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Competence in Unsustainability Resolution—A New Paradigm

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Abstract: Environmental unsustainability in coupled human–nature systems is accumulating. Yet, there is no accreditation requirement for unsustainability resolution competency in higher education. Thus, a new and complete representation of the pedagogy for unsustainability resolution competence has been induced, using what is already available and working. The nature of unsustainability problems points to collaboration and holism attitudes. Resolution requires social skills, namely participation, perspective taking, and the generation of social capital, and cognitive skills, namely project management, knowledge building, and modeling. Resolution is scaffolded in three successive steps during the collaborative process within a systems approach: (i) collapse complexity; (ii) select a path/trajectory; and (iii) operationalize a plan. The hierarchically cumulative abilities toward unsustainability resolution competence are to source data and information about the coupled human–nature system (SEARCH); simplify the dynamics of the human–nature system (SIMULATE); generate and test alternative paths and end points for the coupled human–nature system (STRATEGIZE); chose a favorable path among the available alternatives (SELECT); operationalize the favorable path into a plan (strategy–program–project) with measurable management and policy objectives (IMPLEMENT); and develop criteria/indicators to monitor and adjust when necessary the implementation of the plan toward system goals (STEER). For each one of these learning objectives, the Bloom's taxonomy and a progression from behaviorist through cognitivist to constructivist tools apply. The development of mastery requires the comparison and contrast of many similar cases with the same unsustainability problem and project-based learning with specific cases for deep learning. In this way, it is the resolutions of unsustainability in human–nature systems that will be accumulating.

Keywords: complexity; curriculum development; policy design and evaluation; sustainable development

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Citation: Dikou, A. Competence in Unsustainability Resolution—A New Paradigm. *Sustainability* **2024**, *16*, 8211. https://doi.org/10.3390/su16188211

Academic Editor: Ajda Fošner

Received: 10 August 2024
Revised: 10 September 2024
Accepted: 18 September 2024
Published: 21 September 2024

1. Introduction

The unprecedented global directional forcing agains planetary boundaries in the Anthropocene era is an inconvenient realization [1–3]. The forcing is composed of global problems due to local accumulations, such as climatic anomalies, eutrophication, and resource depletions, that now interact with one another. The climatic anomalies are due mainly to the local release and global accumulation of carbon dioxide in the atmosphere through the burning of fossil fuels for energy. The eutrophication is due mainly to the local runoff and global accumulation of nitrogen and phosphorus in aquatic ecosystems through agricultural and aquacultural fertilization. The resource depletions are due to higher extraction rates compared to regeneration rates of natural resources. The interaction of climatic anomalies, eutrophication, and fisheries depletions now leads to harmful algal blooms [4]. The interaction of climatic anomalies with the over-abstraction of water now leads to more extensive and more frequent droughts and wildfires [5]. The forcing means that the response of our societies needs to be re-steered, strengthened, and hastened. Environmental sustainability has been the corresponding United Nations initiative to cater to the needs of both current and future generations [6] and has been infiltrating education, research, industry, and society for over four decades as an imperative. Recently, 17 goals have been proposed for all nations to pursue simultaneously to transcend from economic development toward a sustainable development paradigm [7]. The resolution of unsustainability has been and is being attempted in higher education, management, and policy.

Higher education has responded with the emergence of Environmental Science and four types of formal education initiatives for environmental literacy, addressing experts, professionals, particular environmental issues, and all disciplines [8]. None of them required problem-solving competency, as the product of knowledge and ability, for accreditation. Lately, the emerging Sustainability Science aims at resolving the unsustainable interactions with our natural environment with generalist and domain-specialist programs, e.g., water, agriculture, tourism, and global development, at the undergraduate and graduate levels. Sustainability readiness in higher education has been sparking creativity and innovation in curricula and syllabi toward the quest for better environmental performance. A program switch from natural sciences-based to social sciences-based curricula [9]; the familiarization of learners with how policy decisions are made [10,11]; synclysis towards (holistic) system thinking and the trans-disciplinary integration of ecological, social, and economic dimensions in coupled human–nature systems [12]; a practical approach in multiple real contexts for deep learning [13–16]; an inquiring approach to learning [15,17]; and the need to incorporate powerful Information Technology tools for big data analysis [18–21] are some of the empirical findings and recommendations. Nevertheless, the means and methods for teaching, learning, and assessing coupled human–nature systems, trans-disciplinary integration, and real contexts vary widely and we still accumulate necessary evidence on the "what", "why", and "how" of their performance regarding sustainability readiness and sustainability competence [22–24]. Most importantly, we still have not determined the (academic) literacy, competency, and learning objectives that ensure not only students' degree accreditation in Sustainability Science but also real life and timely impact. This work aims to justify how to teach the necessary and sufficient attitudes, knowledge, and skills, so that Sustainability Science graduates can resolve unsustainability.

2. Materials and Methods

To develop the pedagogy for competence in unsustainability resolution, I retrieved relevant works using combinations of the following keywords in Google Scholar and Google search engines: learning, teaching, curriculum, syllabus, pedagogy, learning objectives, thinking, synthesis, values, project, design, decision, implementation, management, sustainability, big data, complexity, and integration. The retrieved documents contained elements, such as ideas, concepts, and approaches, which were organized into distinct themes, namely values, policy, management, technology, economy (of natural/environmental resources), and then underwent repeated cycles of purposeful divergence–convergence thinking. During divergence, (new) elements were retrieved until saturation; the elements were associated in many, some of them new, ways; new ideas, choices, and alternatives emerged with imaginative consciousness; and the pedagogy or its frame was identified, defined, and redefined. During convergence, I was selecting the best element, choice, and alternative by contrasting new elements, choices, and alternatives with criteria for appropriateness for purpose, effectiveness, and parsimony. A new and complete representation of the pedagogy for sustainability competence was induced using what is already available and working.

In this paper, I first specify the nature of and describe the attributes of the unsustainability problems. Then, I justify the (holistic) systems approach to integrate the economic, social, and ecological dimensions of a coupled human–nature system. Finally, I discern three key steps in unsustainability problem solving. Each key step in unsustainability problem resolution corresponds to certain abilities, each of which may be developed using the generic Bloom's taxonomy of abilities in the cognitive, affective, and psychomotorical domains [25–27] and tools from the behaviorist–cognitivist–constructivist generic teaching pedagogies [28]; I used contributions from three disciplines, namely system science, decision-making science, and implementation science, and capitalized on emerging generic skills for higher education, namely collaborative problem solving for the 21st-century skills initiative [29] and the e-science paradigm with big data [30].

3. Results

3.1. Pedagogy for Competence in Unsustainability Resolution

3.1.1. What Type of Problem Is Unsustainability?

Problems have been classified into crises and wicked [31]. Unlike acute crisis problems, such as ordinary forest fires, floods, and droughts, that require fine-tuning and coordination, chronic and steadily advancing unsustainability problems, such as climatic anomalies, fisheries depletions, and harmful algal blooms, require decision making and design, or else planning. Rittel and Webber [32] provided the defining characteristics of wicked problems fifty years ago, with city planning as a springer (Table 1). Wicked problems are ill structured because of multiple unknowns and the associated uncertainties that necessitate trans-disciplinarity or the collaboration between various experts and non-experts. They are amenable to multiple alternative (re) solutions that define quite different evolutionary trajectories and system endpoints. As such, they necessitate choices among alternatives, the design of the ideal (re) solution, and its implementation. They cause turbulence and engender surprises due to unintended or/and unanticipated consequences [32]. Therefore, holism and collaboration are justified as the two essential attitudes to resolve unsustainability problems. Holism is defined as the integration of all the complementary perspectives and disciplines. Collaboration is defined as the development of mutual dependence to accomplish a common goal [33–35].

Table 1. Why unsustainability problems are not wicked anymore [a]. Concerns in planning as a design and choice endeavor correspond to the required holism and collaboration attitudes.

Challenges	Responses
1. ”There is no definitive formulation of a wicked problem”	Quantitative System Dynamics Modeling
2.”Wicked problems have no stopping rule”	
3. “Solutions to wicked problems are not true or false, but good or bad”	
4. “There is no immediate and no ultimate test of a solution to a wicked problem”	
5. “Every solution to a wicked problem is a ‘one shot operation’; because there is no opportunity to learn by trial and error, every attempt counts significantly”	
6. “Wicked problems do not have an enumerable (or an exhaustively describable) set of potential solutions, nor is there a well-described set of permissible operations that may be incorporated into the plan”	Multidisciplinary Integrated History-dependent Experience Learning Selection Alignment Goal
7. “Every wicked problem is essentially unique”	
8. “Every wicked problem can be considered to be a symptom of another problem”	
9. “The existence of a discrepancy representing a wicked problem can be explained in numerous ways. The choice of explanation determines the nature of the problem’s resolution”	
10. “The planner has no right to be wrong”	

[a] quotes from [32].

3.1.2. Why the System Approach for Holism?

A system consists of components, the relationships among them, a boundary that surrounds them, and exchanges of matter, energy, and/or information with its external environment, provided it is an open system. Its structure is maintained with causal reciprocal relationships called feedback loops. Its function generates patterns and events, which are that part of the system that we can observe. A system approach is warranted to explain the why and how of events that we observe, taking account of its function and structure to understand, optimize, and/or change it. A coupled human–nature system, where unsustainability takes place, is open to exchanges with its external environment; it is complex due to its many and heterogeneous parts and connections; it has a heterarchical organization, seen as the integration of the variants of the hierarchies with the variants of the networks; it has self-organized regulation, based on feedback loop structures; it evolves by adapting to change, but is also resilient to disturbance; it can exhibit new properties, functions or events; it is history-dependent in regards to the effects of past (human) decisions on the current state and of current decisions on the future state; it is endowed with learning, hindsight, and foresight due to humans; it has an inherent tendency (goal) toward dynamic stability or equilibrium; and its purpose is to continue to exist [36]. Examples of coupled human–nature systems are our agricultural, fisheries, and industrial production systems, our tourism service systems, our urban systems, and our global system.

Heuristics employed to depict the concept of sustainability for a coupled nature–human system show the integration of different perspectives/dimensions, namely natural/ecological, human/social, and economic/technical, yet they imply different assumptions about the way that the respective perspectives relate and interact with one another [37]; they may reflect different underlying philosophies, e.g., convergence Cioffi-Revilla, 2016 [38] vs. socio-ecological [39] vs. panarchy [40]; and they envision different futures [41–44]. Nevertheless, the behavior of coupled nature–human systems as integrated ecological–social—economic systems has been explained by the panarchy theory. In this heuristic theory, the system is depicted as nested cycles at different spatial/temporal/organizational scales (levels). Each cycle consists of perpetually alternating re-organization, exploitation, conservation, and release phases, involving changes in its capacity, resilience, and connectedness through creative destruction and destructive creativity [40]. We have adequate empirical evidence of the panarchy theory, [45] but we do not yet have a formal mathematical representation to simulate the dynamics of a panarchical system.

The system dynamics methodology, however, is well established. With a lifetime of work, Forrester [46–49] showed that the simulation of the dynamics of a system enhances our ability to comprehend the outcome of the simultaneous interaction of multiple feedback loops, which may turn out to be counter-intuitive, and allows us to *a priori* test our interventions, avoid unintended consequences, and navigate independently of the external environment. The single-level system is depicted with numerous stocks (quantities) connected with flows (processes). When populated with time series data, we can visualize the behavior of the system through time and discern leverage points of increasing strength: the constants and parameters of relationships (numbers); the size of stabilizing stocks relative to their flows (buffers); stock and flow structures; the rates of feedback loops relative to the rates of system change (delays); balancing feedback loops; reinforcing feedback loops; information flows; rules; self-organization; goals; paradigms; and the power to transcend paradigms [50]. Generic exemplar system simulation models, such as the urban dynamics model (156 equations), the national economy model (200 stock variables and 400 relationships), the world dynamics model (43 equations), and the limits to growth model (150 equations), have provided numerous valuable insights into the non-linear dynamics of systems with multiple feedback loops and the effects of (policy) interventions on different leverage points of the system [48,50]. There have been applications of system dynamics modeling in many areas of interest, including environmental systems [51–53]. It was facilitated by simulation-based case studies of the generic simulation models (in [48]), wide popularization [50,54,55], user-friendly system dynamics simulation software (e.g., Stella Architect, Vensim, System Dynamics Tools), and decision support systems with system dynamics modeling capabilities (e.g., mDSS [56]; WaterWare [57]; GWDSS [58]). Yet, the application of system dynamics modeling to resolve unsustainability problems has not been streamlined. Just like collaborating stakeholders/perspectives cannot comprehend the outcome of the simultaneous interaction of multiple feedback loops without system dynamics modeling, neither can system dynamics modelers develop satisfactory simulated feedback loops of a coupled human–nature system without input from collaborative processes engaging all the stakeholders/perspectives. The loner system dynamics modeler is yet to be productively embedded within stakeholders' deliberations to collaboratively resolve unsustainability. Such synergies are expected not only to improve environmental management outcomes in education, professional practice, and policy making but also to improve navigation along a new trajectory under the sustainable development paradigm.

System dynamics modeling is one of the five types of quantitative modeling applied to coupled human–nature systems for integrated environmental assessment and management [59]. System dynamics modeling, Bayesian networks, coupled component models, agent-based models, and knowledge-based models (also referred to as expert systems) have not yet been formally compared under the same well-studied context/s to evaluate their relative performance regarding the resolution of unsustainability. Insights from panarchy theory and system dynamics (modeling), nevertheless, point to poor capacity, rigidities, traps, delays, and structural inefficiencies as sources of unsustainability in coupled human–nature systems [40,50,60].

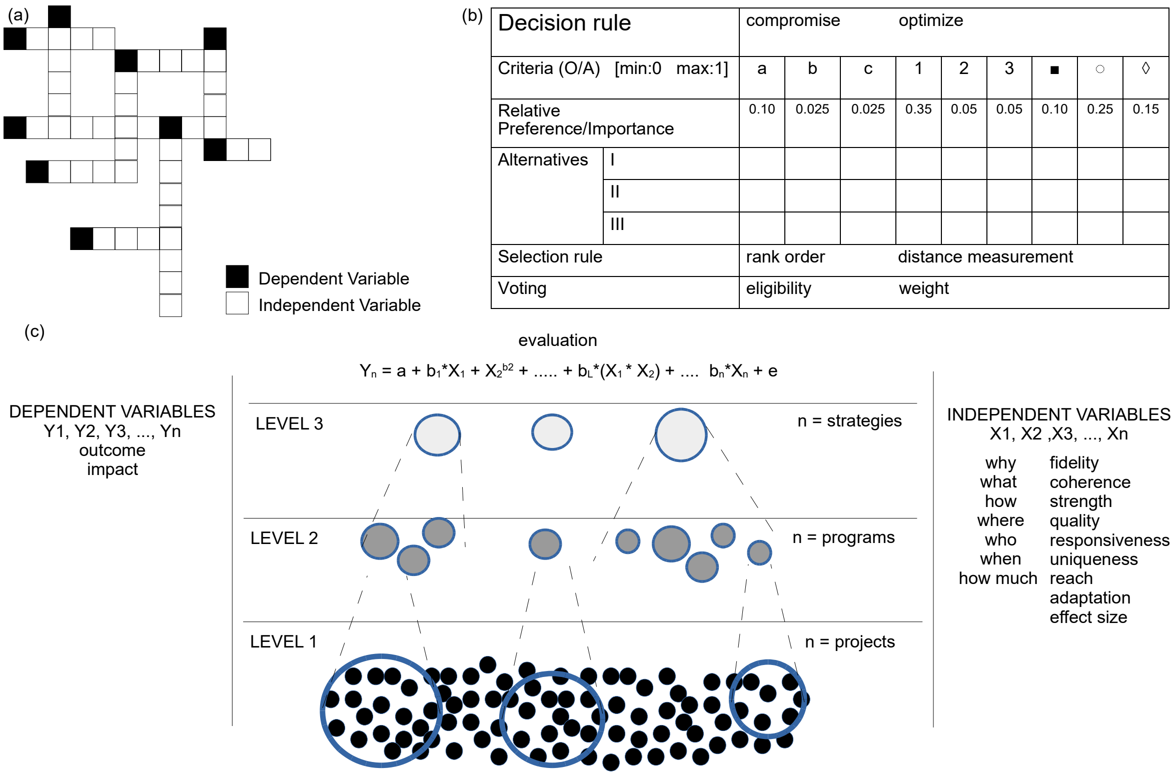
3.2. What Are the Steps of the Unsustainability Resolution Process?

3.2.1. Collapse Complexity: Trans-Disciplinary Generation of Alternative (Re) Solutions Based on Collaborative Problem Solving within a Systems Approach

For context-specific and real-world sustainability problems, it is the deliberate inundation of data, information, and knowledge from all the relevant perspectives and disciplines that enables the collapse of complexity [32]. Qualitative system dynamics tools, such as the iceberg, the connection cycle, the compass, the causal loop diagram, the stock and flow map, the ladder of inference, the compass, and the behavior over time graph can help collaborators create a common appreciation and an explanation of the state of their unique coupled human–nature system and specify the necessary and sufficient variables to develop a quantitative system dynamics simulation of its behavior [47,55]. These necessary and sufficient variables compose a cross-variables puzzle in system dynamics modeling and simulation (Figure 1a). When assumptions and constraints about the system are properly and adequately addressed, system dynamics modeling and simulations enable collaborators to explore, through a "what if" inquiry, their system's future state by trying out interventions at empirically derived system leverage points of different strength. In this way, they can avoid unintended consequences emanating from gaps, overlaps, and/or interactions within their system of interest [48–50].

The intent and potential to turn the whole (outcome) into more than the sum of its parts (learners) in terms of quality and timeliness is dependent on all three of the following: the educator/trainer, i.e., how well prepared the (social and cognitive) background of the group of learners is and whether they have access to resources; the individual learner/team/group member, i.e., how well have they internalized this background preparation and whether they have accessible resources; and the group of learners/team, i.e., how well self-organized and whether they interact in such a way as to allow the best possible contribution from each member toward the joint goal. Thus, the process, the outcome, the individual performance within the group, and the group's performance, as well as self-, and group-reflection are all assessed [29]. The greater the difference between the whole and the sum of its parts, the greater the benefit from the collaboration.

The essential components for both educators and learners to design an effective and rubricable collaborative problem-solving process include the intention goal, prioritization, timing and sequence, communication, structures, interactions, resources, and outcomes [61–63] (Table 2). Formative and summative evaluations for a collaborative decision-making process are available [29,64,65].



$$Y_n = a + b_1{*}X_1 + X_2^{b2} + ... + b_L{*}(X_1 {*} X_2) + ...\ b_n{*}X_n + e$$

Decision rule		compromise			optimize					
Criteria (O/A) [min:0 max:1]		a	b	c	1	2	3	■	○	◊
Relative Preference/Importance		0.10	0.025	0.025	0.35	0.05	0.05	0.10	0.25	0.15
Alternatives	I									
	II									
	III									
Selection rule		rank order			distance measurement					
Voting		eligibility			weight					

Figure 1. Heuristics of the sequence of analytic tools needed for unsustainability problem resolution. (**a**) Cross-relationships puzzle of the necessary and sufficient variables to simulate system behavior and to generate alternative (re) solutions with system dynamics modeling, (**b**) multi-criteria and multi-attribute/objective decision making to compare alternative (re) solutions, and (**c**) multi-level modeling to evaluate the effect of attributes of an implemented (re) solution on system behavior.

Table 2. Essential components to design a collaborative problem-solving process [61–63].

Component	Content
intention	The reason why a group of entities, such as learners, professionals, organizations, and agencies, are prompted to collaborate may be engagement, emergency, information, potential, problem (re) solution, the balance of interests, and impact.
goal	It is a pivotal determining dimension of collaboration that all collaborators share the same explicit common goal, which may be apparent, negotiated, or handed down.
prioritization	The agenda of the collaboration not only includes the objectives required to be met to reach the common goal but also the prioritization of issues.
timing and sequencing	They involves choices regarding the ordering of actions and tasks and their duration across a timeline. Adequate time is needed for collaborators to obtain the data, information, and knowledge required to build confidence, and then to decide. The proper allocation of time ensures breadth, depth, and diversity during deliberation, the maintenance of both concentration and motivation, and guards against the creeping conflicts of interest during the available yet short-lived “window of opportunity” to align the problems, solutions, and interests.
communication	It could be face to face or distant; it may be rare, frequent, or intensive; it may be taking place only internally among collaborators or developing external links as well; it may be open to a broader audience, regulated, or closed; and it may be taking place in gathering spaces or on tele-conferencing platforms.
structures	They involve choices regarding organization; complementarity; redundancy; flexibility; the adaptive cycles of interaction among collaborators; the determination of participants’ (discreet or overlapping) main functions, namely leader, facilitator, or collaborator, and what each one of these functions entails; and the collaborators’ identities, i.e., predetermined or not, fixed or not, and who is to do what, why, and how within the collaboration to attain the common goal.

Table 2. *Cont.*

Component	**Content**
interactions	They are the rules and norms regarding the risks, rights, and responsibilities for collaborators, such as individual and group attributions, rewards for value added, sanctions for violations, exchanges, negotiations, conflict resolutions, compensation, the definition of success, accountability, transparency, conflicts of interest, feedback, meta-cognitive reflection, unanimity or majority in decision making, qualitative or quantitative approaches, and ownership and copyright, which are based on values.
resources	They include expertise for knowledge; data for information; tools for creativity, goal setting, path finding, and decision making; documentation regarding management, evaluation, and assessment; and funding.
outcomes	They are tangible deliverables, small and large, short-term and long term.

3.2.2. Select a Path/Trajectory: Choice among Alternatives Based on Multiple Objectives and Multiple Criteria Decision-Making Methods

The collaborative socio-ecological problem-solving process entails numerous choices to be made. Two of these choices are highly important to warrant a formal comparison of available alternatives: the favorable future state/end point (compromise) and the favorable path to follow/trajectory (optimize) to achieve the favorable future state of the coupled human–nature system. To systematically compare available alternatives, we need to develop comparison criteria, determine their relative importance, and develop a selection rule that enables the ranking of alternatives (Figure 1b). Comparison criteria may be either an attribute, e.g., sustainable, efficient, or economic, or an objective/goal, e.g., higher than X, made of Y, or contains Z. This is essentially an alternatives (rows) x criteria (columns) matrix. Standardized criteria provide comparable (sum) scores to rank alternatives or correlation matrices from the pairwise comparison of alternatives to plot dis/similarities among them as Euclidean distances [66–68]. Voting on alternatives, if added as necessary, considers several issues, such as who is eligible to vote, e.g., those who generated the alternatives or those who are affected by the implementation of an alternative, and whether the equal weight of the vote is justified or not, e.g., due to performance/contribution or expertise or stake [69]. Individual choice on importance/preference or else the weight placed on each criterion may be inherently subjective, but it does not have to be biased or framed once system holism, the lack of logical fallacies, and data veracity can be verified. E-collaboration tools and platforms [70] are evolving into suites [71] and hybrid intelligence systems [72].

3.2.3. Operationalize a Plan: Implementation of a Favorable Path with a Plan Based on Embedded Strategy–Programs–Projects

After a choice or a decision on a favorable (re) solution has been made, it is operationalized into management and policy objectives and implemented with embedded (hierarchical) strategies–programs–projects. These ensure coherence and consistency among the levels of organization of a coupled human–nature system, keep all collaborating entities aligned across these levels, and safeguard against deviation from the intended goals or else mission drift. Embedded strategy–programs–projects also correspond to the temporal sequence of conceptualization, operationalization, and actualization phases, respectively, of a decision; may be developed for any spatial/temporal scale; and may vary from comprehensive through cross-sectoral and sectoral to integrated within existing policies.

Embedded alignment is achieved when strategies, programs, and projects all align across their answers to the following fundamental attributes [73–76], albeit at different levels of detail:

why: driving forces; motivation for repositioning the coupled human–nature system; and the vision for the new position.

what: logic of the purposeful (re) direction of the system as an overarching progressive sequence from the current to the desirable position from preparation through accomplishment to closure; appropriate, fit, and adequate (re) solution to accomplish (re) positioning of the system; assumptions made; strengths, weaknesses, opportunities, and threats identified within the system context; consequences and implications of the (re) positioning process and of the new position of the system; and powers and capabilities.

how: balancing of asymmetries and capitalization on heterogeneities; correspondence of the favorable (re) solution for the repositioning of the system to system leverage points; translation of the intervention upon system levers into appropriate, fit, and adequate programs and projects filled with tasks and activities; assumptions made; (positive and negative) incentives and initiatives involved; the compensation/accommodation/amelioration of negative consequences and implications; accountability and attribution; mechanisms to confront and overcome obstacles and constraints including disruptions and attacks; conflict resolution mechanisms; performance/effectiveness/compliance measurements; the access to and use of data, information, and knowledge; the review, reflection, and dissemination of results and experience to all collaborators; self-sustenance of the results of the intervention.

when: the timeline; timing, and sequence of implementation tools; duration; the regularity and frequency of reporting and dialoguing.

who: entities, such as individuals, groups, organizations, agencies, and populations, to be engaged in collaboration and those (to be/being) affected by this collaboration.

where: geographies and places involved, their position within the system, and spatial resolution.

how much: input; output; leverage; value for money; funding and budgeting.

Important and rubricable attributes to evaluate the embedded alignment of implemented strategy–program–project interventions involve fidelity, coherence, strength, quality, responsiveness, uniqueness, monitoring, reach, adaptation, effect size, and impact [73,75,76] (Table 3). Then, analytic tools for testing the embedded designs can be employed to evaluate the relative contribution of each one of these attributes to the outcome or the behavior of the system due to the intervention (Figure 1c). Multi-level modeling, in particular, provides accurate (due to the control for auto-correlations) and comparable (due to standardization) estimates of the contribution of the quantified attributes (independent variables) of an implemented plan on its outcome (policy and management objectives) and its impact (dependent variables) within any level of interest (strategy, program, project) and across levels and can account for the linear or/and non-linear relationships between variables, such as power law, exponential, and saturation [77].

Table 3. Essential attributes to evaluate the implementation of embedded and aligned strategy–program–project interventions [73,75,76].

Attributes	**Meaning**
fidelity	It is the correspondence between what was actually done and what was intended: (i) turning a favorable (re) solution into system levers to intervene into, (ii) turning system levers into strategies, programs, and projects, and (iii) turning programs and projects into tasks and activities.
coherence	It is how well activities correspond to tasks, tasks correspond to projects, projects correspond to programs, programs correspond to strategy, and strategy corresponds to the favorable (re) solution.
strength	It refers to what was actually done, e.g., the relative strength of the system levers that the collaborators were able to intervene into and the intensiveness and depth of the project's activities.
quality	It is how clearly and correctly different and discreet components of what the collaborators do are conducted, e.g., strategy, program, project, task, and activity.
responsiveness	It refers to the stimulation or attendance of the collaborating entities at any capacity and, of those entities, which are affected by what the collaborators do.
uniqueness	It is the difference between what was done to (re) solve the problem in the specific socio-ecological system and what was done in other, comparable socio-ecological systems with the same problem; it is the inverse of the degree of overlap among different (re) solutions for the same socio-ecological problem.
monitoring	It refers to the nature, amount, and progress of the intervention/strategy/program/project/task/activity to (re) position the system.

Table 3. *Cont.*

Attributes	Meaning
reach	It is the scope and the representativeness of the collaborating entities and the affected entities at any capacity.
adaptation	It is the difference between what the collaborators were initially set to do and what they finally did during the implementation of the intervention/strategy/program/project/task/activity.
effect size	It is the before–after difference in the state and/or behavior of the system due to the intervention/strategy/program/project/task/activity.
impact	It is the influence that the intervention/strategy/program/project/task/activity had on the non-collaborating and non-affected others, through the diffusion of knowledge and practice.

3.3. Skills

The resolution of an unsustainability problem requires the ability to integrate disciplines and perspectives, to reduce/simplify complexity, to collapse the complexity of ill-structured problems, to generate and test alternative solutions, to choose among alternative solutions, and to implement a favorable solution with a plan, all of them collaboratively [13]. Therefore, it requires social skills (namely participation, perspective taking, and the generation of social capital) and cognitive skills (namely project management and knowledge building) during the learning, modeling, and resolving steps of unsustainability problem solving [29] (Table 4).

Table 4. Social and cognitive skills involved in unsustainability resolution for educators and learners in higher education.

Process and Tasks	Social Skills	What Unsustainability Problem Solving Entails	Cognitive Skills
1. Define purpose 2. Deliberate the literature on your own system (analysis of main dimensions breakdown). 3. Deliberate the literature on similar system case studies.	participation (action; interaction/sharing/feedback; task completion; perseverance; internal motivation)	learning [schem[a] a expansion]	project management (task regulation; goal setting; resource management; division of labor; flexibility and ambiguity; (big) data and information search, collection, and verification; systematicity; organization; synchronicity/coordination; strategization and prioritization; progress monitoring; duration and time allocation)
4. Apply basic system analysis tools for the deliberate simplification of reality (customized synthesis). 5. Obtain and use data to calibrate and validate your system model.	perspective taking (adaptive responsiveness; audience awareness; argue and justify)	reduction of complexity [quantitative multidisciplinary dynamic modeling]	
6. Define the current system state. 7. Determine and define the future system state (goal/s). 8. Try out system levers (develop alternative (re) solutions/scenarios). 9. Chose a favorable (re) solution among alternatives.	social capital [b] (negotiation; employ values and criteria; conflict resolution; self-evaluation; empathy; transactive memory; responsibility; initiative; alignment of all perspectives/objectives; positive interdependence/bonding/trusting; recognition and attribution; decision making; transcendence above all work)	decision making [chose among alternative (re) solutions on how to transition from current to future system state]	knowledge building (modeling/reduction of complexity; (new) relationships; contingencies; higher cognition (analytic, creative, critical/evaluation, decision making); analysis and inference: hypotheses testing (deductive thinking) and scenarios development (inductive thinking); introduction of new ideas; operationalization of concepts and ideas; assumptions; higher cognition (meta-analytic, meta-cognitive, transcendence above all work)
10. Implement a favorable (re) solution.		implementation [strategy–program–project]	
11. Evaluate the outcome and impact of the favorable (re) solution implemented.		evaluation [feedback]	

Sources: enriched [78]; [a] as explicated in [79,80]; [b] with precautions of [81].

The development of mastery requires the comparison and contrast of many case studies with the same unsustainability problem (contextual diversity) and project-based learning with specific case/s (Figure 2). What is compared among the similar case studies are drivers, causes, impacts, the quality of any interventions, and any associated system models available including system dynamics models. All the skills in sustainability competency are exemplified in the use of problem- and project-based learning. Problem- and project-based learning works better than unguided instruction; works for all learners with a greater positive effect on under-performing students; and is more suitable and beneficial for deeper learning and knowledge retention, which are primarily attributed to scaffolding and cooperation [22,23,82,83]. It produced better solutions to problems than individuals working in competitive environments or when self-directing individually their learning, and it developed deeper learning, provided that a large enough knowledge base was already developed but did not result in an increase in individual academic achievement as this is measured in standardized exams (in [22]). Evidence suggests that individuals within groups go beyond their predicted potential when there are present features, such as the creation of common ground between group members, tasks that benefit from multiple perspectives, and shared task-relevant information [22,84,85]. What it takes for problem-based learning to work is an expert tutor, explicit instruction in the skills of problem solving, and mutual dependence in small groups. Group members develop mutual dependence not only when they are of complementary perspectives/disciplines but also when there is no risk of being expelled from, or group members defecting from, collaboration. Designing thoroughly and for real-world projects that have already completed their life cycles helps avoid the risks of diverted attention and no commitment and of bumping into "extremely asymmetric cases of power distribution" [86]. Thorough design for real-world projects is also highly amenable to the most influential teacher-related tools in class, namely micro-teaching, comprehensive interventions, and clarity [87]. Problem- and project-based learning have the potential to transform core content foundations and competencies into individual, purposeful, and effective creativity (e.g., [88]) because the history and context are unique in each real-life project/case. For example, the algal blooms of the Great Lakes are attributed to the atmospheric deposition of nitrogen from the internal combustion of fossil fuels, while the algal blooms of Hong Kong are attributed to aquacultural fertilization. Collaboration and innovation are two of the four generic academic competencies of the 21st century, along with communication and critical thinking [29,89–91]. The sustainability skills currently required by the private sector include establishing the value of sustainability; building support; holistic and strategic planning; systems thinking; project management; communication with stakeholders; problem solving; inspiring and motivating others; and leading for action [92]. Feedback through assessment promotes learner's self-regulation when it is made clear to the learner what excellent performance is, how and how much the learner's performance deviates from excellent performance, and which are the available ways to fill in the learning gaps [93]. In addition, learner's meta-cognition is positively correlated with adult learner's critical thinking [94,95]. These require that educators provide or/and demonstrate exemplars of behaviors, skills, and projects and employ rubrics in assessment. I am not aware of how many thoroughly prepared problem/project-learning "assignments" a learner may need to develop mastery. I know, however, that essay mastery, even for its easiest type, the expository type of essay, requires writing more than one essay of that type. Projects that directly affect learners, e.g., the watershed they live in, and projects that ask learners to help people (pro-sociality) or species (biophilia) outside their interacting environment because these people/species desperately need it, e.g., anti-pollution/endangered species solutions, may enhance stimulation.

There are two concerns regarding problem- and project-based learning that need more attention before becoming fully accommodated. The first involves the attribution and copyright of creative work produced during the collaboration. The second involves the sources of bias from data veracity through process manipulation to the domain appropriateness of unsustainability resolutions.

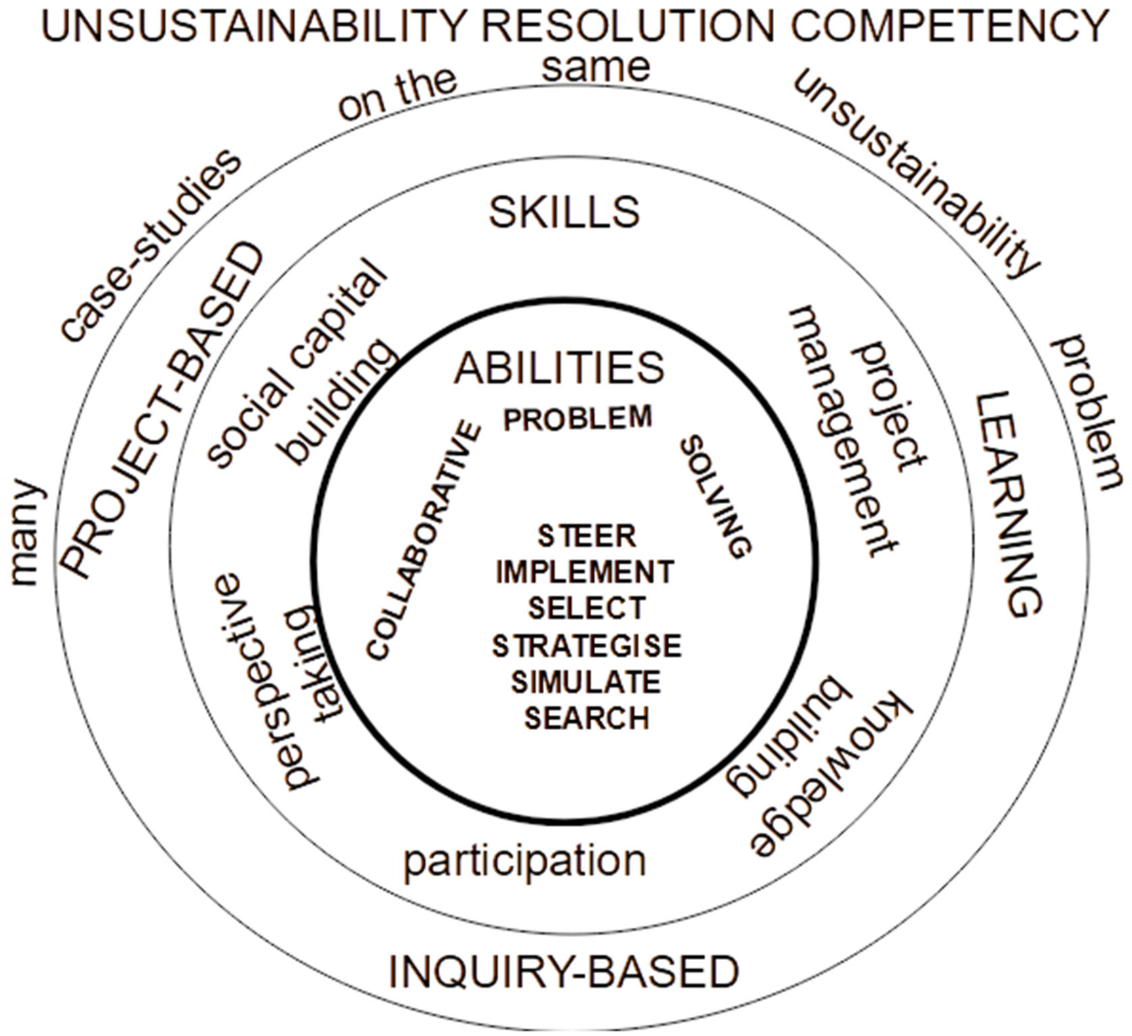


Figure 2. Unsustainability resolution competency requires familiarization with contextual diversity, using many cases of the same unsustainability problem and inquiry using specific project/s to develop social and cognitive skills and resolution abilities.

3.4. Learning Objectives

In programmed instruction settings (formal education), competence in any subject and topic is demonstrated through the hierarchically cumulative abilities to remember, understand, apply, analyze, create, and evaluate factual, conceptual, procedural, and meta-cognitive knowledge [96]. The progression from the lowest in complexity ability to remember toward the highest in complexity ability to evaluate denotes an increase in consciousness and the depth of knowledge. Learning objectives are accomplished with behavioral, cognitive, and constructivist instructional strategies [28]. The behavioral instructional strategy involves teaching practices and tools, such as sequencing toward increasing difficulty, direct and scaffolding instruction, hierarchically ordered task analyses, criterion-referenced assessment, and reinforcement. They dominate the “remember” and “understand” abilities. The cognitive instructional strategy involves teaching practices and tools, such as self-planning, self-monitoring, revising, cognitive task analysis procedures, the use of cognitive strategies, such as (inductive and deductive) reasoning, outlining, summarizing, synthesizing, and advanced organization, the recall of prerequisite skills, the use of relevant examples and analogies, and active learning, such as problem- and project-based learning. They dominate the “apply” and “analyze” abilities. The constructivist strategy involves teaching practices and tools, such as anchoring learning in meaningful contexts/cases, the active use of what is learned, revisiting content at different times in rearranged contexts for different purposes and from different conceptual perspectives, developing pattern-recognition skills, presenting alternative ways of representing problems, and presenting new problems and situations/cases that differ from the conditions of the initial instruction. They dominate the "create" and "evaluate" abilities.

The hierarchically cumulative abilities toward unsustainability resolution competence are as follows: source/obtain data and information about the human–nature system (SEARCH); simplify and simulate the human–nature system (SIMULATE); generate and test alternative paths for the human–nature system (STRATEGIZE); choose a favorable path among the available alternatives (SELECT); operationalize the favorable path into a plan (strategy–program–project) (IMPLEMENT); and monitor the implementation of the plan (STEER) (Figure 2). For each one of the unsustainability resolution competence abilities, namely SEARCH, SIMULATE, STRATEGIZE, SELECT, IMPLEMENT, and STEER, the Bloom's ladder of remember–understand–apply–analyze–create–evaluate abilities with a progressively greater emphasis from behaviorist through cognitivist to constructivist tools applies to achieve mastery.

The learning objective "SEARCH" involves knowledge about data- and info-bases, the tools and techniques for searching, finding, retrieving, and mining (numeric) data sets, text records (articles, reports, plans, and laws), animations, and maps, and for evaluating the veracity of the new data and information obtained, learning and practicing on types, locations, organizational schemata, period coverages, the use of operators, and keywords, downloading and saving in usable formats, and evaluating the veracity of the data and information obtained.

The learning objective "SIMULATE" involves knowledge about systems, as well as the tools and techniques for the reduction of their complexity and the modeling of their dynamics. It involves the delineation of spatial and temporal scales and the boundaries of the coupled human–nature system; the filtering of the available data and information for relevance; the depiction of the structure and function of the system, causal loop diagrams and/or acrylic graphs, and behavior over time graphs; and quantitative model building, namely parameterization, units of variables correspondence, and model calibration, validation, and sensitivity.

The learning objective "STRATEGIZE" involves knowledge as well as the tools and techniques to generate strategies. The learner practices by applying "what if" interventions at different leverage points in the system to gain insights on how the system responds; verifying assumptions and realizing constraints; and generating alternative paths from bundles of interventions, that delineate different trajectories, toward different system endpoints.

The learning objective "SELECT" involves knowledge as well as the tools and techniques for decision making. The learner practices the ladder of inference, the compass, and a suitable multiple-objective and multiple-attribute method to choose the most favorable path among the alternatives.

The learning objective "IMPLEMENT" involves knowledge as well as tools and techniques for operationalization. The learner practices how to translate the simulated favorable path into congruent policy and management objectives through Strategy–Programs–Projects.

The learning objective "STEER" involves knowledge as well as tools and techniques for monitoring and adjusting the implementation of the plan. The learner practices how to develop criteria and indicators to evaluate the difference between the expected and the actual results during the implementation of the plan and steer the navigation of the system accordingly.

The pedagogy proposed is generic, of interest, and applicable to all the academic disciplines and professionals involved in sustainability. It enables both the appraisal of past sustainability (re) solutions (policies), which is more relevant to educational settings, and the planning of future sustainability (re) solutions (policies), which is more relevant to professional practice and policy settings.

3.5. Venues and Avenues

Environmental Science is probably closer to adopting sustainability competency compared to all the other academic disciplines because it delivers multidisciplinary curricula that integrate the ecological, social, and economic dimensions of environmental systems. The graduates of Environmental Science may become excellent facilitators of the sustainability resolution process because they can communicate and exchange with experts from complementary perspectives/disciplines. The graduates of Sustainability Science, however, develop the competency of unsustainability resolution and therefore can lead the unsustainability resolution process. In either case, classes are homogeneous, i.e., classes represent a low complementarity of perspectives among learners compared to the heterogeneous collaborators of real-life unsustainability. For example, employees from different departments of different ministries working together to restore depleted fishery stocks; different stakeholders working on a local co-management initiative to enhance land biodiversity; and UN representatives working on the resolution of a multinational water conflict. The "ridge-to-reef", e.g., [97], and the ecosystem-based management [98] approaches to natural resources management are exemplars for collaborative problem-solving, because they require the active participation of diverse stakeholders involved within spatially explicit settings. Class homogeneity in higher education may be replaced with mocked "perspective taking" by splitting the class into distinct perspectives. The alternative to embedding classes of learners into real-life cases with ongoing unsustainability carries the risk of protraction further from the designated time to master the competency within academic semesters, even under the favorable condition of stakeholders being willing and ready to resolve the unsustainability. Other differences regarding groups working collaboratively to develop the competency of resolving unsustainability involve the relative importance of cooperation versus competition; the relative importance of dependence (directed process) versus autonomy (self-organization process); the relative importance of the assimilation of existing knowledge versus the production of new knowledge; and who (educator, peers, authority, or those affected by the created solution when this is implemented) evaluates what (learning, process, or outcome/solution). All the combinations of the aforementioned conditions can be designed.

For domain-specific integrated curricula or/and professional degrees on sustainability competency, e.g., sustainable agriculture, we may need to invest on cross-faculty (natural sciences and social sciences) collaborations. After all, the formation of interdisciplinary collaborations is available in infrastructure development and urban/regional planning. Just like a construction company that first creates a miniature model and then assembles a variety of expertise to build a house that the owner likes, so too higher academic institutions/organizations can assemble the variety of expertise needed to develop and implement interacting unsustainability resolution strategies, programs, and plans for the different domains of sustainability or even regions, e.g., coastal zone planning. Interdisciplinary faculty collaborations are needed to develop such learning and deliver such competence in domains of the trans-disciplinary Sustainability Science; academic institutions, connectivity, and funding enable them [99]. Just like university basketball teams assemble from different departments and faculties to compete with other universities, so too sustainability teams assembled from different disciplines may compete among universities for the (academically) best resolution of the same unsustainability during an annual Sustainability Olympics tournament. In essence, the proposed pedagogy extends a call to all disciplines to contribute their expertise in Sustainability Science for sustainability competency, rather than expecting Sustainability Science first to mature enough before it can impact all disciplines/domains.

3.6. Examples of Modules for Sustainability Competence

A generic module on sustainability may include a schema/conceptual map of the key concepts of sustainability [37], systems thinking [50,54,55], coupled nature–human systems with ecologic, economic, and social dimensions [100], and panarchy [40,45,101]. This schema expands with key terms, such as ecosystem goods and services, human well-being, natural capital, biocapacity, carrying capacity, assimilative capacity, great acceleration, ecological footprint and deficit/dept; iceberg, causal feedback loop diagram, stock and flow map, the ladder of inference, behavior over time graph, connection cycle, the compass, randomness, complexity, self-organization, resilience, emergence, heterarchy, adaptive capacity, tipping point, regime shift, transformation, global change, unintended consequences, growth–conservation–release–re-organization phases, cross-scale interactions, inefficient system structures, deliberate navigation, leverage points, transition, heterogeneity, asymmetry, and syndrome. The assignment of scientific readings scaffolds for the learners how to dissect, evaluate the quality of, and respond to new knowledge arising from the synthesis of answers provided in the scientific readings through constructive in-class discussions and is evaluated with a rubric known to learners. The EcoTipping Points Project database [102] provides successful examples/cases of the reversal of undesired systems' states and trajectories, whereas the regime shifts database [103] provides examples of undesired systems' states and trajectories; cases may be compared and contrasted against criteria that relate to context, root causes, feedback loops, the system lever of interventions, inefficient system structures, and system states. A project to appraise the sustainability of the world system using the World 3 system dynamics model [104,105] may scaffold the procedural knowledge required on how to develop and use system dynamics modeling to understand, to generate solutions, and to intervene into a system; the assessment rubric focuses, among others, on those attributes that ensure validity in induction or confidence tests. A capstone writing assignment on the sustainability problem, such as an expository essay with an associated rubric, enables the learner's reflection and meta-cognition on the whole module in conjunction with the development of purposeful writing skills.

A domain-specific module on water sustainability may include a schema of the key concepts, such as the hydrologic cycle, hydrologic budget, (spatial, temporal, and water quality) heterogeneity, basin–catchment–watershed units, water allocation, water quality standards, and ecology–management–policy scale matching [106–112]. This schema expands with key terms, such as hydrologic processes; blue, green, grey, black, virtual water; conjunctive, integrated, consumptive, non-consumptive, in stream, out of stream water uses; the point and non-point sources of water pollution; primary, secondary and tertiary water treatment; rights, benefits, obligations, duties, liabilities, and costs in water allocation; water management using strategy, program, project implementation; flooding, drought, and desertification problems; water consumption measurement schemes; water pricing schemes; the total value of water; water use efficiency; water resources development. The assignment of scientific readings scaffolds for the learner's collaborative inductive reasoning by systematically comparing and contrasting the available published case studies of water systems simulated with system dynamics modeling. Learners compare the models' assumptions, constraints, purposes, goals, components, feedback loops, and leverage points among the different case studies. The recurrent and most frequent water system problems are regional planning and river basin planning, urban expansion and water resources management, flooding, irrigation for agricultural development, and water quality/pollution [88,113]. A collaborative project to simulate the anticipated impact of climate change on the sustainability of a real-life water system using a decision support system with system dynamics modeling capabilities (e.g., mDSS [56], WaterWare [57]) is scaffolded by the educator and evaluated with a rubric. The capstone writing assignment is a strategic plan document for the real-life water system of the aforementioned collaborative project (drivers, current system state, future system state, and strategy implementation) that enables learners to apply, integrate, revise, and reflect on all the concepts and tools used in the module.

4. Discussion

4.1. Is It Necessary to Operationalize Sustainability?

The proposed pedagogy overcomes the current problem of different collaborators having different conceptualizations of sustainability. Flint [37] presents alternative representations of the economic, social, and ecologic dimensions/perspectives of a coupled human–natural system: independent, interacting, complementary, or embedded. The proof regarding which conceptualization of sustainability is correct lies within the successful case studies of unsustainability resolution and not within a consensus about what we should all agree to adopt/believe as *the* conceptualization of sustainability before we start or continue working together. The EcoTipping Points Project [102] provides over 100 successful cases of the reversal of unsustainability and can provide "data points" to test the "fit" of each one of the sustainability conceptualizations provided in Flint [37]. The use of a system dynamics approach protects against misconceptions or *a priori* assumptions regarding the operationalization of sustainability. This is because building the model based on an assumption, which is a misconception, will not provide a satisfactory fit of the model to the data, and, for this reason, the misconception will be abandoned. In system dynamics modeling, sustainability is neither a goal nor a stock; it is a state of the coupled human–nature system when its goals are not in conflict.

4.2. What Are Some Focal Points for Instruction in System Dynamics Modeling?

After contrasting Forrester's exemplars in system dynamics modeling with non-Forrester-associated published endeavors using this highly sophisticated, data-intensive, and inductive tool, the following focal points for instruction in system dynamics modeling emerged:

(a) The importance of the spatial and temporal scales of the simulated human–nature system: natural vs management vs political boundaries; the inclusion of all (actual and potential) sources and sinks of energy, people, materials, pollutants, finance, etc.; the time the system has been developing vs the time that the intended intervention will be applied for vs the time needed for the system to reach the new endpoint; and the phase of the panarchy cycle the system is in.

(b) The determination of subsystems as main components: all different system perspectives, their goals, and their relationships (e.g., consequential, embedded, aligned, and independent) are included; the available formal and informal accounts/records/information/data on the development and the evolution of the system are filtered for veracity, importance, and relevance for purpose; the assumptions made and the constraints of the system are identified and clearly stated.

(c) The development of a stocks and flows diagram of the simulated system: the most important stocks (quantities) and flows (connections) in the system; the input and output processes that determine the size of the stocks; and the determinants of the rates of the input and output processes are identified.

(d) The development of a causal loop diagram of the simulated system: the reciprocal causal relationships or else the feedback loops or the self-regulating mechanisms are identified and their relative strength is deciphered.

(e) To populate the simulation with data, time series data of variables are scale- and purpose-appropriate; the units of all the variables match; the gaps, inconsistencies, and contradictions within and between the data sets are identified; the shape of the relationships between the variables emanates when using their full range: the length of the time series of the data used compared to the lifetime of the system, the duration of the intervention, the duration of the effects due to intervention or/and the projection time into the future, and the data selected to calibrate vs the data selected to validate the simulation.

(f) To gain insights into the system from the simulation, the simulation represents reality well, is adequate for purpose and is parsimonious, i.e., it is as complex as necessary but not more complex; produces logical results that do not contradict the assumptions, definitions, and limitations and are domain-appropriate; and has passed all the tests that build confidence in its use. When you simulate the "no intervention alternative" for as long as you are interested in the future, does the system exhibit behavior that indicates a structural inefficiency or else develop any systemic problem?

(g) To improve the performance of the system with the simulation, try intervening at leverage points of different strengths and observe how they affect what you are directly interested in (expected effect) and what you may not be interested in (unplanned for/unexpected effect). What is the importance of time, i.e., of rate, frequency, and duration, regarding the interventions at system levers? If the system presents a problem that corresponds to a specific lever, what happens if you intervene at a lever below (weaker than) or above (stronger than) the problem's lever? If you apply a specific intervention to improve one of the goals of your system, how are all the other goals are going to be affected? If you define a new set of aligned goals, that in tandem define a new endpoint for your system in the future, which system levers do you need to intervene in? If you set a future endpoint for the system, does the system seem to reach it with your leverage interventions? If you are set to resolve a system's problem, how many distinct strategies or bundles of interventions on system levers or pathways/trajectories toward the future do you identify? Which one of these strategies resolves the problem without creating a new problem somewhere else and without unintended consequences?

A competence development framework for learning and teaching system dynamics modeling is available [114].

4.3. What Is the Relationship between Bloom's Taxonomy of Abilities and 21st-Century Skills?

The original, empirical, generic Bloom's taxonomy of cumulative, progressively more complex abilities, namely knowledge, comprehension, application, analysis, synthesis, and evaluation, has been used for half a century to track the progress of a learning process aiming at competency and to align curriculum content, learning objectives, and assessment, regardless of discipline; it has been revised into the abilities to remember, understand, apply, analyze, evaluate, and create [96]. The 21st-century skills initiative in higher education promotes critical thinking, communication, collaboration, and innovation generic skills, regardless of discipline [29]. It is not a taxonomy of hierarchically cumulative abilities as Bloom's taxonomy is. It is driven by the contemporary exponential increase in data and information in all disciplines, the emergence of cyberinfrastructure [115] and the complexity of common/global problems to match the rate of global planetary change with the rate of our responses, locally and globally, to this change. The mastery of each one of the 21st-century skills relies on Bloom's taxonomy. Unsustainability resolution competency draws from all three domains of Bloom's taxonomy: the cognitive (cognitive skills), the affective (social skills), and the psychomotorical (computer-based modeling skills).

4.4. What Is the Organisational Structure for the Collaborative Problem-Solving Process?

The organizational structure to undertake collaborative unsustainability resolution of a complex human–nature system, that learners in higher education or professionals in their jobs will emulate, is described as an organizational matrix [41] or a referent organization [116] or an alignment of all stars [117] and is found to spontaneously emerge under the conditions of crisis/emergency, such as fire fighting and earthquake responses, a dissatisfaction with the current state of affairs, tradition keeping, and exogenous powerful demands, such as a legal mandate or an educator or a developer/client. It has been recommended to stabilize hyper-turbulent environments, govern common resources, and develop efficient inter-disciplinary and multi-agency outcomes. Yet, it is an ephemeral organizational structure that needs to deliver its outcome during an always narrow "window of opportunity" to align problems, solutions, and interests [61], just like learners in higher education will have to deliver within a semester or two either justified future or evaluated past interventions in real-world, coupled human–nature systems. Similarly, the window of opportunity to steer the trajectory of our common future is also narrow [118]. Using the pedagogy proposed, which streamlines pertinent advanced contributions from different disciplines and fields, sustainability-ready and competent professionals will be able to resolve unsustainability in coupled human–nature systems, contributing to the timely transformation away from limits and toward advancement.

5. Conclusions

The competency to resolve unsustainability was developed for higher education by honing generic and successful initiatives, such as schema and panarchy theories, the Bloom's taxonomy, system dynamics and simulation, problem- and project-based learning, and big data analytics, to re-steer, strengthen, and speed up our response to the global directional forcing against planetary boundaries.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: There was no data used or generated in this study other than the references cited.

Conflicts of Interest: The author declares no conflicts of interest.

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