

Teaching and Learning Systems Thinking: What, Why, When, Where, Who, What For, How?

Pierre Bricage

AFSCET Association Française de Science des Systèmes,
<http://www.afscet.asso.fr/pagesperso/Bricage.html>
Paris, France
pierre.bricage@univ-pau.fr

IASCYS

International Academy for Systems and Cybernetic Sciences
<http://iascys.org>

Abstract— Currently everybody needs to be educated for lifelong time, so we have to be careful what we put in the education programs, and when, in order to create a systems thinking acquired culture and an ethical holistic behaviour.

Keywords: curriculum; holistic behaviour; innovation; mind opening; skills; systems thinking; trans-disciplinarity.

1. Introduction

In England, most of the 2 million higher education students are on degree courses in universities. The UK government invests in higher education for its key contribution to creating a skilled, educated economy and society. In 2017, the public funding for higher education, in the form of grants and tuition fee loans, is over £9 billion a year. In recent years, the UK government has increasingly delivered higher education using market mechanisms. But it often needs to intervene to correct market failures. Public service users often need significant support to make useful choices. Higher education is a complex market. It is difficult to choose a course before experiencing it! Most students attend higher education once and cannot learn from experience. So, outcomes are uncertain and depend on the ability and commitment of each student as well as the quality of the providers [1]. In France also, making an informed choice on whether to enter higher education, and what and where to study, is critical given the lifelong impact of this decision [2] and the costs for parents or students [3]. Everywhere in Europe, the proportion of young people from disadvantaged backgrounds entering higher education has increased, but participation remains much lower than for those from more advantaged backgrounds. Unfortunately globalisation increases inequality [4]. A 'systemic solution to this systemic crisis' [5] is first in 'what, and why to teach' in primary school, and how [6]. The first world greatest challenge is not health but education [5]!

What basic education and which accompaniment for which training?

Everybody needs not only to get the right information at the right time to behave societally and environmentally responsibly but first to be able to understand information, to detect lies particularly in using internet sources [5, 7, 8]. Everywhere, what was once a challenge of *quantity* in undergraduate education, of enrolling as many students as possible, is now a challenge of *quality*, of making sure that all students receive the education they need to succeed, that they are able to complete the studies they begin, and that they can do all of this affordably [9]. **The economic, societal and natural crises result from a dangerous one-sidedness, which lacks holistic approach and social responsibility's interdependence** [10] in both human values and knowledge. Everybody educates for lifelong time, thus we have to be careful what we put in the education programs for youngsters [6] to develop an effective and ethical scientific culture [11], an ethical behaviour, with respect for rules [7], and innovate a more socially responsible society. Everybody needs not only to get the right information at the right time to behave responsibly but first to be able to understand that information and to detect lies in communication, like the lack of accountability and lack of transparency, and to develop influences over and factors of innovation, in the respect for international norms of behaviour and respect for human rights! **Sciences have built a universal multi-disciplinary language** using the knowledge and tools of Mathematics, Physics and Chemistry, Informatics and Communication Technology [7] to build models and make simulations [12]: "Knowledge comes by taking

things apart. But wisdom comes by putting things together.“ (John A. Morrison).

Very young children are able to ensure their learning in letters, sciences and arts through biology centred activities [13] and “creative in common“ responsibilities [6]: **table 1. Systems thinking is a keystone ability** for natural sciences knowledge [7, 8, 12] but also in any cognitive way because of the interrelationship between human knowledges and activities [14, 15], whatever we are, in technology, arts, philosophy, or sociology [16].

Table 1. What?, Why?, What for?, and How?:
Knowledge, skills and holistic behavior.

**WHAT: KNOWLEDGE of HUMAN CULTURES
KNOWLEDGE of THE NATURAL WORLD**

HOW: - through study of mathematics, physics, chemistry, biological sciences and social sciences, humanities, histories, languages, and arts, in **an interdisciplinary way**
- but **focusing by engagement** with big questions/ideas, both contemporary and enduring.

**WHY: To increase and develop
INTELLECTUAL and PRACTICAL SKILLS**

- inquiry and analysis, - critical and creative thinking,
- written and oral communication, - quantitative literacy,
- information literacy, - individual and team work

for solving problems

HOW: in a **HOLISTIC SYSTEMS THINKING WAY** (a),
and **practiced extensively, across the curriculum,**
*in the context of progressively more challenging problems,
projects, and standards for performance.*

**WHAT FOR: for to exert PERSONAL, SOCIETAL
and ENVIRONMENTAL RESPONSIBILITY** (b)

- **local and global** civic knowledge and engagement,
- ethical reasoning and action,
- foundations and skills **for lifelong learning,**
- intercultural knowledge and competence

HOW: **anchored through active involvement**
with diverse communities
and real-world challenges.

WITH: an INTEGRATIVE and APPLIED LEARNING

- synthesis and advanced accomplishment
across general and specialized studies
- **demonstrated** through the application of knowledge, skills,
and responsibilities to new settings,

for resolution of complex problems and innovation
- development of partnerships (c)

- (a) **Holistic approach**, which prevents one-sidedness [10, 17].
- (b) Each **responsibility is everyone's responsibility** [10]
for his/her/their influences on society, on humans and nature.
- (c) **Interdependence: a human, biological and social reality** [8],
'no independence' is crucial from the legal viewpoint to prohibit
abuse of the subordinate layers to the benefit of the upper ones.

Adapted from: *-The Future of Undergraduate Education* [9], -
*Une éducation et une formation efficaces et innovantes pour
investir dans les aptitudes* [26], *-Social Responsibility. Methods,
Dilemmas and Hopes* [25].

**2. WHAT FOR?, WHAT?, and HOW?:
'cyber-systemics', towards a multi-disciplinary and
holistic systemic behaviour** [13, 17, 18].

The objective of the education systems is to prepare young people to successfully face the challenges of society and derive benefit from the opportunities it provides. In psychological terms it means that the objective of the education system is to support the development of personality, which is the dynamic organization within the individual of those psychophysical systems that determine his unique adjustments to his environment; and higher is the level of education higher are the emergent adaptive non-cognitive characteristics of mind [7, 19]. Cybernetics is a way of thinking. It involves concepts like control, self-regulation, autonomy and communication. Forming them, and relating them to each other, must figure as central terms in an holistic way of learning [20]. There are various definitions of Systems Science and Cybernetics [21]. There are many local and international organizations covering their various application, e.g. IASCYS [22]. But there is not much literature about an

explicit application of Systems Science and Cybernetics in the area of education. But **every system management, including teaching is a cybernetic process and has to follow systemic principles** [23]. Only a systemic behavior (holism based on inter-disciplinary cooperation, synergies, not only sums result) is the essence of a systemic-cybernetic approach, to make bridges between the traditional sciences [14, 24] to struggle against 'one-minded over-specialization' [18, 25]. **'Systems theory fights the exaggerated specialization, because the latter causes too many oversights and put the humankind in danger'** (Ludwig von Bertalanffy, 1968).

It is easy in biology with the very various objects of study: a plant, an animal, a landscape, a part of an ecosystem, an experimental device in animal, plant or human physiology, a model of a molecular structure, bacterial cultures..., all the levels of organization and functioning of the alive are available! [6, 8]. Practical workshops, either managed by a teacher, or **a team of teachers from different disciplines**, or independently (without teacher, only with pupils, alone or in groups), will allow each pupil (or student) to observe, experiment and make writings, with drawings, data and graphs, and at her/his/their own rate [6]. The oral and written expression through the use of mathematical and graphical languages and the application of knowledge and tools from mathematics, physics, chemistry and computing allow a better acquisition of new biological concepts and reciprocally [2, 6]: **table 1**. Role-playing games may allow the pupil/student to better find her/his working place within her/his workgroup and allow her/him to choose the best way she/he can acquire knowledge by a motivated discovery [5, 7, 26].

"A place for each one according to her/his skills. Each one on the place she/he deserves considering her/his skills" [2, 5, 8, 27].

What pedagogy to adopt to optimize the pupils' success [2]? What governance and which structures to set up to support this pedagogy [5]? Experimentations showed that only a *driving* behavior of the teachers through a very *active, local and global* coaching of the students [5, 27], with a very strong workload of training for both and a total, but *supervised* semi-autonomy of the students, allows to optimize the success of each one. Only the implementation of a continuous assessment and of **"a quality control approach"**, both internal (of the actors: the students, the teachers) and external (of the whole: the curriculum learning and results), allow to optimize the success of all the partners, with the most raised percentage of global success [6, 7, 27, 28].

Students must spend enough time learning! [29]

With the use of internet data children/students can make some parts of the courses themselves. They can write collaborative parts of the teacher's lessons [5, 28] and sign collaborative contracts, partnerships of teaching and learning, with clear objectives of competencies acquisition [2, 5, 28] for competing for a real job [27].

Nothing is obtained without big mutual (global) and reciprocal (local) efforts. "The student has the

teachers whom she/he deserves and the teacher has the students whom she/he deserves, too" [27].

3. WHY? and HOW?: educate for sustainability, for societal and environmental responsibility [25, 30].

PISA, the OECD Programme for International Student Assessment which takes place every 3 years was designed to collect information about 15-year-old students in participating countries. PISA examines how well students are prepared to meet the challenges of the future, rather than how well they master particular curricula [11]. And results are dropping off in European Countries. Why?

Living within an ecosystem with finite resources, among other living beings, each of us is an actor within a world society: **everything and everyone are interconnected and every action sends ripple effects throughout the whole system** [31]. Global warming [30], global financial crises [32], world epidemics [33], and local wars are catastrophic disasters catalyzed by our interconnectedness. A lot of us are not lucky enough to reap the benefits of that integrated whole: the comfort of enough to eat, a vast availability of products through a global supply chain, access to a global information and communication networks, personal safety and security, freedom to travel, and access to a real job market. The arrival of the today economic, social and natural crisis was anticipated 30 years ago [12] by people who had an holistic way of thinking [33]! But nothing was done.

Only in 2013, and for the first time, the World Economic Forum's Global Agenda Council was speaking about our hyper-connected world in terms of complex systems and in holistic way [32]. But **"You can go with your horse to the watering place but you cannot oblige it to drink."** Man is at first a biological being, inserted into an ecological context (with other species which are competing between them and Man for their survivals) and a social (human) context. So Man has an Environmental and Societal Responsibility (table 1) face to himself and for the whole Earth [12]. It is easier for youngsters to be interested with biology [2, 6, 27]. It is easier to have responsibility when you are educated in such a way [13]. But complexity is a problem..., thus **only a trans-disciplinary systemic approach allows to think and to act in the complexity** [2]. This is the only way to allow to transfer concepts into applications, towards solutions of governance, in economy, ecology and sociology [5]. But to get pupils involved in Societal and Environmental Responsibility we need **first to have teachers trained in systemic behaviour and at a long term story** [8, 22, 28].

4. WHEN?, WHY?: "interaction is construction and construction is interaction" [34].

The open-minded state that people are in when they are innovating, allowing to construct and rearrange knowledge, is essential for learning [35]. A system thinking approach has evidenced **a critical phase of apprenticeship**: sooner children will develop the spirit of experimental design, better they will be able to use a

systemic approach [23, 27, 36] and express a holistic behaviour to respect natural and ethical laws [37]. When? Progressively but as young as possible because for being able to read, write and design in sciences [36, 38] there is a critical period of learning [7]. If the habit of using the cybersystemic language is not acquired early enough, the student cannot avoid the risk of never be able to use it: **after the time, this is no more the time**. Learning is an interactive process [34, 39]: **interaction is construction, construction is interaction**. With the communication technology, we are now living in the time of immediacy, simultaneity and short term stories... [32]. We know that 2 ways of reading, direct and phonological, coexist in the brain. They are simultaneously activated and support themselves each other: **"the whole is always both more and less than the sum of its parts"**. During biological evolution, selection of "thinking" neurones networks was made on the function and not on the structure or location of the network. A dynamic modularity, by juxtapositions, embedments and fittings, is a usual characteristic of these networks [5]. The brain imaging shows that all people, everywhere, in all languages, to read, use the same neuronal circuit and, if this circuit is not activated, not set up, or destroyed, the capacity of reading is absent or lost.

It is an emergent capacity which is auto-organised by re-allocation of neuronal populations (percolation) in a network of re-entries, through systems feedbacks [7].

The psychomotor development is established by links which become established between neurones during the neurological, sensory, intellectual and psychological development. *The reading and scientific writing for systems thinking learning or the intellectualisation of the experimental approach* are similar processes, requiring for acquisition and expression, an appropriate stimulation of a neuronal territory, the pre-existent properties of which make it more capable of this task, but which is not initially allocated to it. As for any physiological answer, whatever is the level of organisation, there is a minimal intensity (a threshold) for the release, a latent period for its implementation [40], and requests need to be repeated for the internalisation. It is only because the "operations" of networking are automated by years of learning and take place in parallel, outside our consciousness, that we could naively believe that, as for the reading, the process is immediate and global! The appropriate stimuli must be "worn" at first at the right time: there is a critical temporal window before which and after which nothing is possible [7]. What governs our choices?: The feelings (table 1)! So, **teach functional studies and link to strategic principles: table 2**.

There is a system of neurones working as mirrors in the sight of the actions executed by other people. The same networks of neurones of the pre-driving cortex are activated as well when we make an action that when we see somebody else making the same action. Everything thus seems to take place as if the perception of the actions of others reflects ours, and vice versa. But "we do not learn to swim only by watching the others swimming, even if it can help, but by trying to swim ourselves." The role of the teacher is not only to show what can be made

"virtually", but especially, **to be there, to make and to make estimate how is made what is "really" made** [36].

5. WHEN?, WHERE?, WHO? AND HOW?

Is not the learning of the scientific approach at the time of the multimedia a prerequisite for the reasonable and reasoned expression of the citizenship? Let us expose as soon as possible our children to the use of the experimental approach. At the primary school games for scientific awakening [7] should be a prerequisite for the learning of reading, writing and calculation. As a hunter-gatherer Man was at first an observer-experimenter. Our neuronal potential is thus a priori more adaptable towards **the use of experimental approach** of systems science than towards reading. If this exaptation does not take place, this brain potential is lost because it is recycled towards other purposes.

Table 2. Governance of principles, principles of governance. What?, Why?, What for?, and How?

Principle 1. Teach the functional study of cerebral (*biology*), mental (*anthropology, information science*) and cultural (*sociology*) characteristics of the human knowledge, its processes and modes (*artificial intelligence*), and the psyche (*psychology*), and cultural disposition **to allow the risk** of error or illusion. **Consider the broadest range of competences (knowledge, skills and attitudes) in a multi-dimensional context** [34, 39].

Principle 2. Teach to think about global and fundamental problems, and big ideas, in order to instil the partial and local knowledge, **and reciprocally: "The whole is always both more and less than the sum of its parts."** The significant knowledge principles within the local context are also within the global one (**systemic constructal law** [2, 27]), and they are multi-dimensional and complex (**percolation** [5, 7]). **Point to interconnection and systemic changes as key points in programme curriculum.**

Principle 3. Teach the human condition: every human being is a physical (*chemistry, physics*), biological (*physiology, medicine*), psychological, cultural (*anthropology, sociology*), societal (*systems engineering, big data applied computing*), and historical (*information theory*) **living system of systems.**

Be intentional about responsibility for sustainability.

Principle 4. Teach the whole Earth's identity: teach the history of the planet's eras and of all the life forms that are **sharing** a common environment of survival [eco-exo-tope (<http://armsada.eu>)] and their fate. **Be intentional about societal and environmental responsibility for development and change** [12].

Principle 5. Face the uncertainties: teach strategic principles that allow to deal with the un-expected and to modify future development according to recently acquired information.

Fulfill each one self-determination and self-fulfillment [8].

Principle 6. Teach to tolerate in order to **teach for peace**, against racism, xenophobia and disrespect. **Support girls to 'read' context, gender, and power.**

Principle 7. Teach towards humankind ethics. Ethics must be formed in the minds from the consciousness that human beings are, **at the same time**, individuals, a part of a society, a part of a species, a part of ecosystems and through democracy to conceive of humanity as a planetary community [12, 33]. **Be intentional about human responsibility for human development and change** [37].

Adapted from: -Sustainability in Mexican Higher Education: towards a new academic and professional culture [41], -Translating Competencies to Empowered Action. A Framework for Linking Girls' Life Skills Education to Social Change [42], -Les sept savoirs nécessaires à l'éducation du futur [43, 44].

Even if a scientific training (table 1) is not useful for the self-fulfilment of each one (table 2), it becomes necessary for every one in an advanced hyper-connected

technological society because the societal governance must **be able to take into account the advantages and the inconveniences of technology** (e.g. bio-technologies) and sciences (e.g. nuclear-energy engineering). The respect of the accommodation facilities of our environment of survival implies the knowledge and the control of our capacity to be welcomed here.

What sort of governance will be able to respect and develop our societal and environmental diversity? [2, 5]

What pedagogy to operate for that? Is not curiosity the first motor and respect the first skill? [5, 6, 27]

In school systems where students spend more time in regular science lessons, average science scores are higher [11]. When students spend more time studying science after school, average science scores are lower [29]. Currently, in primary and secondary schools, teachers' knowledge of systems thinking is usually poor. However, this is not a barrier to integrate systems thinking in these schools. Of course, easy-to-access supporting material and motivational factors such as self-efficacy and self-determination are proved to be important. However, above all, the attribution of significance by teachers is the most promising leverage to foster the adoption of systems thinking in classrooms [45].

6. WHAT FOR?, HOW?: Not only for higher education, not only in applied sciences [8, 24].

The '*playful state of mind*' is the state of mind that people are in when they are innovating or learning from their experiences. *Completely open-minded and able to construct and rearrange knowledge*, both **in Humanities, Arts and Sciences**, this state is essential for children learning. The essence of innovation is a break in our perception. When it has emerged, it becomes so obvious that it is difficult to imagine that it did not exist before. However, before the break, the issue at focus is a complex problem in the sense that the relationship between cause and effect can only be perceived in retrospect but not in advance. Sooner children have developed the spirit of experimental design [6, 7, 34], better they will be able to experiment, compete, collaborate and innovate [2, 27, 36]. An overcrowded and fragmented science curriculum was recognized as one of several factors in students' perception that science was a disconnected series of facts of very little wider meaning. Part of the solution to this problem was to conceive the goals of science education, not in terms of the knowledge of a body of facts and theories, but as a progression towards understanding key ideas of relevance to students' lives during and beyond school [46]: tables 1, 2. Education, like health [47], can not be satisfied by ready-to-think or ready-to-heal [48]. Many people are not satisfied with the ready-to-wear, like MOOCs [49]. But the "*standard*" people have not the money to pay for better individual-made solutions. Maybe ready-made solutions are necessary for a lot of people but they are neither factors of progress nor of success. Progress is always at the margins, and in the "*do-it-yourself*". Any teacher is primarily a craftsman.

Nature itself creates new life forms from a "*crafty embedding*" of previous ones, but respecting mandatory rules: - there are never any rights without duties, - nothing is got without effort.

We need first a new way of formation for "systemic thinking" teachers of teachers [8, 18, 28, 38, 48].

Undergraduate landscape good teaching is generally undervalued. Faculty are rarely trained, selected, and assessed as teachers, and their effectiveness as instructors is rarely recognized or rewarded [9]. It is critical for the quality of undergraduate education that effective teachers should be able to build successful professional lives!

Currently **everybody needs to be educated for lifelong time** [28, 38], so we have to be careful what we put in education programs to create a systemic acquired culture and an ethical holistic behavior. Dangers are in lacks of transparency and accountability. Cybersystemics can help to develop everyone capacity of influences and factors of innovation [5] in the respect for international norms of behavior and for human rights [37]. Digital technology can enhance learning and enable learning on the large scale at a lower cost. Digital technology can support teachers supporting learners. Access to digital technology and to online courses enhances the potential for equity through learning at scale [49]. A global community needs global knowledge, and the research and innovation activity that allows its advancement [10, 18] has to develop in a way that is fully conscious of community needs and expectations, at both local and global levels [50].

Teaching systems sciences and cybernetics is a way to support research and innovation originality and creativity. The important point is not to be led by administrative capacities, and to add value. Not to replicate national educational systems, but to put in place the foundations for a programme that incentivises inter-disciplinarity and inter-nationalism [51, 52]. We must **focus on human, societal and ethical aspects** [37] not just economic or industrial benefits, **and impact for the long-term** [52]. Cyber-systemics recognises fully the value and importance of the humanities and social sciences, and ensures these diverse disciplines have a central role.

The supply and demand for graduates is changing in Europe. The proportion of the population with tertiary qualifications is increasing everywhere. The supply of graduates will continue to rise, but the future for graduate jobs is especially uncertain [53]. So only new skills will allow new jobs to sprout. Think with systems thinking if you want to acquire both new skills (table 2) and a wider professional competency (table 1) [39].

7. Conclusion

Living systems are complex, adaptive controlled and controlling systems of systems, engaged in network interactions, both inside (between their functional structures within their body: their endo-physio-topo [33]) and outside (between other systems sharing the same

environment: within the same eco-exo-tope [8, 33]): systemic constructal law [8, 12].

Deep problems as the nature of life, mind, and society, are naturally driving to questions of philosophy and epistemology [13, 54]. Cybernetics as a science studies the principles of organization in complex systems. System thinking is concerned not only with what systems consist of, but how they function and survive. ***Being inherently trans-disciplinary, cyber-systemic reasoning can be applied to understand, model and design systems of any kind:*** physical, technological, biological, ecological, psychological, societal (tables 1, 2), or any of their combination [16]. Second-order cybernetics in particular studies the role of the human observer in the construction of models of systems and other observers (table 2).

We need an holistic cyber-systemic education for students because the improvement of the quality of higher education and the improvement of conditions for researchers at universities are linked together and they are the prerequisite for innovation and corporate research [55]. We need an holistic cyber-systemic education for managers because the civilian science, technology and industrial development plans are linked together [47, 56]. ***An inter-disciplinary curriculum is needed to focus on understanding and development of cognition*** [51]. A fruitful education system needs to remain dynamic if the quality of education is the main concern, making it a complex system. For example space technology is an interdisciplinary science, which is costly and developing at a fast rate [57]. So every curriculum, towards a trans-disciplinary, holistic way of behaviour and through a life long learning way, must be engineered the same manner [2, 6, 7, 8, 27, 28, 34, 35, 38, 39].

Personalized Learning appears to be promising for improving student achievement. But, its full effects vary in different school contexts and may take some time to emerge [40]. Higher education is one of the most important investments individuals can make for themselves and for their Country. Many students access student loans to help finance their education [3]. The International Academy for Systems and Cybernetic Sciences (IASCYS <http://iascys.org>) is a not-for-profit society [22]. It was created as an honor society by the International Federation for Systems Research (IFSR, Vienna Austria, <http://ifsr.org>) which is an umbrella society of smaller, usually national, academic societies in the field of systems and cybernetics. IASCYS would like to do more than simply honor outstanding contributors so it is expanding the number of international associations it works with (e.g. IRDO, ISSS, SESGE, UES-EUS, WOSC, X-SHS) and it is engaged in offering short courses in systems and cybernetics in various Countries, like China, India or Japan, encouraging academicians to offer open courses and valuable degree programs elsewhere, not only at their home universities.

Social learning, for the sustainable management [12], use and re-use of finite resources [33], like water [58], is

a keystone in environmental policy [59]. Not only technological, but also social innovations can help solve societal challenges. And the most widespread obstacles to innovation are excessive innovation costs and economic risks [3, 48]. Better mutual understanding of the diverse mental models, deep understanding of the interconnectedness between possible actions in order to develop efficient and cost-effective management strategies are keystones for continuous co-learning and refinement of management strategies, particularly in developing countries [60], not only in higher education and not only for boys. Promotion of girls' life skills education is the best way for social changes [42]. We need special worldwide educative structures ***to struggle against disruptive economical and societal changes*** [47, 61, 62, 63] and to promote youngsters' success [64]. ***"We cannot make the world without you, it will be better only if we could do it with you"*** [65]. ***"Be intentional about prerequisite variety"*** [5, 8].

"L'éducation est l'arme la plus puissante qu'on puisse utiliser pour changer le monde." Nelson Mandela

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