concerned community and hereby collectively referred to as *paradigmatic premises*;
- an *episteme*, or conceptual or content knowledge, that consists of a repertoire of *conceptions*, i.e., concepts, laws, theorems, and other relationships among concepts, along with related semantics, and syntax;
- a *methodology*, or repertoire of procedural knowledge that includes cognitive and sensorimotor *skills* and *procedures* of specific rules and guidelines, along with necessary tools and resources chosen or developed in accordance with specific norms and standards.

Paradigmatic premises govern the inception of conceptual and procedural knowledge for serving specific purposes, as well as the corroboration, deployment, and continuous evaluation and regulation of such knowledge, and thus of the paradigm altogether. Because of their generic nature, some if not most of these premises often cut across different disciplines in the same field or different fields. Disciplines in the same field (e.g., dance and music in arts, biology and physics in natural sciences, and philosophy and sociology in social sciences) would then be distinguished by at least part of their episteme and methodology more significantly than by their paradigmatic premises. That is why the word "paradigm" is often reserved in the literature to refer exclusively to paradigmatic premises within the same discipline or the same field, without incorporating episteme and methodology as well.

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