بسم الله الرحمن الرحيم

The Integration of knowledge Thesis: Epistemological Foundation

Professor MH Biraima

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General Systems Transdisciplinarity as A Strategy for Integration Of knowledge

1- Introduction

"Although a true unity of knowledge might be an unattainable goal, an increasing consilience of knowledge is not out of the question. One possible route to such consilience is offered by the vision of a general theory of systems. If everything in the world is a system or part of one, then general systems knowledge would not only be of transdisciplinary relevance, but afford deep insights about the interconnectedness of everything, and readily reveal to us important insights that cannot easily be seen from any specialized point of view…. Increasingly, knowledge of systems is seen as presenting a paradigm for addressing complex problems, that is, those involving phenomena that cannot be adequately modelle dusing the classically powerful approaches based on reductionism and linear causal mechanism. Additionally, it is ever more valued for its potential to support transdisciplinarity, i.e., the principles and models that characterise aspects of systemicity can be applied in multiple disciplines. The systems perspective is progressively seen as both necessary for understanding the complexity of the world in general, and as useful to researchers in a multitude of specialised fields" (David Rosseau et al).

"Systems researchers have in recent years proposed the term "Systemology" to refer to the organized body of knowledge about systems, and "General Systemology" to refer to the subset of systemology that represents the organized body of knowledge about the inherent nature of all systems, that is to say about what is essential to or universally true about systems. General systemology is thus especially concerned with those attributes that confer "systemhood" or "systemness" or "systemicity" on things that we recognize as systems, and how the combination of these universal attributes gives rise to the behaviours we see in specialized kinds of systems. Thus, [in principle] there exist models, principles and laws that apply to generalized systems, or their subclasses, irrespective of their particular kind, or the nature of their component elements, and the relations or "forces" between them. It seems legitimate to ask for a theory, not of systems of a more or less special kind, but of universal principles applying to systems in general. In this way we come to postulate a new discipline, called General System Theory. Its subject matter is the formulation and derivation of those principles which are valid for "systems" in general" (Rousseau et al).

- Another way of stating the above is through the following postulates:

1. Everything, whether concrete or abstract, is a system or an actual or potential component of a system;

2. systems have systemic (emergent) features that their components lack, whence

3. all problems should be approached in a systemic rather than in a sectoral fashion;

4. all ideas should be put together into systems (theories); and

5. the testing of anything, whether idea or artifact, assumes the validity of other items, which are taken as benchmarks, at least for the time being.

- Every system is investigated by studying its components, structure, environment, and mechanisms.

2- The Rationale for Adopting General Systemology as a Strategy for Islamic Integration of Knowledge (IIOK)

- I have chosen to suggest General Systems Transdisciplinarity (GSTD) as a methodological framework to develop a strategy for IIOK for many reasons:

Firstly, it is a live scientific research program for the integration of knowledge in Western academia and in many parts of the world, led by leading Western scholars across the spectrum of natural, social, and human sciences, and situated in leading Western universities and specialized research centers. As such it represents the efforts for scientific reform by those who are at the frontier of scientific knowledge and technology which define the globalized civilization of today.

Secondly, by conducting IIOK within the framework of GSTD we ensure that we are on a par with the scientific efforts of the world and the input of IIOK should be a valuable contribution and a welcome addition to these efforts.

Thirdly, IIOK project will benefit from the most mature methodology and methods available for integration of knowledge**.**

Fourthly, since the goals of GSTD, defined above, are almost the same goals of IIOK this should provide an opportunity to universalize the IIOK project such that non- Muslim scholars could join the efforts and assimilate the project within the global efforts to integrate knowledge, thus making available extra human and financial resources needed to advance the IIOK.

Fifthly, once internationalized the present scholars advocating IIOK must raise the rigor of their academic skills to international standards, a standard sadly lacking in most of today's academic products of the project.

Sixthly, it is high time to move from the presently fragmented efforts of the scholars working on IIOK to a more concrete, coherent and methodologically well-defined scientific research program sanctioned by the international scientific community. Making such a strategic step will pool together and integrate the meagre scholarly resources currently involved in the project. This may result into a rapid and fruitful developments in discoveries of the scientific treasures of Revelation.

Seventhly, by making IIOK a rigorous scientific research program, well situated within an international scientific ambarella, the chances of attracting more competent Muslim scholars to it will increase as well as draw the attention and get respect from academic circles and institutions in the Muslim world, who are currently very skeptical about the endeavor.

Eighthly, the GSTD strategy that will be summarized below shows clearly where the Islamic dimension can make a decisive difference in the whole enterprise of systemic integration of knowledge; i.e., via the "Guiding Framework".

Ninthly, since the utility of any science in real life situations is an integral part of any viable discipline these days, particularly in the systems field, then integrating the Islamic dimension in the overall systems framework will make real life practices an integral part of the development of any special hybrid sciences that may spring out of IIOK in the future. Usefulness is an Islamically required virtue of any knowledge, otherwise it will be classified as an undesirable knowledge.

- What follows is a summary of the book "*General Systemology: Transdisciplinarity for Discovery, Insight and Innovation*" by Rousseau et al (2018).

3- An Overview of the Strategy for General Systems Transdisciplinarity

- A core claim under the systems perspective is that everything we encounter is a system or part of one. If this is true then ‘being a system’, i.e., having the attribute we might call ‘systemness’ or ‘systemhood’, or being something that is ‘systemic’, is a matter of considerable significance. But what is that significance? The full meaning of the term ‘system’ is not settled yet, but the term ‘system’ appears to be used somewhat like how we use the term ‘energy’, a general term for the something we can only know through specific instances. And just as coming to understand the nature of energy transformed our understanding of how specific things work and what particular kinds of change are possible, so too, perhaps, will understanding the nature of systems transform our understanding of the world as a grand scheme, and transform our understanding of our place and our potential within that scheme.

- Researchers have in recent years proposed the term “Systemology” to refer to the organized body of knowledge about systems, and “General Systemology” to refer to the subset of systemology that represents the organised body of knowledge about the inherent nature of all systems, that is to say about what is essential to or universally true about systems. General systemology is thus especially concerned with those attributes that confer “systemhood” or “systemness” or “systemicity” on things that we recognize as systems, and how the combination of these universal attributes gives rise to the behaviours we see in specialized kinds of systems.

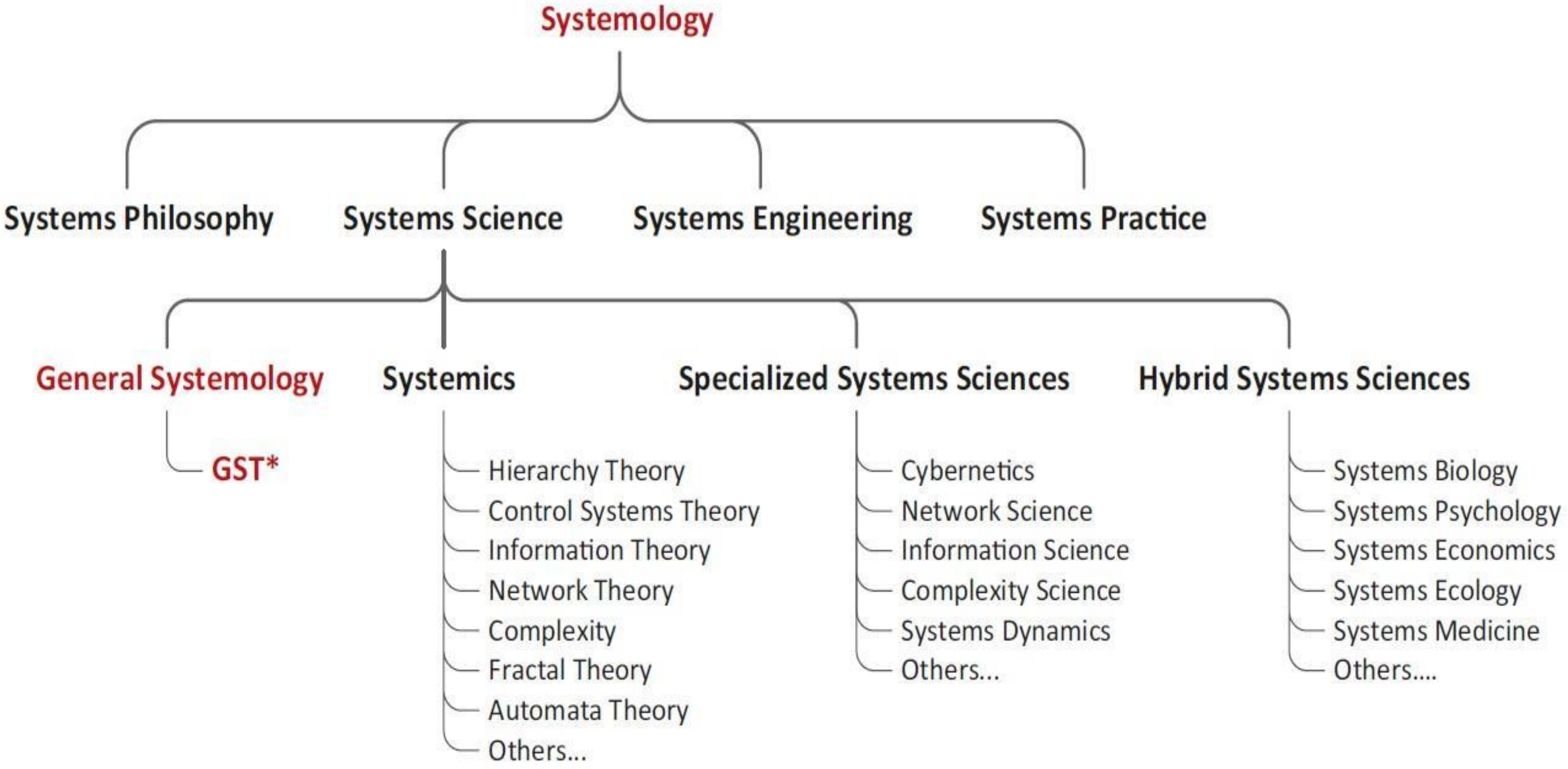
- General systemology is still in the early stages of its development, but like any other scientific discipline its scope would develop to include concepts, principles, theories, methods and practices, and hence be more than just a theory (or group of theories). The central theory of general systemology would be, the one that explains the nature of systems.
- Systemology, in the sense just defined, is a broad field, and encompasses systems philosophy, systems science, systems engineering and systems practice. As will be explained later on, 'systems science' encompasses the discipline of general systemology (which includes the general theory about the nature of systems (GST*)), various specialised systems sciences (for example cybernetics, network science, information science, complexity science), and the hybrid systems sciences (which includes the disciplines dealing with the systemic aspects of specialised subject interests, for example systems biology, systems psychology etc.).

- The specialized systems sciences are grounded in a range of specialised systems theories collectively known as the “Systemics” (representing the collection of specialised theories dealing with particular aspects of systemic behaviour, for example hierarchy theory, control systems theory, automata theory, etc.). The basic distinctions just enumerated are illustrated in Fig. 1 below.

3.1- Potential Significance of General Systemology

- The systems field is not yet unified because we are still lacking a general theory of systems. The existence, in principle, of a general systems theory (GST*) was first suggested about a hundred years ago, but the quest for establishing it only took hold in the West after the middle of the last century, and this was largely due to the work and advocacy of Ludwig von Bertalanffy, who is now widely regarded as the founder of the “general systems movement”.

Fig.1- Systemology Field



- The founders believed that a GST* would support interdisciplinary communication and cooperation, facilitate scientific discoveries in disciplines that lack exact theories, promote the unity of knowledge, and help to bridge the divide between the naturalistic and the human sciences. The pioneers of general systems research saw this as a strategy and action plan for averting immanent social and environmental crises, and for opening up a pathway towards a sustainable and humane future. However, despite significant advances in the specialized systems sciences ("Systemics") the ambition to develop a GST* and leverage it for human and ecological benefit remains largely unfulfilled.

3.2- Developing a Scientific Theory About the Nature of Systems

- Making progress towards a more complete general theory of systems is crucial for the academic unity, credibility and advancement of the systems field. As discussed above, this means moving towards having scientific models that can reconcile the different perspectives on the nature of ‘system’ in a compelling manner. To support such a scientific unity the subject matter must be defined in terms of a theoretical framework that has explanatory and/or predictive value. Such a scientific general theory provides a conceptual and explanatory foundation on the basis of which the discipline or field can grow as a scientific endeavor of increasing epistemic and empirical competence.

- In the life of a discipline or field the transition from viewing its subject matter merely in terms of descriptive models and theories to being able to represent it in terms of explanatory/predictive theories is of crucial significance. It is well known from the history of science that general theories such as Newton’s Laws of Mechanics, Mendeleev’s Periodic Table of the Chemical Elements, Lyell’s Principles of Geology, and Darwin’s Theory of Biological Evolution, transformed their respective disciplinary fields by (a) unifying hitherto fragmented areas of study under a common conceptual and explanatory framework, and (b) rapidly opening up new avenues to scientific discovery.

- In the case of the systems domain, the sought-for scientifically-unifying theory would be the “General Systems Theory” (GST*) as originally envisioned by Ludwigvon Bertalanffy. Von Bertalanffy proposed that structures and behaviors that recur isomorphically across kinds of systems indicated the existence of general systems principles that would underpin the formulation of general systems laws that could be applied in diverse disciplines for problem solving, modelling, and design. The key advances toward a GST* seem mostly to have been made long ago, and general systems research has been a minority endeavor for the last 30 years. In reality, it was the practical offshoots of theories about individual isomorphies that took precedence, resulting in advances in Information Theory, Cybernetics, Organization Theory, Control Theory, Management Science, and so on. This pragmatic focus produced progress at a high cost, for “it left these theories together with the possibility of a “GST” philosophically immature”.

- The systems field cannot become an established academic discipline without developing a unifying framework grounded in a general theory of systems. Such a unifying framework for the systems field exists in principle and that its development is a practical prospect. Such a unifying framework would support the development of powerful and useful systemic methodologies for discovery, insight, innovation, intervention, management, control and engineering in all branches of science. To develop a general systems theory (GST*) the following questions need to be addressed:
  - What is "GST*"?
  - How might it fit into the "systems field"?
  - What would it look like?

- Does it exist in principle? Under what perspective(s)?
- How might we discover/develop it?
- What might its potential be? Would it have any distinctive powers?
- How can we support progress towards establishing it?
- What can we discover if we take on board recent developments in science and the philosophy of science and apply this to what we know about systems?

❖ Progress towards establishing a valuable and competent General Systemology can be made by focusing on the development of:

1- a **General Systems Worldview** (**GSW**) that is informed by our best scientific knowledge, by new discoveries in systems science, by advances in general systems
research, and by the debate about the unity of science and the plurality of perspectives employed in systems thinking and practice.

2- a **General Systems Theory** (**GST***) that includes:

• an ontology of systems that can be used to describe systems and classify them in an unambiguous way;

• models that characterize the conditions and processes that support the evolution, persistence or degradation of systems; and

• principles and theories that explain the mechanisms that underpin the evolution persistence or degradation of systems.

3- General Systems Methodologies (**GSMs**) that can leverage GST* under the guidance of the GSW to:

- extend and refine GST*, the GSW and the methods of General Systemology;
- discover new Theoretical Systemics, i.e. specialised theories about kinds of systemic structures, processes, behaviours, etc., or enhance existing ones;
- discover new Methodological Systemics, i.e. specialised methods for systemic research, design, engineering, management, education etc., or enhance existing ones; and
- support exploratory science in all areas of scientific inquiry.

4- General Systems Transdisciplinarity (**GSTD**) that employs the GSMs to address the looming and present crises facing human civilization; and to contribute to the building of a thriving future world.

4- A Disciplinary Field Model for Systemology

4.1- A Generic Model of a Discipline

- The most urgent issue to be resolved in addressing the academic challenges of the systems domain was to resolve the basic terminological ambiguities in referring to the field and its components, so that a clear strategy can be formulated for dealing with the field’s scientific challenges. This can be achieved in a systematic way by mapping the components of the field onto the structure of an academic discipline.

4.1.1- A Systems Model of Discipline

- Any disciplinarians' worldview motivates and constrains the focus of their actions, and determines the meanings they ascribe to their data, theories, methods and outcomes. From this perspective we can see that a discipline is really a kind of system, comprising *a form of action* conditioned by *a worldview* and expressing *a body of knowledge* centered on some area of interest. The evolving body of knowledge belonging to a discipline not only *informs* its worldview but derives its *meaning* from the discipline's worldview.

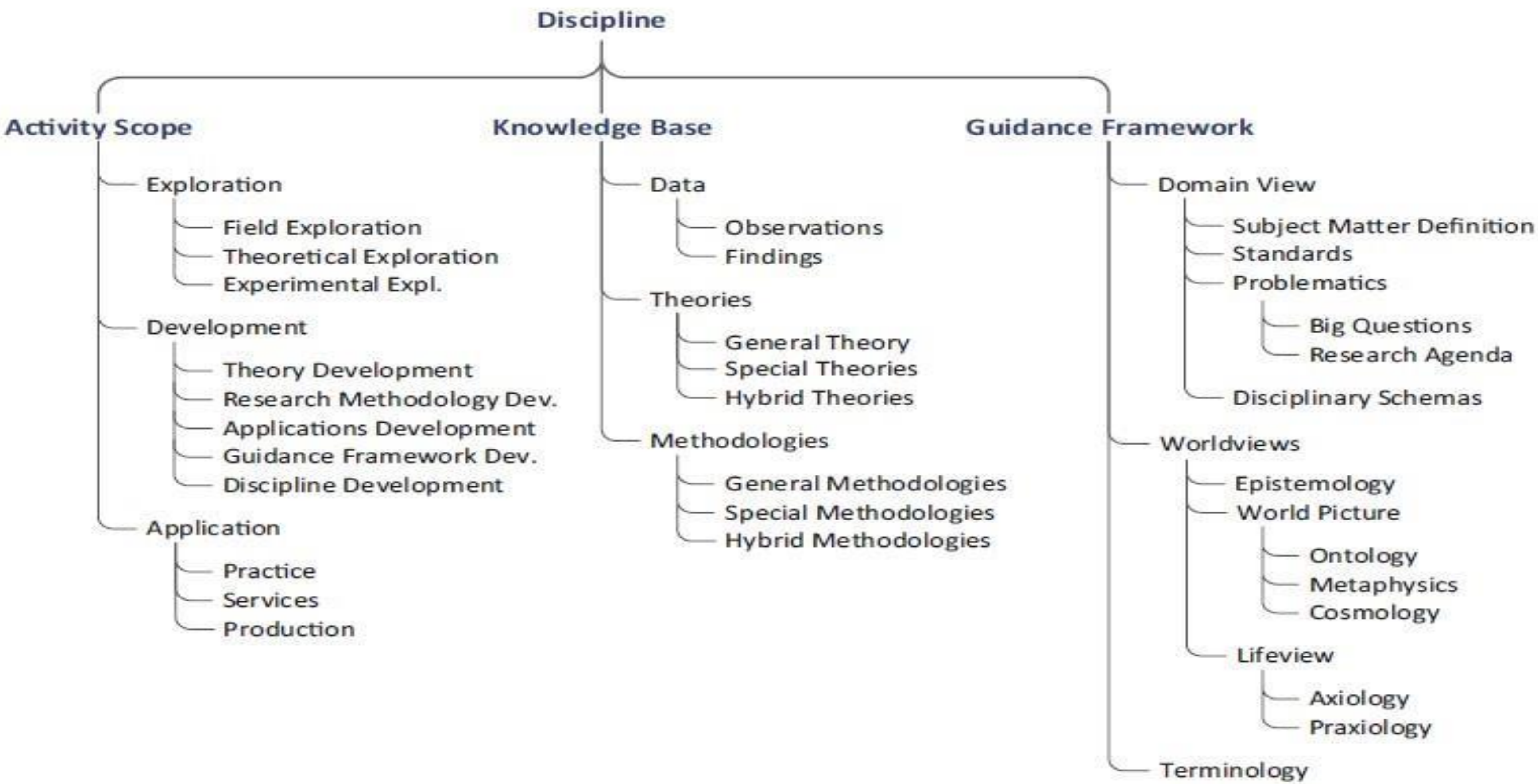
- In this light we propose that a discipline can be modelled as a system comprising an “activity scope” that is enabled by a “knowledge base” but conditioned by a “guidance framework”, as shown in Fig. 2. Let us call this the “Activity-Knowledge-Guidance Model of a Discipline” or “AKG model” for short. Fig. 2 shows the main elements of a disciplinary system and the ways in which they interdepend. Each of the main elements has components that are again interdependent but for simplicity these subcomponents are merely listed. These components have internal subdivisions too.

Fig. 2- AKG Model

- An interesting point highlighted by this model is that the Guidance Framework of a discipline typically involves multiple worldviews. The same subject matter can be studied from different worldviews, and the theories around a given subject can be interpreted differently from different worldview perspectives. Such different approaches to the same subject matter give rise to "disciplinary schools" within a discipline. The schools have the body of knowledge in common, but their different worldviews differentially guide the interpretations and activities of the schools' adherents. For example, within Biology the naturalistic school and the creationist school have different interpretations of the meaning of the theory of evolution, and have different perspectives on the purpose of studying the natural world, and on how knowledge about the natural world may be used. In general, references to a discipline are actually references to the dominant school, and the competing schools are identified by qualifications such as "creationist" or "realist" or "constructivist".

- To expand the AKG model in a manageable way we will from now on show it using a tree structure, as shown in Fig. 3. Such a hierarchy preserves containment relationships but unfortunately it obscures the dynamic interactions between the system components. However, it has the important advantage that it can be expanded to show increasing levels of detail as needed.
- The structure and subdivisions of Fig. 3 broadly follow conventional understandings of the terms used, but some differences necessarily arise because of the attempt to be comprehensive without getting bogged down in pedantry about terms. For this reason, it will be useful to give a brief outline of the conceptual terrain captured by the terms and relationships depicted in Fig. 3.

Fig. 3- AKG Model



4.1.2.- The Disciplinary Activity Scope

1. Exploration, being research activities that include:

(i) *Field Exploration*, research aimed at describing the subject matter in its natural context;

(ii) *Theoretical Exploration*, research aimed at identifying alternative possible interpretations of the field observations and generating hypotheses for testing; and

(iii) *Experimental Exploration*, research aimed at testing hypotheses under partially controlled conditions.

2. Development, involving research and reflection towards:

(i) *Theory Development*, to update or extend disciplinary theories to accommodate the findings of experimental exploration;

(ii) *Research Methodology Development*, to use the insights from theory development to provide new/improved research methodologies;

(iii) *Application Development*, to use the findings and insights arising from exploration and theory development to develop new/improved methods for professional practice and physical production, and new/improved designs for products and service systems;

(iiii) *Guidance Framework Development*, to adjust the discipline’s guidance framework in the light of the meanings and implications of the findings and insights; and

(v) *Discipline Development*, work aimed at sustaining, improving and expanding the discipline as such, for example the development of disciplinary standards for conduct and education, and the development of disciplinary targets and priorities.

3. Application, involving using disciplinary knowledge and skills to enable:
(i) *Professional Practice* that addresses specific problems of individuals by giving advice, taking action or providing support;
(ii) *Services* provided via service systems that address, for example, general human needs for safety, health, education, dignity; and
(iii) *Production* of materials, equipment and infrastructure that support individual and social welfare.

4.1.3 The Disciplinary Knowledge Base

- The disciplinary knowledge base comprises the key resources that enable disciplinary activity. These comprise:

  1. Data, consisting of:

  (i) *Observations***,** being descriptions of the subject matter as encountered in ordinary contexts. These include descriptions of the subject matter entities in terms of their appearance, structure, behaviour, powers, and functions; and

  (ii) *Findings*, representing the outcomes of experiments and tests under partially controlled conditions.

2. Theories, consisting of:

(i) *a General Theory*, i.e., a theory that applies always and everywhere within the discipline, and is the basis of its scientific unity, for example the Periodic Table of Elements in chemistry and the Theory of Evolution by Natural Selection in Biology;

(ii) *Special Theories*, i.e., theories about subclasses of the subject matter. For example, in Chemistry these include theories about classes of chemicals, for example metals, radioactive isotopes, polymers; and

(iii) *Hybrid Theories*, i.e. theories that combine special theories with theories from other disciplines when interests overlap. For example, in the case of Chemistry these are hybrid theories such as those of Biochemistry, Geochemistry, Nuclear Chemistry, and Neurochemistry.

3. Methodologies, consisting of:

(i) *General Methodologies*, i.e. disciplinary ways of working that are of general utility across the specializations of the discipline;

(ii) *Special Methodologies*, i.e. structured ways of tackling specialized kinds of disciplinary problems; and

(iii) *Hybrid Methodologies*, i.e. structured ways of tackling problems involving multiple disciplines. In substantive cases they become the methodologies of Hybrid Disciplines.

4.1.4- The Disciplinary Guidance Framework

❖ The disciplinary guidance framework provides the context that conditions disciplinary activity, giving direction and focus, and setting boundaries, standards and priorities. More specifically, it involves:

1. A **Domain View**, comprising:

(i) *a Subject Matter Definition* that specifies the scope and range of the discipline's interests;

(ii) *Standards* for governing professional conduct and ensuring quality;

(iii) *a Problematics* comprising:

- *The "Big Questions"* the discipline seeks to answer;
- *A Research Agenda* that defines and prioritizes the work of the discipline; and

(iv) *Disciplinary Schemas* that map the relationships between the components of the discipline.

2. *A* ***Worldview***, comprising:

(i) *an Epistemology*, that explains what knowledge is, describes what enables, conditions or prevents the acquisition of kinds of knowledge, discusses opportunities for and limits on what we can come to know; and explains how the models and theories of the discipline can be used to acquire knowledge relevant to the purposes of the discipline; and

(ii) *a World Picture* comprising:

• *An Ontology*, i.e. a theory of what exists most fundamentally, for example "physical atoms", or "God" or "Tao";

• *A Metaphysics*, i.e. a theory about the nature of what exists and hence what is possible, for example "all changes are proportional to changes elsewhere", or "all events have sufficient reasons", or "all outcomes are due to Divine providence"; and

• *A Cosmology* (model of the origin, history, organisation and possible futures of the concrete world). Things are "concrete" if they have causal powers; this distinguishes them from *abstract* things, which can also be considered to be "real" in the sense of having existence independently of our imagination (for example numbers) but that do not have causal powers.

3. *A* ***Lifeview***, comprising:

• *an Axiology* (a value system and theories about the nature of values and how to make value judgements); and

• *a Praxeology* (theory about the nature of action, agency, freedom and responsibility).

4. A Terminology that provides the standard terms and coherent concepts needed for model building in the discipline's domain of operation.

4.2- Kinds of Disciplines

❖ The AKG model provides a way of distinguishing between a topic, theory or activity, and a complete discipline. A discipline, in this light, is an interconnected system, comprising activities that, under the conditioning influence of a guidance framework, produce outputs that include updating knowledge about a defined subject matter. The term “discipline” so defined is clearly very broad, and hence it can be used to characterize a variety of kinds of disciplines, which can be differentiated as follows.

Theories can be either general, specialized or hybrid theories, and hence the methodologies they enable can be either general, specialized or hybrid methodologies. The general theory that characterizes the subject matter of the discipline applies in and connects the special and hybrid theories/methodologies, and in this sense is a “meta-theory” over the special and hybrid theories and methodologies, thereby forming the basis of the unity of the discipline.

- As a discipline matures its theories and methodologies become rich and diverse, and this gives rise to sub-disciplines dedicated to refining, extending, promoting and applying the original discipline’s individual theories or methodologies. In this way a strong discipline soon becomes a “disciplinary field”, divisible into general, special and hybrid *disciplines*. In this case the general theory (meta-theory) of the field becomes a special case of a *transdisciplinary* theory, because it now applies in and connects between the special and hybrid disciplines of that field. In this way the “general discipline” in a field is a “transdiscipline” that applies across the special and hybrid disciplines of the field, and is also the discipline that underpins and develops the scientific unity of the disciplinary field. The disciplines commonly encountered across academic institutions are the most advanced ones, and hence the disciplinary divisions we typically encounter in academia are disciplinary fields.

- An interesting observation that follows from looking at disciplines and fields in this way is that there is a meta-theory at the heart of every discipline, and a transdiscipline at the heart of every disciplinary field. The scope of such metatheories and transdisciplines is however typically limited to the scope of the discipline or field they unify. This represents a special case of transdisciplinarity, different from how it is usually discussed, namely as applying across the major traditional academic divisions we have here identified as fields. However, this framing follows directly from the basic meanings of the terms ‘transdisciplinarity’ and ‘discipline’. This does not eliminate or replace the idea of a transdisciplinarity that crosses the boundaries between fields, but it does indicate that there are different kinds of transdisciplinarity which we should be careful to disambiguate.

- As noted earlier, disciplines fragment into schools based on differences in worldviews such as Naturalism, Creationism, and Constructivism. However, within a field there are also connections between the schools that share a worldview, so that together they form a community of practice we call a disciplinary “tradition” within the field. A tradition opens up channels of communication and co-operation between schools, via the perspectival unity provided by the common worldview. These channels extend beyond the disciplinary field to also facilitate communication and cooperation with consilient schools in other fields. This is powerful for the schools associated with the dominant tradition in a field, but it can also be a limiting factor by inhibiting exploration of alternative perspectives and reducing sensitivity to the inherent fallibility of human perspectives.

- A *discipline* can be viewed as something that has the tripartite content structure we elaborated earlier, comprising an activity scope, a body of knowledge, and a guidance framework (the AKG model), and has a fixed subject matter but not a fixed worldview. If the worldview is fixed, then we have a *school* within the discipline. A discipline can be comprised of *sub-disciplines*, each focused on a specific aspect of the disciplinary subject matter. A collection of disciplines unified under a general theory constitutes a *field*, and as the general theory is then transdisciplinary the discipline that provides it a (unifying) *transdiscipline*. Within a field there can be various *traditions*, represented by the schools that share a common worldview.

- Every discipline, school and tradition in the field will have the tripartite content structure (activity, knowledge base, guiding framework). The field includes the contents of all its constituent disciplines, and therefore it also has the AKG structure in terms of its contents. It should however be noted that the field is more than merely the sum of its constituent disciplines. The field's structure establishes systemic relationships between the constituents that both limits and empowers them, and the whole provides a stronger basis for the development of the constituents by placing them in context relative to other disciplinary fields. The status and strength of the field lends credibility to its constituent disciplines and schools, creating opportunities for funding, recruitment and participation, and providing connections that stimulate theoretical and methodological innovation.

On the other hand the field also constrains its components by introducing standards, regulating behaviour, setting priorities, and so on. The field is unified by the general theory that is the same for all the disciplines. In practice the situation can be even more complicated, and so we have to recognize the existence of fields that have both fields and disciplines as components, in which we can call the component fields “sub-fields” and the overarching field a “super-field”.

- For example, we can view science as a field that includes subfields such as physics, chemistry and biology as well disciplines such as philosophy of science. Science (as the study of nature) is unified under a shared theory about the nature of nature as comprehensible and investigable. Biology is a subfield of science that unites the biological disciplines under the theories of evolution and genetics. Biology disciplines such as plant biology have many sub-disciplines studying aspects of plants (for example plant toxicology) or kinds of plants (for example xerophytes). Biology contains multiple schools for example the naturalistic school and the creationist school, and these schools are the biology representatives of the naturalistic and creationist traditions in the field of science.

4.3- Systemology Modelled as a Disciplinary Field

- Applying the AKG model of a discipline we can now begin to characterize the systems domain in disciplinary terms. To do this, we have to select suitable names for the various elements of the systems discipline.

4.3.1- The Nature of the Systems "Discipline"

- In the light of the analysis just given, systems science is a disciplinary field containing the general discipline of general systemology, many specialised systems disciplines (for example Cybernetics, Management Science, and Operational Research), and many hybrid systems disciplines (for example systems biology and systems psychology). These disciplines can all be represented by schools grounded in specific worldviews such as in Scientific Realism or Constructivism. The disciplinary schools can be grouped into traditions, that span across the divisions into philosophy, science, engineering and practice.
- "Systemology" will be used as the name designating the systems field, to encompass the specialized systems disciplines and sub-fields such as systems philosophy, systems science, systems engineering and systems practice.

4.3.2- The General Theory of Systemology

- The crucial step along the path to becoming an academically viable disciplinary field is the establishment of a unifying theory. In the case of Systemology, this would be a general theory about the kinds, nature and evolution of systems. It is postulated that there exists, in principle, a theory encompassing “the universal principles applying to systems in general”. Let us denote this unifying general systems theory (GST*).

4.3.3- The Unifying Transdiscipline of Systemology

- Apart from the need to develop a general theory, there is also a need for the establishment of a new discipline the subject matter of which is the derivation and formulation of the general systems principles, with a view to putting them to use to empower all the disciplines dealing with systems. This new unifying transdiscipline will be named “General Systemology”.

4.3.4- The Specialized Theories of Systems Science

- The “special disciplines” of a field are concerned with developing and applying theories about specialised aspects or elements of the field’s subject matter. For systems science (Systemology) these would be theories about specific kinds of systemic structures or behaviours, for example control theory, network theory, hierarchy theory, automata theory and so on. The term “Systemics” will be used for this set of special theories. The systems concepts being transdisciplinary, the Systemics are all formal theories, and hence applicable in different kinds of concrete contexts.

- A formal theory is one that makes no ontological commitments, ranging over abstract entities that could be instantiated in many ways. This contrasts with concrete theories, which has specific ontological commitments that are essential for the theory to be valid. However, note that there are also “Abstract Methodological Systemics”, i.e., formal methodologies for analyzing systemic complexity for example in specialised systems disciplines such Systems Dynamics, Systems Analysis, and Operational Research.

- When the abstract theoretical and methodological Systemics are employed by specialized orthodox disciplines (which have concrete subject matters), this gives rise to hybrid disciplines such as Systems Biology, Systems Geology and Systems Medicine. The theories of the hybrid disciplines can be called “Applied Theoretical Systemics” and their methodologies “Applied Methodological Systemics”. The “applied” systemic theories/methodologies differ from the “abstract” ones in that they involve specific ontological commitments, and hence are concrete theories/methodologies rather than formal ones.

- Compared to other academic disciplines Systemology is unique in having this structure. In the case of for example Mathematics “pure” Mathematics and Applied Mathematics are both formal disciplines, and in the case of the orthodox sciences a “pure” science and its associated applied science are both concrete disciplines. Systemology however has both formal and concrete dimensions. This explains why many of the Abstract Theoretical Systemics (“Systemics”) are studied in Mathematics departments while the applied ones (specialised and hybrid sciences and systems practices) are not.

4.3.5- The Transdisciplinary Nature of Systemology

- Systemology is an unusual disciplinary field because its core concept, “system” is a transdisciplinary one. From the systems perspective one could characterise all the orthodox disciplines as studying specific kinds of systems, and hence the concepts, principles and models involved in characterizing aspects of systemicity (for example feedbacks and hierarchies) can be applied across the spectrum of orthodox disciplines. Consequently, the special theories, methodologies and disciplines of Systemology are *all* transdisciplinary theories, methods and disciplines. This sets Systemology apart from orthodox disciplinary fields, because orthodox fields have only one transdiscipline each, namely the one developing the general theory that unites the field. However, it should be noted that despite containing many transdisciplines Systemology has only one transdiscipline responsible for developing its unifying theory (General Systemology).

4.3.6- A Typology for Systemology

- We can now present a typology for Systemology from two perspectives, one showing the disciplinary structure of Systemology (a disciplinary spectrum model of Systemology), as illustrated in Fig. 5, and one showing how its content is organised (a hierarchical AKG model of Systemology) as illustrated in Fig. 6.

- In the AKG map shown in Fig. 6 we have focused on the Knowledge Base of Systemology. The process of drawing the AKG map showed that Systemology is rich in methodologies (many hundreds) and relatively rich in special theories and hybrid theories (dozens), but poor in material relevant to GST*.

Fig. 5

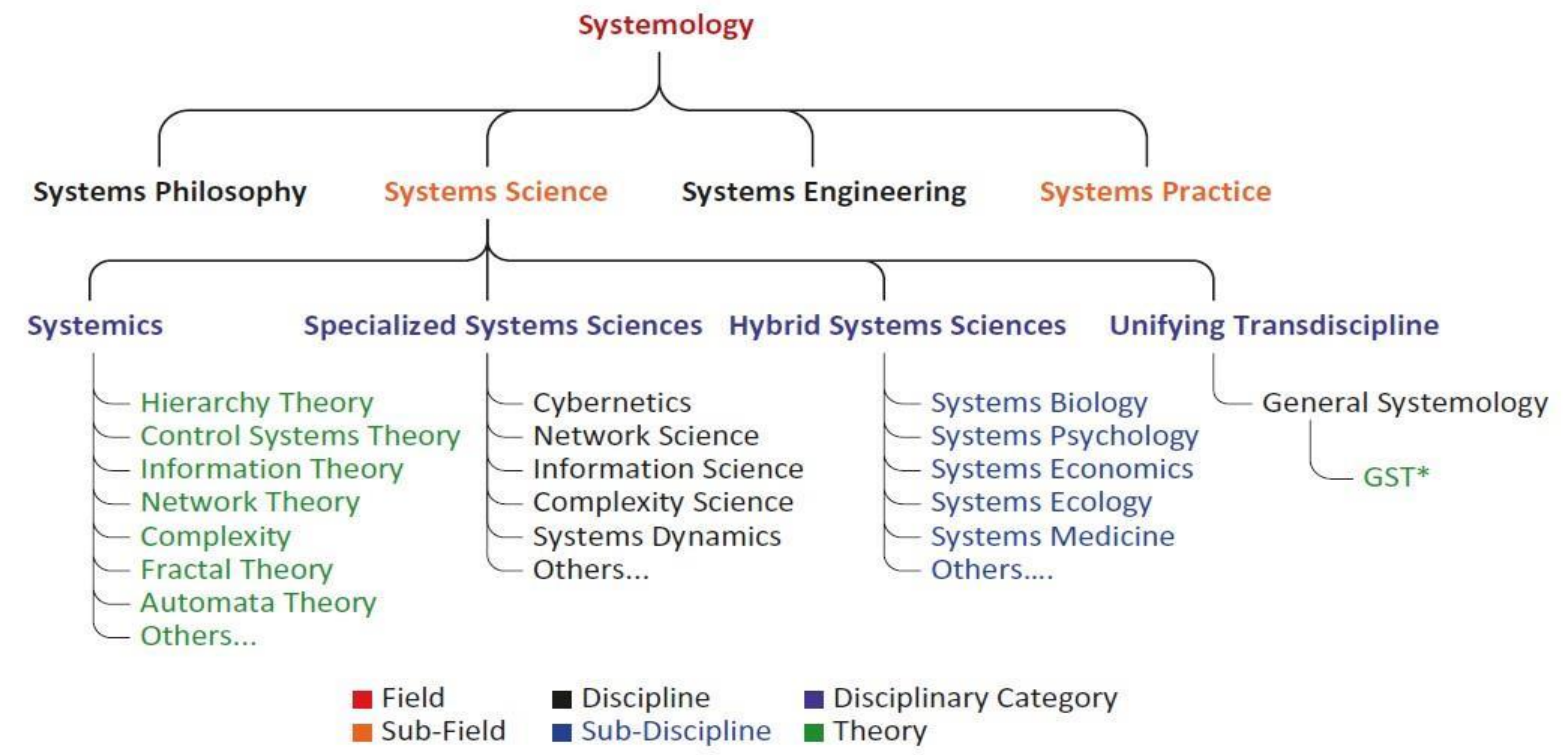
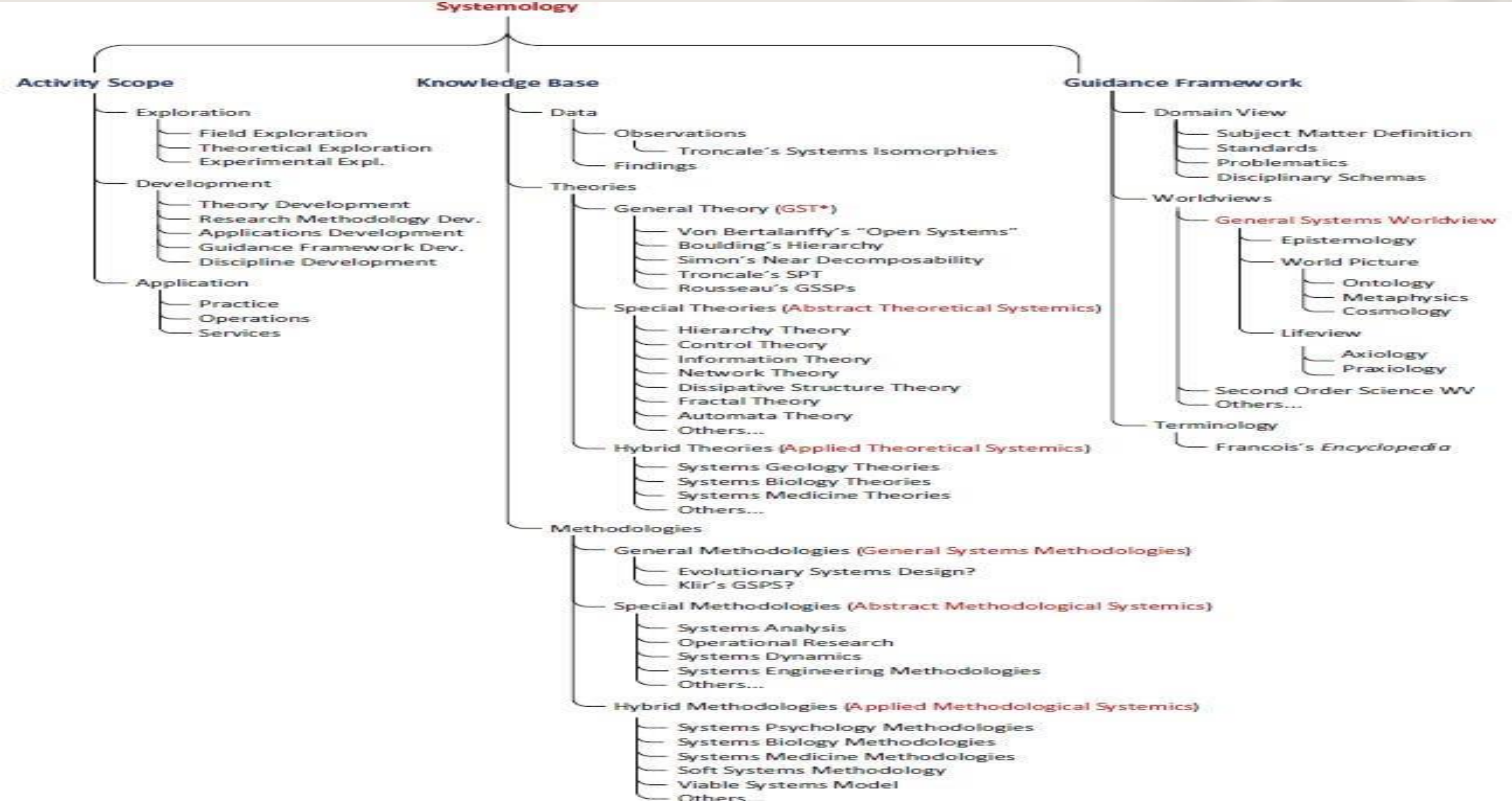

Systemology
Systems Philosophy
Systems Science
Systems Engineering
Systems Practice
Systemics
Specialized Systems Sciences
Hybrid Systems Sciences
Unifying Transdiscipline
Hierarchy Theory
Control Systems Theory
Information Theory
Network Theory
Complexity
Fractal Theory
Automata Theory
Others...
Cybernetics
Network Science
Information Science
Complexity Science
Systems Dynamics
Others...
Systems Biology
Systems Psychology
Systems Economics
Systems Ecology
Systems Medicine
Others....
General Systemology
GST*
Field
Sub-Field
Discipline
Sub-Discipline
Disciplinary Category
Theory

Fig. 6


Systemology
Activity Scope
Exploration
Field Exploration
Theoretical Exploration
Experimental Expl.
Development
Theory Development
Research Methodology Dev.
Applications Development
Guidance Framework Dev.
Discipline Development
Application
Practice
Operations
Services
Knowledge Base
Data
Observations
Troncale's Systems Isomorphies
Findings
Theories
General Theory (GST*)
Von Bertalanffy's "Open Systems"
Boulding's Hierarchy
Simon's Near Decomposability
Troncale's SPT
Rousseau's GSSPs
Special Theories (Abstract Theoretical Systemics)
Hierarchy Theory
Control Theory
Information Theory
Network Theory
Dissipative Structure Theory
Fractal Theory
Automata Theory
Others...
Hybrid Theories (Applied Theoretical Systemics)
Systems Geology Theories
Systems Biology Theories
Systems Medicine Theories
Others...
Methodologies
General Methodologies (General Systems Methodologies)
Evolutionary Systems Design?
Klir's GSPS?
Special Methodologies (Abstract Methodological Systemics)
Systems Analysis
Operational Research
Systems Dynamics
Systems Engineering Methodologies
Others...
Hybrid Methodologies (Applied Methodological Systemics)
Systems Psychology Methodologies
Systems Biology Methodologies
Systems Medicine Methodologies
Soft Systems Methodology
Viable Systems Model
Others...
Guidance Framework
Domain View
Subject Matter Definition
Standards
Problematics
Disciplinary Schemas
Worldviews
General Systems Worldview
Epistemology
World Picture
Ontology
Metaphysics
Cosmology
Lifeview
Axiology
Praxiology
Second Order Science WV
Others...
Terminology
Francois's Encyclopedia

4.3.7- Assessment of the Developmental Status of General Systemology

1. **Activity Scope**: At the moment we have no established GST*, and hence no GSTD as such, although some researchers are working towards developing and establishing it.
2. **Knowledge Base**: As yet we have no general theory of systems, but we have interesting and useful components to build on, including von Bertalanffy's proposed general systems principle – that there are no closed systems in nature.
3. **Guidance Framework:**

(i) *General Systems Domain View*: The potential scope and value of General Systemology have been widely discussed, but these presentations were often of wider scope due to the ambiguity of the historical term "GST";

(ii) *General Systems Worldview*: We have no comprehensive synthesis yet, although we have early candidate models;

(iii) *General Systems Terminology*: Despite the clarifications terminology remains a problematic issue for General Systemology as indeed it does for Systemology as a whole.

- The incomplete state of GST* and the GSW is a serious impediment to the maturation of Systemology as an academic field, but in the light of the AKG Typology we can see where the key gaps are, and from this develop a focused plan for development. GST* would not only provide a scientific unification of the field and extend existing powers, but moreover a strong general theory would open up routes to discovering new abstract Systemics, and together with a developed GSW would open up new opportunities in exploratory science. Such advances would contribute in important ways to systemology becoming established as an academic field in its own right.

4.3.8- Summary

- In the above sections we have developed a generic model for the structure of a discipline and of a disciplinary field, and used this to develop a Typology for the domain of systems. In order to do this, we introduce a generic systemic model of a discipline in terms of the interactions between a discipline’s activity scope, knowledge base and guidance framework (“AKG model”) and the structure of a disciplinary field in terms of a spectrum of fields, disciplines, schools and traditions.

- Using these models, we developed a typology by:

  (i) identifying the domain of systems as a disciplinary field, and advocating it be named "Systemology";
  (ii) identifying the unifying theory of the field as von Bertalanffy's "GST in the narrow sense" and naming it GST* (pronounced "G-S-T-star");
  (iii) identifying the transdiscipline GST* would ground as von Bertalanffy's "GST in the broad sense", and adopting "General Systemology" as the name of this transdiscipline; and
  (iv) identifying the special theories of the field as corresponding to Bunge's use of the term "Systemics", and correspondingly introducing the class-names "Abstract Theoretical Systemics" and "Applied Theoretical Systemics" and the methodological correspondences in "Abstract Methodological Systemics" and "Applied Methodological Systemics".

- We have used the models and naming conventions developed in the above sections to sketch a preliminary map of the 'systems territory' conceived as a disciplinary field, and explored how to use it to assess and discuss the structure and completeness of Systemology and its components in a non-ambiguous way, and to place the work that is being done to complete or improve systemological components in their proper context. We are hopeful that will lead to further constructive discussions about the nature, structure and completeness of the field of systemology.

- Moreover, we have tried to show that the lack of a developed general theory of systems (GST*) is at the root of the fragmentation and limited influence of the systems field, and that progress with such a theory will be key for establishing Systemology academically and enhancing its impact.

- We believe that these concepts, models and views will be helpful in formulating agendas and strategies for developing Systemology into an established and valued academic discipline.

5- The Potential of General Systemology as a Transdiscipline

5.1- What Is Transdisciplinarity?

The term “transdisciplinarity” was coined in a typology of terms devised at the first international conference on interdisciplinary research and teaching in OECD member countries, held in Paris in 1970, where it was defined generically as “a common set of axioms for a set of disciplines”. Since then, interest in transdisciplinarity has grown rapidly, and it is currently “marked by an exponential growth of publications, a widening array of contexts, and increased interest across academic, public and private sectors”.

5.2- The Scope of Transdisciplinarity

As a relatively new academic development there is as yet “no universal theory, methodology, or definition of transdisciplinarity (TD)”, and there is a considerable diversity of opinions about its nature, scope, value and potential. Sue McGregor called it a philosophical movement, while Nicolescu identified it as a new kind of methodology but claimed it is not a new kind of discipline. Gibbons and colleagues deny that it involves a methodology, but do claim that it is a new means of producing knowledge. According to both Cicovacki and McGregor, it requires a distinct axiological underpinning, but according to Nicolescu it does not. Nicolescu has identified three kinds of TD which he classifies as respectively “theoretical TD” (which is concerned with developing transdisciplinary methodologies), “phenomenological TD” (which is concerned with using trans-disciplinary principles to build models and making predictions), and “experimental TD” (which is concerned with doing experiments using transdisciplinary methodologies).

5.3- The Aims of Transdisciplinarity

Despite this diversity of views about the *nature* of transdisciplinarity, there is considerable coherence in claims about its *aims*. Klein indicated that it is about addressing unsolved problems, especially societal ones, Gibbons and colleagues say it is about joint efforts to address problems pertaining to the interplay between science, society and technology; problems that are not circumscribed in any existing disciplinary field. McGregor says it is an approach to solving deeply complex, interconnected problems that are too complex to be solved from within the boundaries of one discipline or by using a conventional empirical methodology. For Tella, transdisciplinarity is intended to address the complex, wicked problems facing humanity (such as climate change, unsustainability, poverty), and for McGregor it is about interconnecting science, politics and technology with society in a way that respects the survival of humanity in a future that is worth living.

5.4- The Character of Transdisciplinarity

All forms of transdisciplinarity engage with at least one of three overlapping concepts: **transcendence**, **problem-solving**, and **transgression**:

- ***"Transcendence"*** is about overcoming the barriers between disciplines, and in this sense transdisciplinarity is close to the ancient quest for the unity of knowledge, although the notion of "unity" has changed over time, to include aspects such as compatibility and consilience;
- Transdisciplinary approaches to "***problem-solving"*** deviate from traditional approaches by placing great emphasis on "real world" problems, by involving feedbacks between organizations involved in research, design, education, services, and policymaking, and by a commitment to social, environmental, economic and ethically sustainable development; and

- ***"Transgression"*** is about questioning the constraints of traditional disciplines. This is not a rejection of the ethics or rationality of disciplinary inquiry, but an acknowledgement of uncertainty and a willingness to critique, reimagine, reframe or reformulate the status quo. This attitude allows established boundaries and limitations to be challenged and existing knowledge to be recontextualized, and in so doing opens up new routes to discovery, insight, and innovation.

5.5- The Varieties of Transdisciplinarity

TD is currently a dappled arena, with much consistency in its overall aims but also much diversity in how those aims are pursued. TD is simultaneously an attitude and a form of action. This characterisation is helpful in understanding the diversity of forms TD currently takes, when taken together with the definition of TD as "a common set of axioms for a set of disciplines". There are many kinds of "axioms" that can be proposed as assumptions, beliefs or principles that would, if adopted, lead to the kind of "better world" that TD is focused on.

- This diversity highlights a key question for transdisciplinarity, namely whether it represents a discipline in its own right or merely modulates the attitude with which existing disciplinary work is undertaken. This issue could be resolved in the light of the systemic model of an academic discipline. This represents a discipline as an “Activity Scope” informed by a “Knowledge Base” and conditioned by a “Guidance Framework”, which we call “the AKG model” for short.
- The AKG model provides a way of distinguishing between a topic, a theory, an activity, an attitude and a complete discipline. In the light of this model, we can see that the current diversity of kinds of transdisciplinarity can be characterised in terms of two major types. The first type involves a concern for the application of specific transdisciplinary values such as equal opportunity or sustainability. These kinds of values can be applied across multiple disciplines, but this serves only to extend the guidance frameworks of existing disciplines rather than generating transdisciplines as such.

- In the second type, TD involves the application, under a guidance framework (which includes values), of transdisciplinary theories such as GST* or Cybernetics. For this second type it is appropriate to speak of TD as the application of a transdiscipline, since there is a distinct discipline involved *in addition to* the orthodox ones over which its applicability might range.
- In this light we can not only understand the origins of the diversity of kinds of TD that we have today, but we can see that the first type of disciplinarity is likely to evolve into the second type, as its proponents firstly develop methodologies for applying those value systems in different disciplinary contexts, and as theories are developed that explain the utility or appropriateness of those values and hence ground those methodologies in principled ways. From this we can view "type 1" TD as "early-stage type 2" transdisciplinarity, and see its evolution from "type 1" to "type 2" as a maturation from an intuitively compelling form of activism to an objectively compelling species of scientific endeavour.

- However, we can also see that the value systems of current “type 2” transdisciplines will increasingly evolve under the influence of “type 1” transdisciplinarity to include transdisciplinary values, shifting them further from the classical ideal of science as a “value-neutral” endeavour to one that accepts responsibility for its impact in the world. We can thus foresee an evolutionary trajectory for all kinds of transdisciplinarity, involving the development of transdisciplines that incorporate transdisciplinary theories, methodologies and values. Moreover, we can anticipate that on the basis of an emerging consilience between transdisciplinary theories, methodologies and values the diverse transdisciplines might coalesce into a coherent transdisciplinary field. We will henceforth discuss transdisciplinarity only in terms of an “ideal type” that is the expression of a transdiscipline involving transdisciplinary theories, methodologies and values, and whose values align with a concern for building a “better world”.

5.6- Kinds of Disciplinarity

The focus of TD on problem solving calls for an explanation of how TD differs from other kinds of disciplinarity in its approach to problem solving, and how its particular value arises. Several kinds of disciplinarity arenow recognized.

1. Mono-disciplinarity**:** this involves only a single discipline and is suitable for addressing well-bounded phenomena or a single aspect of a complex phenomenon;

2. Multi-disciplinarity**:** this is used for addressing multiple aspects of a phenomenon by making use of several disciplines. It acknowledges their differences but involves no attempt to bridge between them;

***3.* Cross-disciplinarity:** this is used where several academic disciplines are interested in the same aspect of a complex phenomenon. The different disciplines' distinct methods are brought to bear on the same problem in a coordinated way, establishing a kind of middle ground;

4. Inter-disciplinarity**:** this involves combining several disciplines, attempting to synthesize them into something that provides a new perspective on the given problem; and

5. *Transdisciplinarity*: this involves disciplinary frameworks that are developed from generalisations based on patterns1 that recur across or connect between several disciplines, and hence it involves insights about the general nature of the world rather than the special natures of specific kinds of phenomena. In contrast to other kinds of disciplinarity which bring the means of one or more specialised disciplines to bear on a specific problem, transdisciplinary frameworks are relevant to the phenomena studied in several disciplines, and hence TD introduces new means that can enhance the effectiveness of the disciplines it is partnered with.

- Note that TD is different from the others in that it adds something new to the disciplines it generalises over, rather than combining or merging existing disciplinary resources. Its value is realised when it is used in conjunction with one of those disciplines to address problems originating in those disciplines.

5.7- The Range of General Systems Transdisciplinarity

- In every discipline the central objective is to maximize the scope of what can be explained, predicted, managed or utilized. Doing this calls for different kinds of disciplinarity depending on the complexity of the issue. When dealing with a specific challenge the kinds of disciplinarity are typically engaged in the order of their relative complexity, in order to find the solution in the simplest possible way. However, given the nature and range of phenomena that still lie beyond scientific explanation, it is likely that scientific investigation will increasingly call for transdisciplinary working.

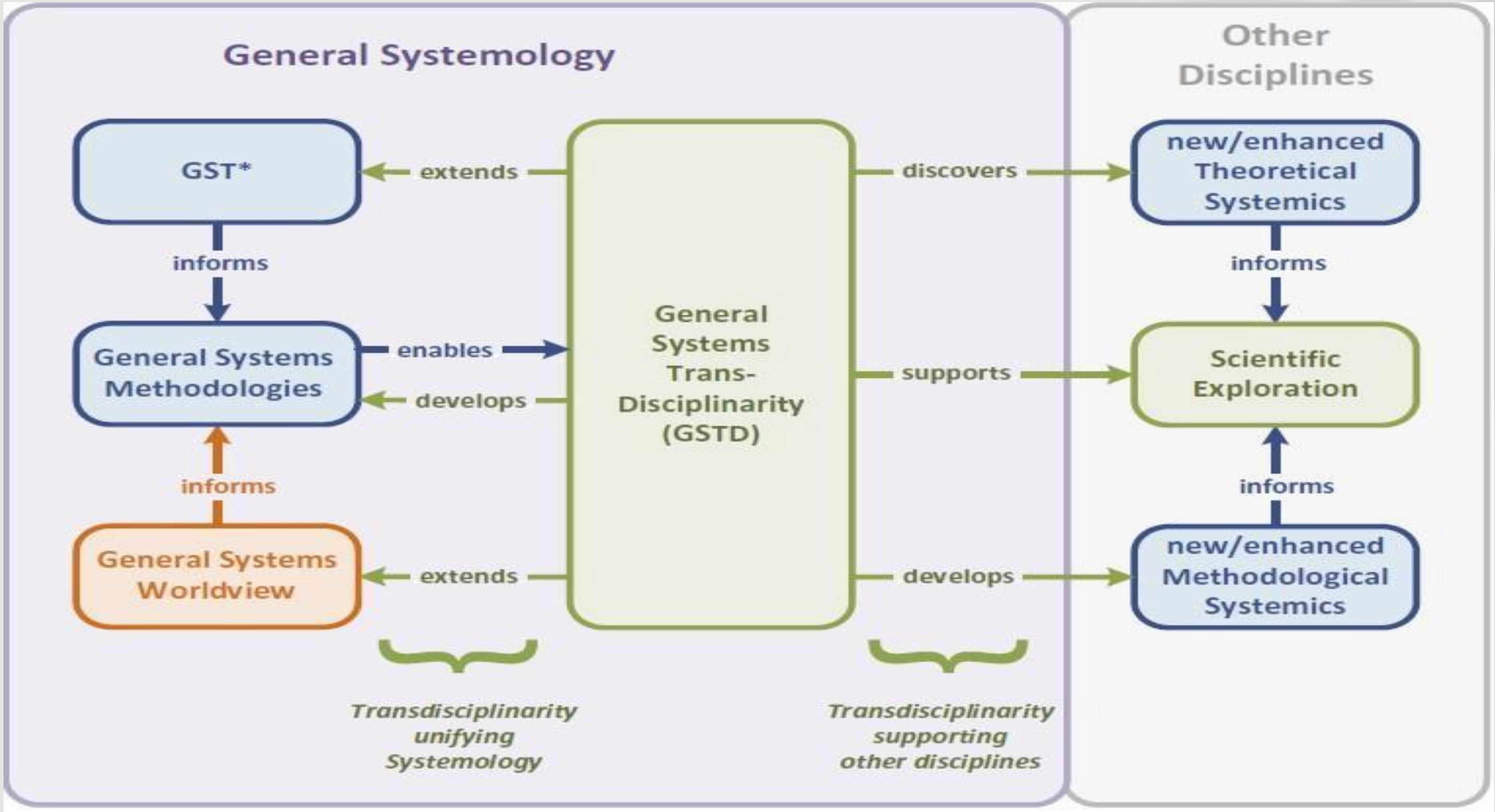
- Transdisciplinarity is grounded in insights about patterns that recur across or connect between disciplines, and therefore it tells us something about the fundamental nature of the world that is not readily evident from within the specialized disciplines. Because of this it can powerfully enhance problem solving techniques in specialised areas, and thus be especially useful where specialised disciplines are addressing apparently intractable disciplinary problems, such as those that reflect deep ontological or epistemic issues.
- Amongst the transdisciplines, General Systemology is arguably the potentially most powerful, because it is grounded in the deepest of the general principles applying to the “real” world. Just like conservation of energy the principles of General Systemology will represent insights that are relevant in all disciplines and in all contexts. However, some of them will have application beyond the principles of science, applying also, for example to abstract and conceptual systems.

5.8- The Scope of General Systems Transdisciplinarity

- GSTD is more versatile than other forms of transdisciplinarity. This is so because General Systemology seeks to identify universal principles underlying the origin, evolution and behaviour of all kinds of complex systems. As such its concepts, models and methodologies could be relevant in all areas of investigation and theory development. The transdisciplinary insights of General Systemology might be used not only to address complex problems, but also to support exploratory science, i.e., to develop testable hypotheses about unexplained complex phenomena that are not considered to be problematic but are nevertheless part of the context in which problem-solving is undertaken. For example, many familiar human abilities such as creativity and abstract thinking remain largely mysterious, and yet understanding them would contribute much to achieving the thrivable future that is the focus of transdisciplinary ambitions.

- The way in which GSTD can support these new developments is illustrated in Fig. 9. We use the blue color for components of the Knowledge Base, orange for components of the Guidance Framework, and green for components of the Activity Scope. The diagram illustrates the key components of General Systemology and shows the scope of its activities. As can be seen in the diagram, the activity scope of General Systemology has two transdisciplinary aspects. In the first, shown in the left half of the diagram, General Systemology functions as the unifying transdiscipline for Systemology, refining and extending the general theory (GST*) that applies across the specialized and hybrid systems disciplines. In the second aspect, shown in the right half of the diagram, GSTD leverages the methodologies of General Systemology to support/extend other disciplines and fields.

Fig 9


General Systemology
Other Disciplines
GST*
extends
informs
General Systems Methodologies
enables
develops
informs
General Systems Worldview
extends
General Systems Trans-Disciplinarity (GSTD)
discovers
supports
develops
new/enhanced Theoretical Systemics
informs
Scientific Exploration
informs
new/enhanced Methodological Systemics
Transdisciplinarity unifying Systemology
Transdisciplinarity supporting other disciplines

- Amongst the transdisciplines, General Systemology is perhaps the only one that has a *scientific strategy* for finding transdisciplinary patterns, by following von Bertalanffy's injunction to look for isomorphies of structures, behaviors and processes present in the designs of different kinds of systems under the guidance of the GSW. However, it must be noted that unlike the science ideal of neutrality, General Systemology has from the outset maintained a concern for meaning and value and a commitment to building a "better world". As such it has always pursued the ambition of bridging the gap between the object-oriented and the subject-oriented disciplines in a way that preserves the merits of each, and recent developments in General Systemology suggest that such a bridge can in fact be attained via the development of GST* and the GSW. In this light, General Systemology is likely to contribute significantly to the discovery, problem-solving and cultural transformation that will be needed to help us attain and sustain a thriving eco-civilization.

5.9- Summary

- In the above sections we explored the differences between kinds of disciplinarity, including mon-, multi- cross-, inter- and TD, and reflected on the value of each. We pointed that at present there are multiple kinds of TD, but argued that these reflect differences in evolutionary trajectories and they can be expected to converge (or at least become consilient) as transdisciplinary theories become more mature, and as links between them become evident on the basis of advances in GST*. In this way, we foresee the development of a general systems TD (GSTD) that will have relevance in all areas of human and scientific inquiry, and provide a means to explore and address deep problems beyond the current scope of other kinds of disciplinarity.

6- The Existence, Nature and Value of General Systems Theory (GST)*

*6.1- The Potential Utility of GST**

- Assertions about the lack of utility GST* would have as a general theory are contradicted by examples from the history of science. Darwin's *Theory of Evolution by Natural Selection*, Mendeleev's *Periodic Table of the Chemical Elements*, Newton's *Laws of Mechanics* and Lyell's *Principles of Geology* transformed their respective disciplines by unifying hitherto fragmented areas of study under a common conceptual and explanatory framework, thereby rapidly opening up new avenues to scientific discovery.

- Given the examples of history, it seems reasonable to suggest that if a GST* existed it is likely to be as important in relation to the study of kinds of systems as these other theories have been to their respective subject matters. Extrapolating from these analogies it is plausible that a mature GST* will unify the systems field by providing both a ‘gestalt’ that relates the special theories describing the specific systemic behaviours and structures that occur in Nature to each other, and the principles that entail their evolution in Nature.
- Insofar as specific systemic structures and behaviours are modelled by the special theories collectively known as “Systemics”, the implication is that the development of GST* will provide a principled basis for the discovery of new Systemics via General Systemology, as opposed to the incidental way in which Systemics have been discovered to date within the specialised disciplines. However, this positive outlook is subject to two significant caveats:

- First, the examples given earlier of unifying theories offered as analogies are all empirical theories about some aspect of concrete nature, whereas GST* is a formal theory that generalizes over the special systems theories, themselves generalizations over multiple disciplines. The “meaning” of GST* in any specific empirical context is thus unclear until it is combined with an appropriate philosophical framework representing the concrete world in terms of the systems paradigm.
- Second, the extent of the value of GST* depends on a very strong philosophical claim, namely that every concrete thing is a system or part of one. This is a core tenet of the GSW, and if this assumption is true then GST* would be relevant in all cases where science is studying concrete phenomena. In this case, having a GST* would be enormously empowering to all the specialized disciplines. Investigating the validity of the assumption that everything is a system or part of one must therefore be one of the core objectives of a research agenda for General Systemology.

*6.2- The Potential Existence of GST**

- The central focus of Systems Philosophy is to develop a worldview based on scientific principles and the systems paradigm, and to use it to solve important problems in science, philosophy and society. There is an intimate relationship between this worldview and GST. We do not yet have a fully-fledged version of this worldview either, but the situation is much more advanced than is the case for GST*. The worldview at stake here is informed by the findings of science and philosophy of science as well as by the systems paradigm, and so has much material to draw on. This perspective is traditionally called the “General Systems Worldview” (GSW).

- The tenets of the GSW entail the existence of a GST*, that the development of the GSW can make important contributions to the development of GST*, and that progress with GST* will in turn inform the refinement of the GSW. To prepare the ground for presenting these arguments, a closer look at the notion of "worldview" is needed.

6.2.1- Worldview as a Perspective on the World and on Life

- The term “worldview” is the English rendering of the term *Weltanschauung*. It was coined by Immanuel Kant, and it rapidly developed as “a term for an intellectual conception of the universe from the perspective of a human knower”. Essentially, a worldview is a “map of reality” that people use to order their lives. A worldview can be characterized as comprising three main elements, namely a perspective on the nature of knowledge (“epistemology”), a perspective on the objective nature of the universe (a “world picture”) and a perspective on the subjective significance of one’s existence in the world (a “life view”.

- Technically and in more detail, we can define a worldview in contemporary terms as encompassing the following components:
  1. An Epistemology (theory about what kinds of knowledge are possible and how to gain knowledge);
  2. An Ontology (model of what exists most fundamentally);
  3. A Metaphysics (model of the nature of what exists, i.e. what is possible given the Ontology;
  4. Cosmology (high-level theory of the origins, history, organisation and destiny of the world);
  5. Axiology (value system and theories about what is important and why); and
  6. Praxeology (theory about the nature of action, agency, freedom and responsibility).
  In this list, Ontology, Metaphysics and Cosmology comprise the objective "world picture" and Axiology and Praxeology comprise the subjective "life view".

6.2.2- The Foundational Tenets of the General Systems Worldview (GSW)

- The General Systems Worldview includes fundamental commitments in each of the worldview components, and these condition the way in which research toward completing and refining the GSW and the search for a GST* proceeds. In particular, accepting the very concept of a GST* already implies a commitment to certain worldview tenets. Most fundamentally, the GSW outlook is a systemsoriented moderate scientific realism. It is realistic in that it holds that the world has some objective aspects that we can have knowledge of; scientific in that it takes seriously the findings, methods and standards of science; it is moderate in that it acknowledges the limitations and conditionality of our knowledge and our ability to improve it; and it is systems-orientated in that it uses the systems concept to analyze the organization and dynamics of the concrete world.

- For present purposes we can summarize the key tenets of GSW using a framework of seven positions. Very briefly, the fundamental philosophical tenets of the GSW are:

T1. ***Moderate Epistemological Realism:*** We can progressively gain more complete real knowledge of the real world;
T2. ***Moderate Ontological Realism:*** A real concrete world underlies some of our experiences (but experiences can also be distorted or constructed or hallucinated);
T3. ***Broad Naturalism:*** Nothing supernaturalistic exists, but concrete phenomena cannot all be reduced to Physics;
T4. ***Moderate Systemic Realism:*** The concrete world is inherently systemic (but we can also project systemicity onto our experienced world);
T5. ***Systemic Universalism:*** Every concrete thing (everything that has causal powers) is always a real system or part of one;

T6. ***Moderate Axiological Realism:*** Values are largely constructed via cultural processes, but natural systemic processes also influence them; and

T7. ***Moderate Praxeological Realism:*** We have the capacity and freedom for uncoerced choices and actions, but our choices and actions can also be conditioned by natural and cultural factors.

- These seven tenets are all metaphysical claims, in that they are about the nature of what exists most fundamentally or about what is inherently possible, but they bear on the full scope of a GSW. Specifically, they have implications for all six of the elements of a worldview as discussed earlier: T1 bears particularly on epistemology, T2 on ontology, T3 on metaphysics, T4 and T5 on cosmology, T6 on axiology and T7 on praxeology.

*6.2.3- Arguing from GSW's Tenets to the Potential Existence of GST**

- Taken together, the tenets T1–T7 listed above entail not only the existence of a GST*, but moreover that GST* has the kind of potential ascribed to it by the early systemists. If we assume that a real concrete world exists (T2), and that we can have a scientific model of it (T2 & T3), and that there are real systems in the concrete world (T4), then by implication, there is a scientific theory that models the systemic aspects of the concrete world. Granted this, if we assume that *all* concrete properties are conditioned by systemic processes (T5), it follows that there is a scientific theory about systemicity that applies everywhere and always. Hence there exists a GST*.

- However, this argument goes beyond a mere existence claim, because if GST* is a theory involving principles that apply everywhere and always, then it has the same ubiquity and utility as general ‘Laws of Nature’ such as Conservation of Energy and the General Theory of Relativity. Discovering and developing a GST* could thus be of profound significance for science. Not only that, but under the tenets of GSW, GST* would also have implications that go beyond those usually associated with such Laws of Nature, just as the early general systemists proposed.
- ***First***, if values are to some degree systemically conditioned in a naturalistic way (T6), then GST* would be relevant to both naturalistic and humanistic concerns. ***Second***, if we have agency and free will (T7), then we can use our knowledge and our values to make a difference to how things turn out, so we can in practice use the insights provided by GST* to change how the world evolves.

- These are important inferences, but of course they hinge critically on the validity of the foundational tenets of the GSW. Given the unproven (but not wholly controversial) nature of these tenets, a careful articulation and modern defence of these foundational philosophical assumptions are important outstanding tasks for a contemporary general systems research agenda. In the meantime, it is acknowledged that these tenets form a foundational but provisional assumptive framework for GeneralSystemology.

*6.3-The Potential of the General Systems Worldview (GSW) to Support the Development of GST**

- So far, we have shown, on the basis of arguments grounded in the tenets of the GSW, that we can have some confidence that a GST* exists in principle, and that it would be of great practical value to have it. We will now go further, and argue that the GSW can also support the discovery and development of GST*. To develop this argument, we will first discuss an insight into the synergy between GST* and the GSW.

6.3.1- The Relationship of GST to the Systemics and the Specialised Disciplines*

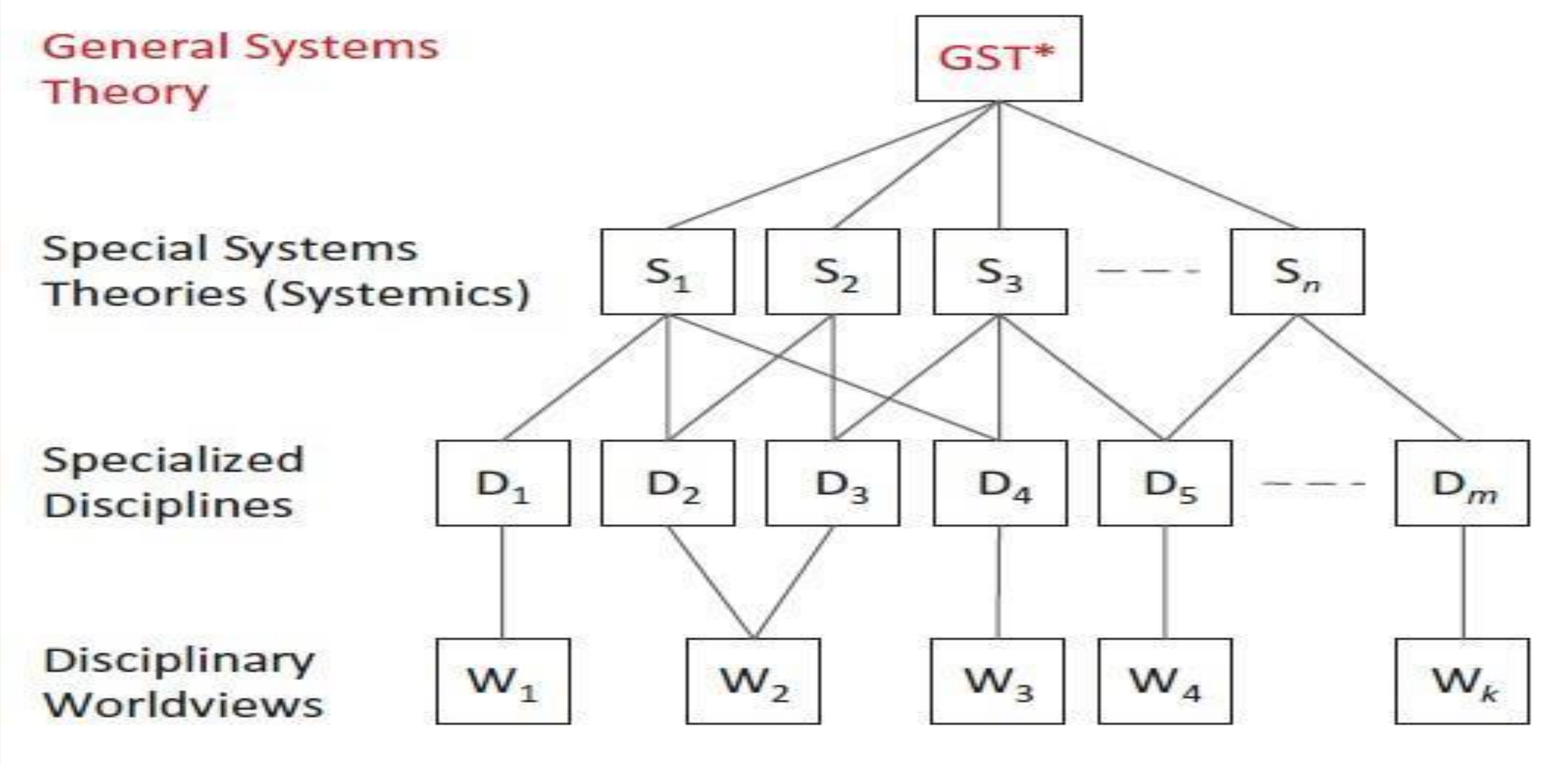


Fig 10

❖ If there were general systems principles, then these would manifest as structures or behaviours that are isomorphic between different kinds of systems. In this sense, identifying and studying such “isomorphies” might present a fruitful approach to discovering the general principles of a GST*. However, to date the study of specific systemic structures and behaviours has only resulted in more-or-less autonomous theories about specific systemic aspects, for example control theory, network theory, automata theory, hierarchy theory, dissipative structure theory, and so on. Mario Bunge coined the term “Systemics” for the set of these theories that each deal with a specific “isomorphy”. Although these isomorphies have not yet been assimilated into a general theory, it can be said, broadly speaking, that the Systemics pick out ‘patterns’ that recur across multiple kinds of natural systems (and hence across the specialised disciplines), and that GST* would pick out other kinds of ‘patterns’ that recur across all the Systemics, as roughly indicated in Fig. 10. Here, the individual disciplines are represented as a series of specialized disciplines Di and the Systemics as a series of systems theories Si.

- As also indicated in Fig. 4.1, the specialized disciplines each have their implicit or explicit worldviews W*i*. Some disciplines of course share worldviews, for example Chemistry and Geology, which are both grounded in Scientific Realism and Physicalism, while others are very different, for example the Social Sciences typically embrace a Constructivist or Postmodern perspective.

*6.3.2- GSW as a Counterpart of GST**

- The Systemics and GST* are formal theories, that is, they contain no information about how the systems they describe are implemented. For example, Communication Systems Theory describes the functions and limitations of a communication system (for example encoding, signal transmission, detection, noise mitigation, decoding) but does not tell us anything concrete about the many ways in which such components as signal transmitters and receivers might be realized.

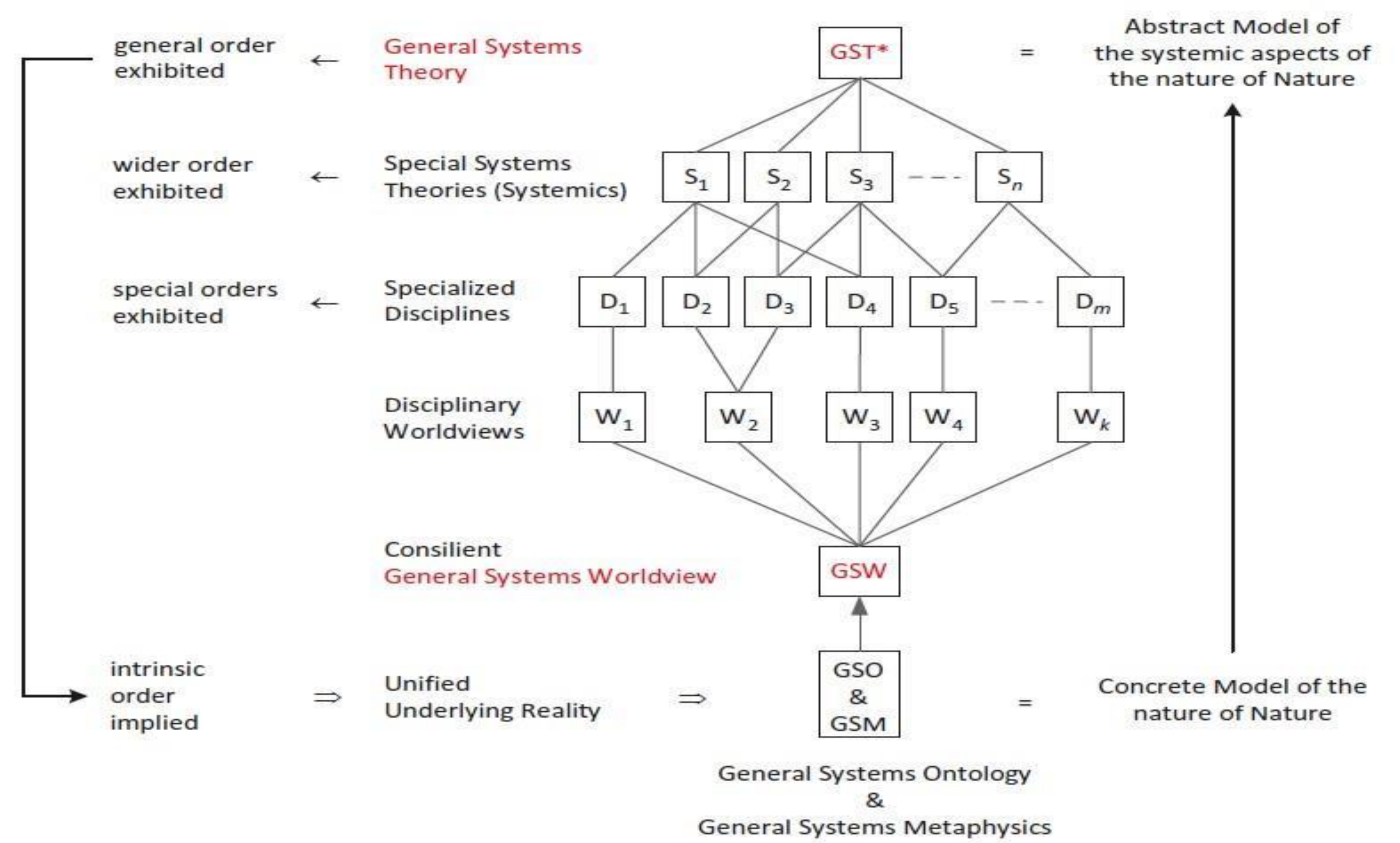
- Their lack of ontological commitments guarantees the Systemics' general applicability, but it does raise a puzzle as to why they should be effective in describing real-world phenomena across multiple domains, given that the disciplines in which they apply sometimes have dissonant ontological models. For example, both social systems and mechanical systems exhibit systemic properties such as emergence, synergy and dynamic stability, and yet macro-physical scientists typically assume the existence of an objective reality while social scientists mostly regard reality as a social construction.
- The solution to this puzzle was proposed by Ervin Laszlo in his book *Introduction to Systems Philosophy: Toward a New Paradigm of Contemporary Thought*. Laszlo's argument can be summarized as follows (Fig. 11):

- The existence of specialized disciplines (Physics, Chemistry, Genetics, Sociology etc.) shows that the concrete world is *organized into intelligible domains*. The Systemics, by revealing patterns that recur isomorphically across these domains, cumulatively show that the concrete world is intelligibly organized ***as a whole***. This global organization would be reflected in the principles and models of GST*. The existence (in principle) of global organizing principles entails that the concrete world's special domains (as characterized by the specialized disciplines) are contingent expressions or arrangements or projections of a unified underlying intelligibly ordered reality. In this way Laszlo argued that:

(a) the ***existence*** (in principle) of GST* implies that there is an intrinsically ordered, and hence unified, reality ***underlying*** Nature (designated here by the "General Systems Ontology (GSO)" in Fig. 11) and

(b) the ***content*** of GST* provides an abstract model of the systemic nature of this concrete underlying reality (designated here by the "General SystemsMetaphysics (GSM)" in Fig. 11).

Fig 11


general order exhibited
General Systems Theory
GST*
=
Abstract Model of the systemic aspects of the nature of Nature
wider order exhibited
Special Systems Theories (Systemics)
S_1 S_2 S_3 S_n
special orders exhibited
Specialized Disciplines
D_1 D_2 D_3 D_4 D_5 D_m
Disciplinary Worldviews
W_1 W_2 W_3 W_4 W_k
Consilient General Systems Worldview
GSW
intrinsic order implied
Unified Underlying Reality
GSO & GSM
=
Concrete Model of the nature of Nature
General Systems Ontology & General Systems Metaphysics

- In this light the metaphysical nature of the underlying reality provides the conditions for the manifestation of systemic structures and behaviors in the specialized disciplines, since their phenomena are all grounded in a unified reality that is systemic in nature.
- The specialized disciplines all have explicit or implicit worldviews, and these each have an ontological and metaphysical dimension. At present these are not aligned in the way that Laszlo's argument suggests they might be. However, his argument suggests that present-day metaphysical differences between the different worldviews are a historical contingency, and that as science progresses these specialised worldviews will converge in their foundational metaphysical commitments, so that despite their specialised differences they will become *consilient*, reflecting the unity of the underlying reality. This does not imply that these currently distinct worldviews will collapse into a single 'master' worldview, but it does imply that none of the disciplines will ultimately carry foundational implications that are inherently contradictory to any other's.

*6.3.3- The Value of GSW for Developing a GST**

- Work towards developing the GSW can support the discovery and development process for GST*, in that the two are linked via the metaphysical framework we have called GSM. Via the GSM bridge advances in either GSW or GST* will inform and advance the other. The development of a GSW is not dependent on progress towards a GST*, but can proceed on the basis of the findings arising in the specialized disciplines. This work can be facilitated by taking a more systematic approach, in which we summarize and compare the worldviews of the specialized disciplines in a consistent way.

- This could be done by first constructing a systems-oriented model of the structure and scope of a worldview, and using this as a template for recording the basic commitments of the specialized worldviews. This will help us to identify common foundations but also metaphysical conflicts between worldviews. The former would represent the core of an emerging integrated GSW, and the latter could identify questions for investigation using a systems approach.
- As the "core GSW" emerges from this comparison exercise, so would we develop better clarity about the metaphysical foundation that links GSW and GST*. The richness of the material available in this area of work is immense. The opportunity for discovering general systems principles when working systematically with the basic findings of all the disciplines must be very substantial, and much greater than when trying to abstract such principles from the study of a relatively small number of isomorphies.

- If it is true that the dynamics of all the structures evolving throughout nature are exemplifying underlying general systems principles, and all the kinds of systems we find in nature behave in ways consistent with general systems principles, then these principles can be expected to ‘shine through’ the data describing the world, if the data is organized in an appropriate systemic way. What we are seeking in constructing GSW in a systemic way is not merely a *taxonomy*, organizing the data in line with a set of empirical criteria, but a representative *typology*, a classification according to concepts that ‘carve at the joints’ of reality, or at least that part of reality that is represented by the body of scientific knowledge. If Systems Philosophy can find the joints of the body of science, then it can be opened up to reveal the skeleton on which its integrity depends, GST*.

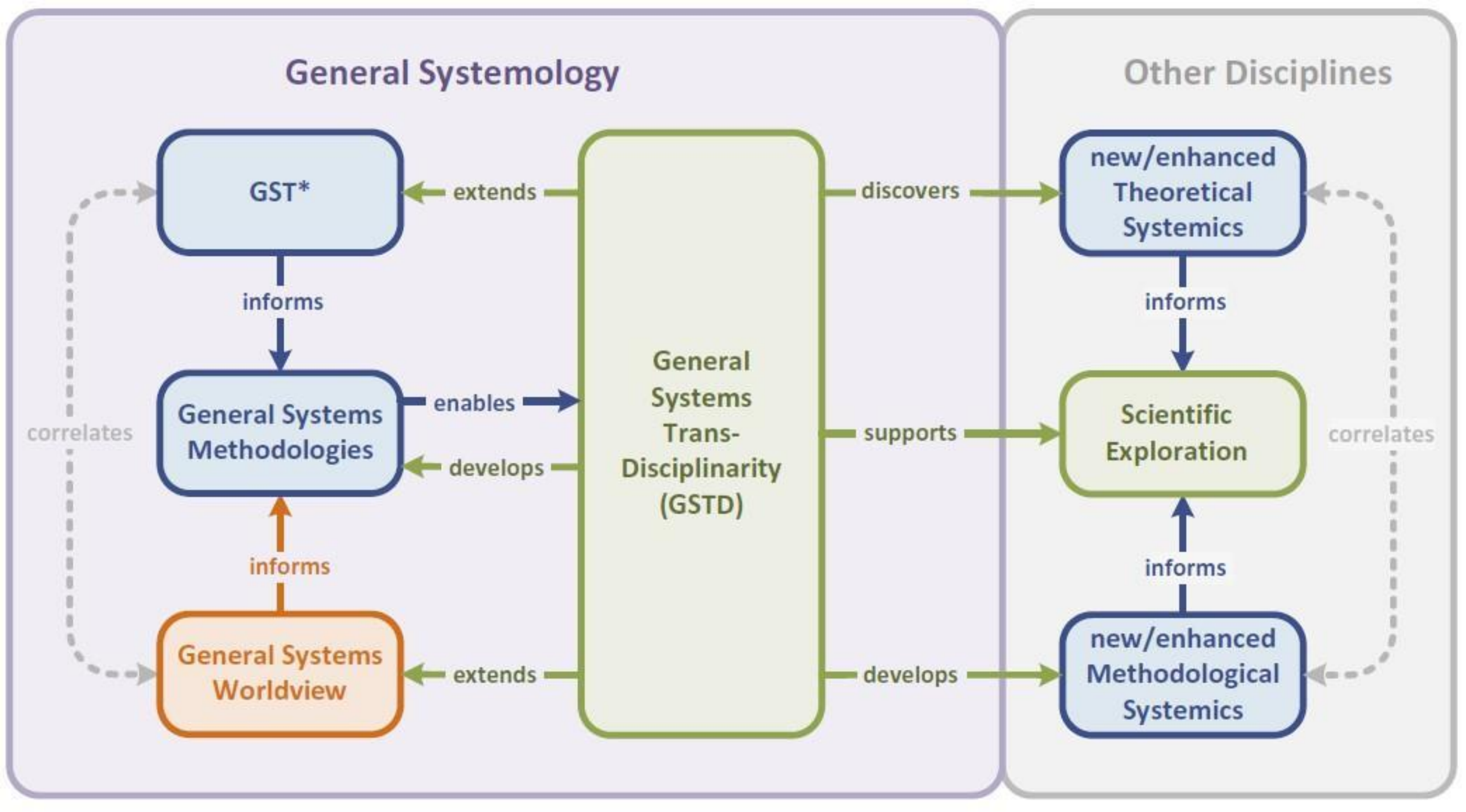
- The development of such a worldview comparison framework is thus an important initial step towards a new and promising strategy for accelerating progress towards GST*, and should be added to the research objectives of a contemporary research agenda for General Systemology.

6.4- The Potential Value of the Synergy Between GST and GSW*

- A GST* would provide a framework from which we can discover, in a principled way, kinds of systemic structures and systemic behaviours unanticipated by contemporary science. This is important for it heralds the discovery of new ways to understand, design, engineer or govern systems. A GSW, on the other hand, embodies our best understanding of the nature, state, and potential of the world as a total system, providing us with a framework for discussing questions of ultimate concern. Moreover, using the GSW framework to compare and analyze worldviews we can identify opportunities for systems research that can deepen or extend our fundamental insights. Taken together, the mechanisms newly identified in the concrete world due to the development of GST*, and the potentials in the concrete world newly identified by developing GSW, can open up significant new avenues of systemic intervention.

- In Fig. 12 we present this view of General Systemology’s scope in a schematic way. We have here used the same colour scheme as we did for the “AKG Model” of a discipline we presented earlier, and used blue for components of the Knowledge Base, orange for components of the Guidance Framework, and green for components of the Activity Scope.
- This framework heralds a new era of General Systems Transdisciplinarity, in which we use GST* and GSW as reference baselines for methods of doing fundamental research towards new Systemics and new fundamental insights, and use these advances to develop methods for future waves of systemic intervention towards building the ‘better world’ the founders of the general systems movement envisioned. Such an extended version of General Systemology would realize the General Systems Transdisciplinarity that our present world needs even more urgently than it did at the founding of the general systems movement.

Fig 12


General Systemology
Other Disciplines
GST*
extends
informs
General Systems Methodologies
enables
develops
correlates
informs
General Systems Worldview
extends
General Systems Trans-Disciplinarity (GSTD)
discovers
supports
develops
new/enhanced Theoretical Systemics
informs
Scientific Exploration
informs
new/enhanced Methodological Systemics
correlates

7- The Knowledge Base of General Systemology

7.1- A General Perspective on General Theories

- In section 4 we argued that the AKG model shows that all scientific disciplines (and disciplinary fields) can be modelled as having both a similar structure and similar dynamics in their development, and that this applies also to Systemology, even though it is a transdiscipline. In section 4 we also argue that each discipline has a unifying theory, and that this is a "general theory" in that it applies always and everywhere within its discipline. We argued that for Systemology that unifying theory would be GST*.

- On the basis that this model shows disciplines to have a generic structure and generic dynamics, we suggest that the general theories of all disciplines have a similar structure to each other too, and are also developed insimilar ways. Consequently, we would therefore suggest that GST*, as the general theory of Systemology, will have a similar structure (and developmental pathway) to other general theories in other disciplines. In this section we will therefore expand the generic model of the knowledge base of a discipline, to show the generic structure of the general theory component (and its generic context), and from this propose where to look, and what to model, as we search for a GST*. In this way we hope to present a conception of the scope and structure of a GST* that can guide research towards its development in a more systematic way than has been available previously.

- Our strategy for developing the expanded model of a disciplinary knowledge base is to draw on the history and philosophy of science, by following the stages through which disciplinary activity builds up its knowledge base and guidance framework. We observe that scientific frameworks and core theories are built up cumulatively as scientists (and scientific philosophers) try to answer (or improve answers to) a structured series of generic questions. All these questions can be worked on in parallel, and the answers to each cross-inform the work on others, but overall being able to make good progress with any one is dependent on the progress that has already been made with prior ones.

- For ease of reference, we summarize these questions in Fig. 13, before discussing them in more detail in Sect. 7.2. Each question motivates activity relating to a certain kind of disciplinary content, which we will label for convenience of reference. These terms are either used in conventional ways or in ways that generalize their conventional meanings.

- Answering Q1 and Q2 produces essential precursors to knowledge generation by setting out the empirical boundary and the technical vocabulary for the investigation. The scope of these is conditioned by worldviews, which can be made explicit by answering Q3. In terms of the AKG Model Q1–Q3 represent components of the discipline’s Guidance Framework.

Fig 13

Questions		Content Type	Content Category	AKG Element
1	What qualifies something as a subject entity for the discipline?	Empirical identity criteria for subject entities	Empirical domain boundaries	Guidance Framework
2	How can we describe the subject entities?	Technical terms and definitions	Subject terminology	
3	Why do we limit the scope of the discipline as we do?	Perspectives and narratives about knowledge, nature, life and self	Worldviews	
4	What are the subject entities like?	Descriptions of observable features of empirical entities	Morphology	Data
5	How do they work?	Studies on the processes that produce/ sustain specific morphological features	Morphodynamics	Special Theories
6	How do they come about?	Studies on the intrinsic nature (natural kind) and intrinsic dynamics of the subject entities	Morphogenetics	General Theories

- This framing regulates and enables the building of the discipline’s Knowledge Base. The foundational element of this is the collection and classification of empirical data (Q3). Data represents pre-theoretical knowledge that underpins scientific theory development, and it documents observable features of the subject entities. We will refer to this study area as “morphology”. Data enables theory development, and this commences with activity towards developing specialized explanatory theories about the functions of specific entity features and the particular processes that underlie them (Q4). We will refer to this area of study as “morphodynamics”. Data and specialized knowledge set the stage for work on a natural next question, namely how the subject entities come about (Q6). We will refer to this area of study as “morphogenetics”.

- Q6 is pragmatically addressed viamfour subsidiary questions, namely: *how do the simplest subject entities come about*? *how do complex entities come about*? and *why do certain kinds of entities or entity designs not arise or persist?* The answers to Q6-type questions describe and theorize over factors relevant to all subject entities, and are therefore contributions to the general theories of the discipline. Being common ground for the discipline these theories provide scientific foundations for the unity of the discipline.

- Although strong progress with any of these questions typically requires strong progress with ‘earlier’ questions in this series, it is of course also the case that progress with ‘later’ questions can provide insights that trigger significant revisions of ‘earlier’ work, so that this build-up of knowledge is more like a maturing system than a linear growth process. This ‘feedback’ loop is particularly evident in relation to general theories. Although general theories are concerned with foundational aspects of the discipline, their development requires much prior progress of specialized kinds, and hence scientifically significant general theories typically arrive late in the life cycle of a discipline. However, once they begin to appear they can trigger significant new work and important advances in specialized theories, which in turn can enable new advances in general theory development. They can even cause revision of the domain boundaries, as happened in the separation of Chemistry from Alchemy and Astronomy from Astrology.

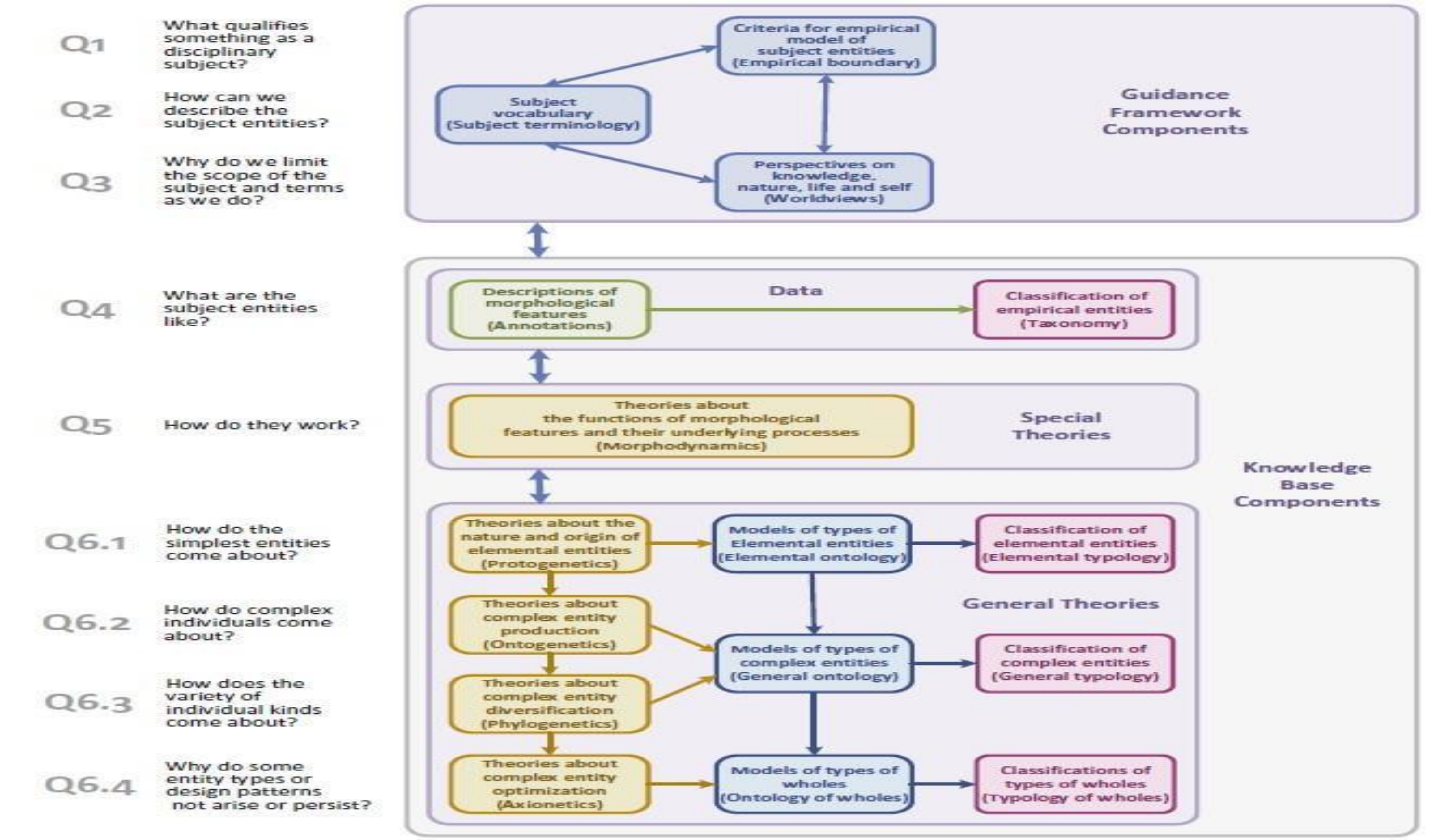
7.2- Core Questions for the Development of a Scientific Knowledge Base

7.2.1- Guidance Framework Questions

- The activity of building up a disciplinary Knowledge Base (Figs 14-15) is conditioned and enabled by three prerequisite elements that form part of the disciplinary ‘Guidance Framework’, namely an empirical definition of the discipline’s subject matter, a specification of descriptive technical terms, and worldviews.

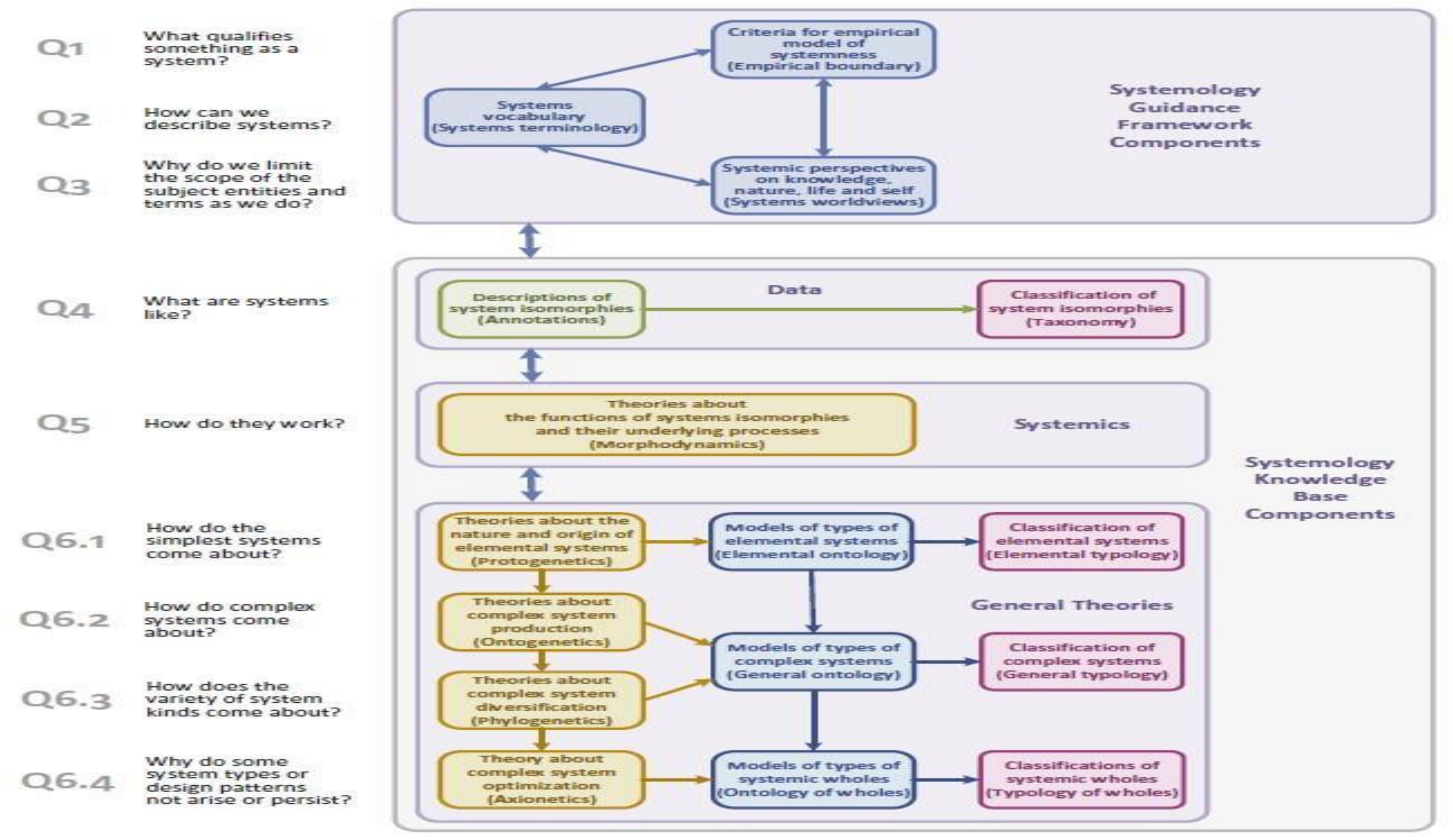
- The key prerequisite for theory building is data collection, and for this we need to establish empirical boundaries for disciplinary inquiry. These limits are set by answering Q1, thus providing a subject definition for the discipline. The definition serves as the initial unifying framework of the discipline, even if only of an administrative or political kind.

Fig 14


Q1
What qualifies something as a disciplinary subject?
Q2
How can we describe the subject entities?
Q3
Why do we limit the scope of the subject and terms as we do?
Q4
What are the subject entities like?
Q5
How do they work?
Q6.1
How do the simplest entities come about?
Q6.2
How do complex individuals come about?
Q6.3
How does the variety of individual kinds come about?
Q6.4
Why do some entity types or design patterns not arise or persist?
Criteria for empirical model of subject entities (Empirical boundary)
Subject vocabulary (Subject terminology)
Perspectives on knowledge, nature, life and self (Worldviews)
Guidance Framework Components
Data
Descriptions of morphological features (Annotations)
Classification of empirical entities (Taxonomy)
Theories about the functions of morphological features and their underlying processes (Morphodynamics)
Special Theories
Knowledge Base Components
Theories about the nature and origin of elemental entities (Protogenetics)
Models of types of Elemental entities (Elemental ontology)
Classification of elemental entities (Elemental typology)
General Theories
Theories about complex entity production (Ontogenetics)
Models of types of complex entities (General ontology)
Classification of complex entities (General typology)
Theories about complex entity diversification (Phylogenetics)
Theories about complex entity optimization (Axionetics)
Models of types of wholes (Ontology of wholes)
Classifications of types of wholes (Typology of wholes)

- Typically, this definition provides empirical criteria for identifying entities of interest, for example in biology the subject entities are ‘organisms’, and they might be identified as entities that jointly have capacities such as respiration, metabolism, reproduction, growth, self-repair, and homeostasis. The subject entity definition forms part of the “domain definition” of the discipline included in the disciplinary guidance framework. This wider definition includes the objectives of the discipline (specifying why the subject entities are studied) and the stance of the discipline (such as specifying limits on how studies might be done for example using ethical criteria).

Fig 15



Q1
What qualifies something as a system?
Q2
How can we describe systems?
Q3
Why do we limit the scope of the subject entities and terms as we do?
Q4
What are systems like?
Q5
How do they work?
Q6.1
How do the simplest systems come about?
Q6.2
How do complex systems come about?
Q6.3
How does the variety of system kinds come about?
Q6.4
Why do some system types or design patterns not arise or persist?
Criteria for empirical model of systemness (Empirical boundary)
Systems vocabulary (Systems terminology)
Systemic perspectives on knowledge, nature, life and self (Systems worldviews)
Systemology Guidance Framework Components
Data
Descriptions of system isomorphies (Annotations)
Classification of system isomorphies (Taxonomy)
Theories about the functions of systems isomorphies and their underlying processes (Morphodynamics)
Systemics
Systemology Knowledge Base Components
Theories about the nature and origin of elemental systems (Protogenetics)
Models of types of elemental systems (Elemental ontology)
Classification of elemental systems (Elemental typology)
General Theories
Theories about complex system production (Ontogenetics)
Models of types of complex systems (General ontology)
Classification of complex systems (General typology)
Theories about complex system diversification (Phylogenetics)
Theory about complex system optimization (Axionetics)
Models of types of systemic wholes (Ontology of wholes)
Classifications of systemic wholes (Typology of wholes)

- ***7.2.1.2- Q2: How Can We Describe the Subject Entities?***
- Data collection entails making descriptions, and for this a precise vocabulary is needed. A vocabulary associated with a field of study is called a “terminology”. To answer Q2 we only need a subset of the discipline’s complete terminology, which we will call the “subject terminology”. The subject terminology provides standardised terms for characterising disciplinary subject entities in terms of standardised concepts. In the context of scientific theorizing the subject terminology represents a controlled vocabulary that provides “formal representations of areas of knowledge in which the essential terms are combined with structuring rules that describe the relationship between the terms”. The full disciplinary terminology also contains other domain-specific technical terms, for example ones needed to specify tasks and tools used in methodologies.

7.2.1.3- Q3: Why Do We Constrain the Scope of Inquiry and Terminology as We Do?

- Drawing boundaries for the empirical scope of the discipline and defining concepts for which we need technical terms involve judgements that are conditioned by the worldviews of the researchers. Making worldviews explicit thus helps to make clear how these judgements about limits and interpretations are grounded in judgements originating to some extent from beyond the discipline.

- There is typically not complete agreement in the discipline about boundaries, and this is especially the case in nascent disciplines. The worldviews of disciplinary members condition how aspects of the disciplinary scope and some of the terms in the subject terminology are interpreted *by those members*. This creates richer possibilities for exploratory activities within science, but as progress is made some convergence of worldviews may occur within a discipline (depending on the subject matter). For example, convergence can occur where one worldview's interpretation of the technical terms or empirical scope of the discipline is more productive than another in terms of making discoveries, developing useful theories, or advancing cultural values such as communal well-being. By making worldviews explicit researchers are better able to reflect on how their worldviews may impede, bias or facilitate both their personal scientific work and their collaborative efforts.

7.2.2- Data Questions

- The primary knowledge in a discipline is the data collected in answer to **Q4**, namely “What are the subject entities like?” These answers represent pretheoretical knowledge about the subject matter and is acquired via observation, experimentation and pre-theoretical analysis. Disciplinary data represents the “morphology” of the subject entities, and it ranges over:
  (i) descriptions that answer the question: *what are the features of subject entities?* These descriptions use terms from the subject terminology to characterize the properties of specimen subject entities in terms of observable characteristics such as form, structure, composition, functions, behaviours, powers, developmental stages, etc. These descriptions constitute what is known as “annotations”. Annotations index entities in ways that enable systematic classification; and

(ii) an empirical classification that answers the question: *what are the relationships between the empirical subject entities?* The classification orders the knowledge about morphological characteristics in a theoretically neutral way, providing a “taxonomy”. Taxonomies are typically based on (statistical) cluster analysis, and yield categories called “taxons”, representing what we will call “empirical kinds” (of subject entities).

7.2.3- Special Theory Questions

- **Q5** is concerned with the issue of “how do the subject entities work?”. The availability of data makes possible the development of theories that explain or predict different aspects of the subject entities’ morphology. This typically proceeds by iteratively addressing the question: *how is each kind of specific morphological feature produced or sustained?* The special theories identify the mechanisms involving processes that produce or sustain the morphological features (including functions) of the subject entities, and jointly constitute a construct we call “morphodynamics”.

- In reflecting how things actually work, rather than merely how they appear to be or what they appear to do, special theories strive for increasing objectivity about the nature of their subject entities, and hence increasing independence from the perceptual constraints implicit in empirical studies. Finding out "how things work" is often thought of as the main or only objective of science, and developing such theories is indeed the major activity in most disciplines. However, scientific work extends also into a further and important area, namely the development of general theories, which is our main concern here.

7.2.4- General Theory Questions

7.2.4.1 Q6: How Do the Empirical Entities Come About?

- Addressing Q6 results in work on the general theories of the discipline, because the answers involve factors relevant to the whole spectrum of subject entities. The reason for this is that in order to answer very general questions in a scientific way we have to transcend the issues around what the subject entities appear to be or what we believe them to be, and try to understand their intrinsic nature. It is by trying to understand entities from an objective or ‘natural’ perspective that we become increasingly able to match “nature’s logic” in the building of explanatory theories about natural systems and systems built from naturalistic components. It is in part because general theories deal with the intrinsic nature of subject entities that general theories provide common scientific grounds for the discipline, and hence scientific foundations for the unity of the discipline.

Q6.1: How Do the Simplest Subject Entities Come About?

- A pragmatic approach to answering Q6 is to begin by trying to explain how the simplest subject entities come about (Q6.1). We will indicate this subfield of morphogenetics by the term “protogenetics”. Q6.1 firstly drives us to first find out what the simplest subject entities are. In general, these have turned out to be *elemental* entities, i.e., all complex subject entities can be viewed as organized compositions of elemental entities. Examples of elemental entities are atoms in Chemistry and cells in Biology. In general, the elemental entities are also the prototypes of the subject entities, in the sense of being historically the first to exist.

- The elemental entities are ‘natural kinds’, that is they represent natural or objective entities rather than empirical or subjective ones. The intrinsic nature of natural entities is determined by the nature of their parts and the nature of the processes that bring the parts into association (and, under some notions of emergence, by how the parts are organized). By such reasoning scientists conclude, for example, that chemical substances are (intrinsically) physical substances composed of physical atoms. The elemental entities can be seen as concrete special instances of an abstract “general elemental model”, for example the atom model in Chemistry and the cell model in Biology. For each kind of general elemental model there is typically a range of concrete instances, for example there are many types of atoms in Chemistry and many types of cells in Biology. This range of types constitutes what we will call an “Elemental Ontology”.

- A central task in formulating a theory about how the elemental entities come about is to work out the principles and mechanisms involved in bringing the parts into organized association. On the basis of having a general elemental model and principles for element production we can work out what types of elements could possibly exist, and the conditions for their synthesis.
- In virtue of the elements sharing a common architecture there are natural relationships between their natural or intrinsic properties, and this can be demonstrated via a kind of classification known as a “Typology”. “Types” are natural or logical categories of entities, in contrast to empirical or statistical kinds which are “taxons”, as explained earlier in relation to taxonomies. Typologies order knowledge in a scientifically significant way, revealing patterns of intrinsic properties across types. Examples of typologies classifying elemental types are the Standard Model in Physics and the Periodic Table in Chemistry. These typologies can be important research instruments, suggesting avenues for scientific exploration and discovery.

- The general elemental model forms an important ‘building block’ in the building of general theories about subject entities. It ‘evolves’ as the discipline matures, and progress with it can radically change the discipline’s perception of the nature and potential of its subject entities. Typically, the generic elemental model proceeds through a series of increasingly sophisticated models that at each stage have significant implications for the general theory of the discipline and for advances in the special theories. For example, in Chemistry the atom model progressed through the ‘spherical impenetrable marbles’ model starting with Democritus and still defended by Newton, to the Rutherford-Bohr model of a positively charged nucleus with electrons in surrounding circular orbits, to the Quantum Mechanical model in which the orbitals are modelled using the wave mechanics developed by Schrödinger.

- Each advance revolutionized our understanding of the nature of empirical chemical substances, and these in turn brought about dramatic advances in technologies and applications that employ chemical substances. Likewise, in Biology the discovery of DNA revolutionized our understanding of the nature of cells, the potentials of simple and complex organisms, and of the evolutionary relationships between organisms.
- There is in this history an interesting implication for the systems sciences, where the notion ‘system’ is still far from settled. Typically, for any discipline the understanding of the nature of its subject entities is ultimately determined by advances in its general theory (especially in its Elemental Ontology), rather than by debates between groups with different perspectives or vested interests. We can therefore expect the issue of what ‘system’ represents to be resolved via a series of advances in general systems theories, and (given the lessons of history) we should expect to be both surprised and empowered by each of the advances.

Q6.2: *How Do Complex Entities Come About?*

- Once we have an understanding of the elemental entities, we have scientific foundations for developing theories about how complex entities develop from simpler beginnings. The study of developmental mechanisms and processes is called “ontogeny” or “ontogenetics”, literally meaning the study of the origin or mode of production of what exists. We are here generalising this term from its use in Biology where it refers only to the origins of individual *organisms*. Examples of ontogenetic theories are those of nucleosynthesis in Physics and embryology in Biology. Ontogenetic theories not only explain the origins and life cycles of individual entities but also enable us to distinguish between entities that are of different types and ones that are merely life-stage forms of a given type, and to explain what types of entities are possible.

- Having identified the range of possible complex types we can explore the relationships between them using typological classifications, once again revealing patterns of properties across types that can be useful for developing either explanatory or exploratory research. Examples of complex entity typologies include Phylogenetic Trees in Biology and the Hubble Galaxy Sequence in Astronomy.

Q6.3: How Does the Variety of Complex Entities Come About?

- Developmental theories explain some of the observed diversity of subject entities, by showing how some of this variety reflects merely different life cycle stages of the same type of entity. However, this does not account for all the observed diversity, indicating the existence of multiple developmental trajectories with different kinds of starting points. This calls for theories explaining mechanisms whereby new types of entities can arise from existing types. Typically, this would involve mechanisms that modulate existing morphodynamic and ontogenetic processes to produce starting points from which new kinds of complex individuals can be developed. An example is Darwin’s theory of evolution by mutation followed by natural selection of the best adapted individuals.

- Evolutionary mechanisms and processes are studied under a construct called phylogenetics, and we propose that this term be applied in a wide sense referring to the origins of all kinds of "tribes" of types of entities, not just "tribes of organisms" as is the current practice.

Q6.4: Why So Some Entity Types or Design Patterns Not Arise or Not Persist?

- Developmental theories explain how complex individuals come about, and evolutionary theories how kinds of complex individuals come about. This leaves unanswered another general question about the subject entities, namely: *why, amongst all the variety of kinds and types that are theoretically possible, do some types and patterns not arise or not persist?*

- Another way of posing the above question is to ask: *why do things work as they do?* In general, there are many different organizational patterns that can perform the same functions, so why do the things that actually exist have the specific functional patterns they do? Such issues are studied under a construct we will call "axionetics". Axionetics studies the interactions between the productive, developmental and evolutionary possibilities of specific designs and the constraints entailed by operational or existential contexts. This balancing interplay can be seen both in the genesis of natural systems and engineered systems.

- To answer Q6.4 we have to develop theories about how things are “channelled” towards the forms they attain by mechanisms or processes that seek to optimize designs not only for functional parameters but also against system “value criteria” such as efficiency, effectiveness, low resource reqyuirements, and ease of repair. Such criteria can only be met by taking into account the various kinds of environments in which the entity operates, and it is by being optimized for their complex environmental contexts that entities acquire traits such as resilience, robustness, evolvability and so on.

- Regarding natural systems there is a shift in perspective here from the orthodox evolutionary one, in which change originates in the individual (for example genetic mutation or intellectual creativity) and the environment then selects for survival: the axionetic perspective recognizes that the environment is also a complex source of change, that the entities have adaptive or regulatory powers that can facilitate or oppose the selection features in its environments, and that environments can be modified in significant ways by the dynamics of embedded entities. In this light we can see that entities and environments evolve together via an interplay of their respective change mechanisms and respective adaptive/regulatory mechanisms, and resilience comes from optimization over the design of the entity-environment whole. For engineered systems their design is likewise modulated by a trade-off between technical capabilities and socially-determined contextual value criteria.

- The models involved in axionetics can provide deep insights into why things have turned out as they have, and what might be viable possibilities for the future. In complex nature it is the axionetic principles that underpin viability, resilience and sustainability, and in complex socio-ecological scenarios it is through the understanding of axionetic principles, and the use of axionetic models, that we can have a reasonable hope of minimizing unintended consequences of our actions, interventions and technological productions.
- Axionetic theories see subject entities in terms of wholes comprising subject entities embedded in environments in a way that drives continuous optimization of entity designs. This represents an important shift in the scientific perspective, in recognizing that entities cannot be properly understood when studied without consideration for the optimality of their designs for different systemic environments/ contexts.

- It is of course the case that developmental and evolutionary theories also take environments into account, but the focus here is different: developmental theories tell us about the processes that build things that can perform specific functions, and evolutionary theories tell us about processes that enable the building of things that can perform new kinds of functions, but axionetic theories tell us how the designs of working things become elegant, and hence how entities become robust and resilient even though their environmental context can fluctuate over their lifecycle. Axionetic theories are explicitly systemic theories, whereas in general the systemic nature of scientific theories is not always so overt.

- Axionetic theories lead us to recognize a special kind of systemic whole in nature, where entities are simultaneously parts in what can be modelled as multiple overlapping contexts, are optimized for balance with each type of context, and continuously rebalancing their optimality in the face of continuous change. This kind of whole represents a kind of nested panarchy,16 rather than the hierarchical wholes of more classical approaches. There are multiple ways in which entities can be configured to achieve an elegant harmony with their multiple environments, and multiple ways in which a panarchy can adjust to balance the activities of dynamic embedded parts. Ecosystems are examples of such wholes, and an Ecosystem Panarchy provides an example of a typology of axionetic wholes.

- The axionetic perspective on systems brings into focus an aspect of systemness that has received insufficient attention in terms of theory development. Current debates about the nature of systems are often focused on systems more-or-less as they are at a moment in time, for example debates about emergence consider the consequences of the concurrent relationships amongst present parts of the system, and Koestler's famous "holon" model considers a system's properties as determined by a balance between the consequences of the concurrent interactions between the parts of the entity and the concurrent interactions of the entity with its environment. These perspectives tend to de-emphasize the idea that the diachronic evolution of systemic designs towards increasingly elegant configurations embedded in (consequently) increasingly stable environments is an inherent rather than coincidental aspect of systemness. This is a regrettable neglect, for axionetic theories of systemness may provide us with the most profound insights into the nature and potentials of systems.

*7.3- Modelling the Structure of GST**

- Following the model of a generic Disciplinary Knowledge Base developed in the previous sections, we can now represent the data and theories of Systemology in the same way, as answering the same general questions *mutatis mutandis*, for example What counts as a system? What are systems like? How do systems work? How do systems originate, develop, and evolve? Why are some kinds of systems more resilient than others? This then generates the same knowledge components with the same relationships between them as in the generic model. This leads to a structure for Systemology’s knowledge base as shown in Fig. 15.

- The structure presented in Fig. 15, provides us with a useful framework for developing GST*, as it frames the required elements in detail and in familiar terms, in a way that is consistent with the general structure of general theories in orthodox disciplines. The structure allows us to make a more detailed inventory of what we already have in hand, devise targeted strategies for developing the components in a systematic way, and make a more confident assessment of the potential value of GST*.

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7.4- Completing the Diagram of the Structure of a Disciplinary Knowledge Base

- A complete knowledge base also includes kinds of hybrid theories and kinds of methodologies. We will now briefly discuss these extra components and then update the model of a knowledge base, so as to provide a complete view of the structure of a disciplinary knowledge base. This is an easy extension of the model already provided, but as we will discuss at the end this provides a model with significant additional utility.

7.4.1- Hybrid Theories

The world is complex in ways that do not always fit into the neat categories of the individual disciplines, and this creates the need for interdisciplinary work. Such work eventually leads to hybrid theories representing a synthesis of two or more specialised perspectives on a single phenomenon, for example neuropsychiatry or biochemistry. Each one of the special and general theories of a discipline can become the basis for such an interdisciplinary synthesis, significantly extending the utility of a discipline.

7.4.2- Methodologies

- In a discipline, methodologies typically arise as soon as data collection starts, providing heuristics for action and technological applications (for example selective breeding programs appearing before scientific theories of evolution, and pottery glazes developed before scientific theories of Chemistry). Once theories are developed each kind of theory can provide insights which can facilitate the development of new/improved methodologies for new/improved kinds of interventions and technological applications. This holds for special, general and hybrid theories. As with the development of theories, methodologies develop cumulatively as data collection and theory development expands, and as with theory development ‘earlier’ methodologies can be significantly revised on the basis of results derived from the application of ‘later’ methodologies and advances in ‘later’ theoretical frameworks.

7.4.3- Complete Structure of a Disciplinary Knowledge Base

- We can now add the hybrid theories and methodologies to Fig. 15 to produce the complete model of a Disciplinary knowledge Base as shown in Fig. 16. With this structure in hand, we can now draw the same diagram for the structure of the Knowledge Base of Systemology, as shown in Fig. 17.

Fig 16

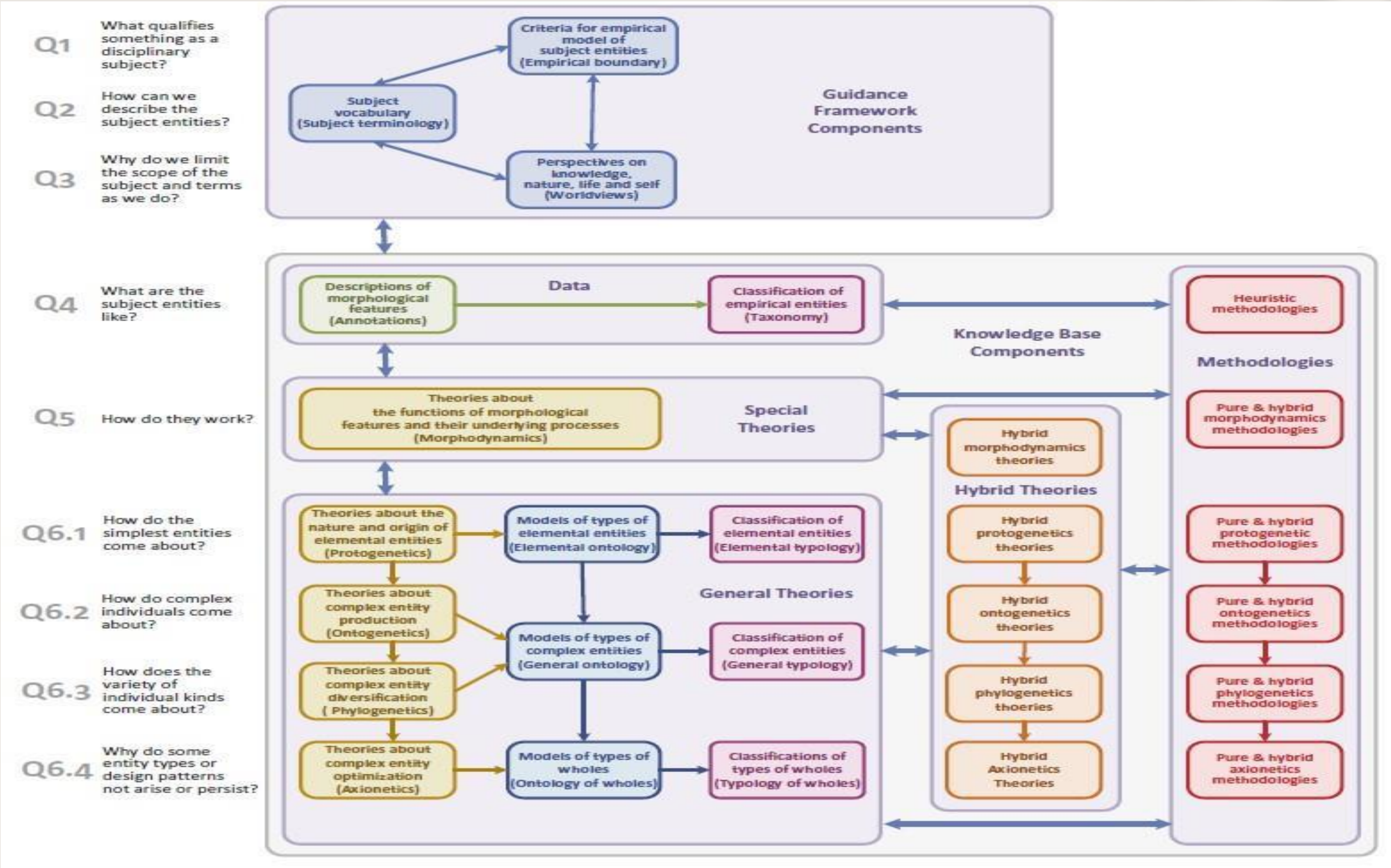
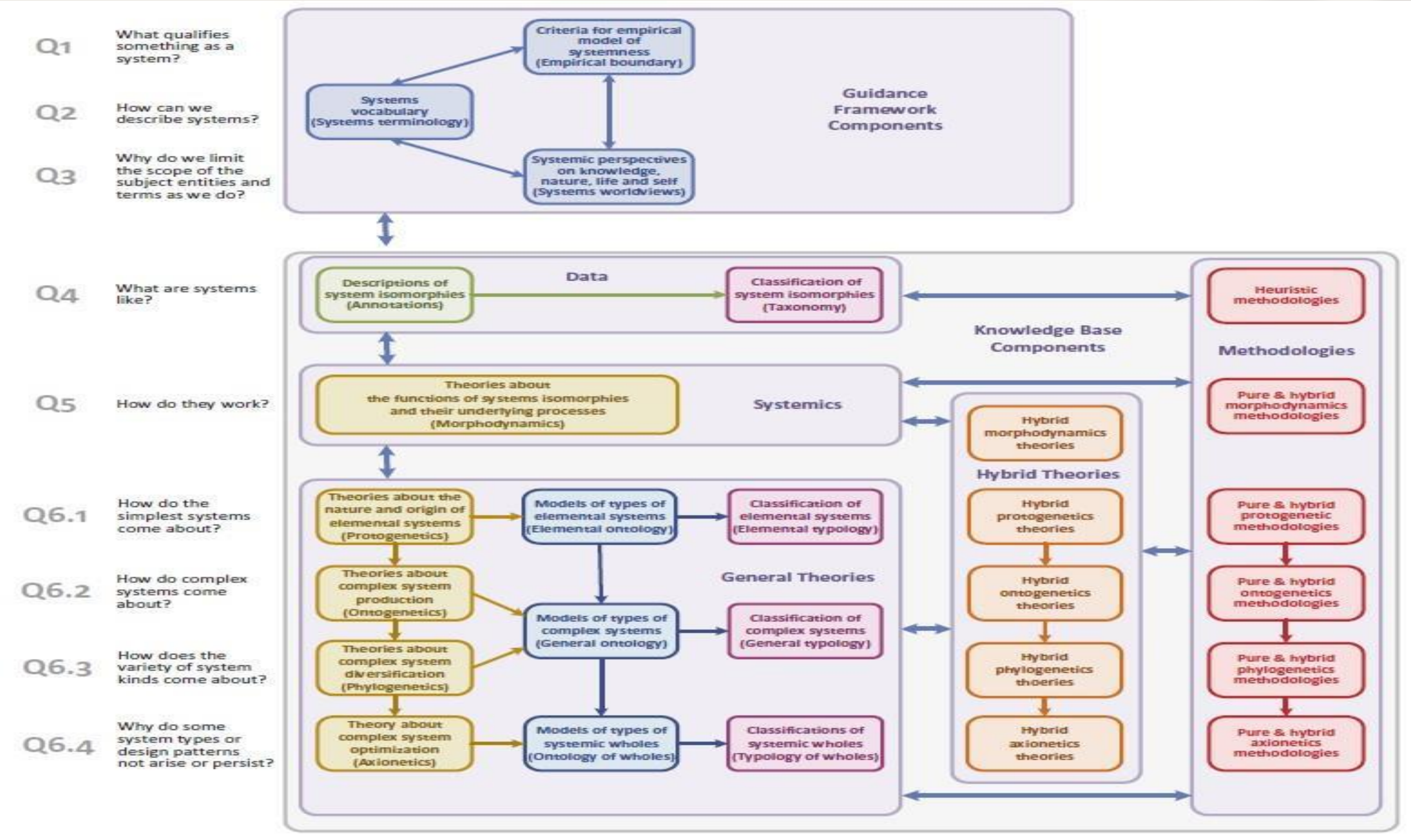

Q1
What qualifies something as a disciplinary subject?
Q2
How can we describe the subject entities?
Q3
Why do we limit the scope of the subject and terms as we do?
Criteria for empirical model of subject entities (Empirical boundary)
Subject vocabulary (Subject terminology)
Perspectives on knowledge, nature, life and self (Worldviews)
Guidance Framework Components
Q4
What are the subject entities like?
Data
Descriptions of morphological features (Annotations)
Classification of empirical entities (Taxonomy)
Knowledge Base Components
Heuristic methodologies
Methodologies
Q5
How do they work?
Theories about the functions of morphological features and their underlying processes (Morphodynamics)
Special Theories
Pure & hybrid morphodynamics methodologies
Hybrid morphodynamics theories
Hybrid Theories
Q6.1
How do the simplest entities come about?
Theories about the nature and origin of elemental entities (Protogenetics)
Models of types of elemental entities (Elemental ontology)
Classification of elemental entities (Elemental typology)
Hybrid protogenetics theories
Pure & hybrid protogenetic methodologies
Q6.2
How do complex individuals come about?
Theories about complex entity production (Ontogenetics)
General Theories
Models of types of complex entities (General ontology)
Classification of complex entities (General typology)
Hybrid ontogenetics theories
Pure & hybrid ontogenetics methodologies
Q6.3
How does the variety of individual kinds come about?
Theories about complex entity diversification (Phylogenetics)
Hybrid phylogenetics thoeries
Pure & hybrid phylogenetics methodologies
Q6.4
Why do some entity types or design patterns not arise or persist?
Theories about complex entity optimization (Axionetics)
Models of types of wholes (Ontology of wholes)
Classifications of types of wholes (Typology of wholes)
Hybrid Axionetics Theories
Pure & hybrid axionetics methodologies

Fig 17


Q1
What qualifies something as a system?
Q2
How can we describe systems?
Q3
Why do we limit the scope of the subject entities and terms as we do?
Q4
What are systems like?
Q5
How do they work?
Q6.1
How do the simplest systems come about?
Q6.2
How do complex systems come about?
Q6.3
How does the variety of system kinds come about?
Q6.4
Why do some system types or design patterns not arise or persist?
Criteria for empirical model of systemness (Empirical boundary)
Systems vocabulary (Systems terminology)
Systemic perspectives on knowledge, nature, life and self (Systems worldviews)
Guidance Framework Components
Data
Descriptions of system isomorphies (Annotations)
Classification of system isomorphies (Taxonomy)
Knowledge Base Components
Methodologies
Heuristic methodologies
Systemics
Theories about the functions of systems isomorphies and their underlying processes (Morphodynamics)
Pure & hybrid morphodynamics methodologies
Hybrid Theories
Hybrid morphodynamics theories
Hybrid protogenetics theories
Hybrid ontogenetics theories
Hybrid phylogenetics theories
Hybrid axionetics theories
General Theories
Theories about the nature and origin of elemental systems (Protogenetics)
Theories about complex system production (Ontogenetics)
Theories about complex system diversification (Phylogenetics)
Theory about complex system optimization (Axionetics)
Models of types of elemental systems (Elemental ontology)
Models of types of complex systems (General ontology)
Models of types of systemic wholes (Ontology of wholes)
Classification of elemental systems (Elemental typology)
Classification of complex systems (General typology)
Classifications of systemic wholes (Typology of wholes)
Pure & hybrid protogenetic methodologies
Pure & hybrid ontogenetics methodologies
Pure & hybrid phylogenetics methodologies
Pure & hybrid axionetics methodologies

7.4.4- Potential Value and Uses of the Detailed Knowledge Base Model

❖ The model of a Disciplinary Knowledge Base developed here can be of value in multiple ways, especially to nascent disciplines and for the study of phenomena not yet scientifically understood.

Firstly, it can be used as a framework for making an inventory of current knowledge holdings. This can be useful in several ways, for example:

• putting the work of different researchers into context relative to each other, thus identifying connections that suggest opportunities for productive synthesis or collaboration;

• identifying key knowledge gaps in the discipline in support of formulating strategically prioritized research agendas; and

• defining the resources or skills needed to extend or leverage the disciplinary data, theories or methodologies, and hence to define disciplinary roles and associated skills matrixes required for data collection, theory development, methodology development and practical application.

Second, the structure of the Knowledge Base can be used to develop a classification framework for indexing disciplinary knowledge, making it accessible to systems researchers in a principled way.

Third, because the structure reflects work of increasing sophistication due to the progression of inquiry-driving questions, this can be used as the beginnings of a framework for a maturity model of the discipline. This is important for assessing the potential and current competence of the field, and for developing appropriate agendas for research, fundraising, recruitment and education.

Fourth, because it reveals the dependencies between different kinds of knowledge, the structure can serve as a guideline for knowledge development in young disciplines or for the study of puzzling phenomena, so as to avoid squandering resources on attempting sophisticated 'late stage' theory building when 'early stage' theories are still very immature or absent, and to ensure that appropriate foundations are developed for each stage of theory development.

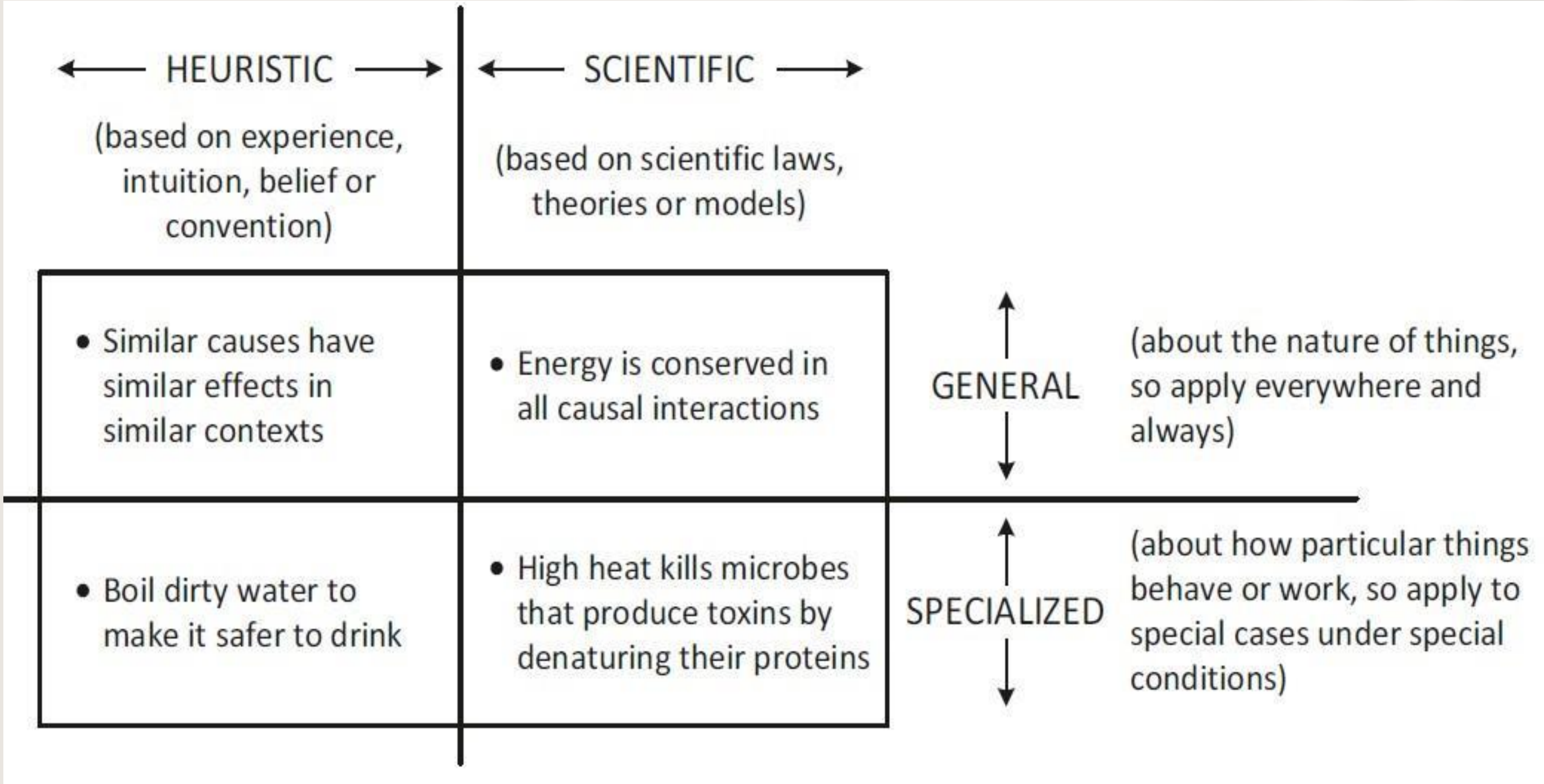
8- Scientific Principles for General Systemology

8.1- The Nature and Role of Scientific Principles

8.1.1- What Are 'Principles'?

- A 'principle' is a fundamental idea or rule that can provide guidance for making a judgement or taking action. Principles can take the form of injunctions, beliefs, concepts, assumptions or insights. Principles can range from fully heuristic ones (distilled from experience, intuition, belief or convention) to fully scientific ones (distilled from scientific theories or models). Principles are encountered in every sphere of human activity, so we have for example principles relevant to ethics, aesthetics, economics, politics, science, engineering, agriculture, etc.

Fig 18


HEURISTIC
(based on experience, intuition, belief or convention)
SCIENTIFIC
(based on scientific laws, theories or models)
• Similar causes have similar effects in similar contexts
• Energy is conserved in all causal interactions
GENERAL
(about the nature of things, so apply everywhere and always)
• Boil dirty water to make it safer to drink
• High heat kills microbes that produce toxins by denaturing their proteins
SPECIALIZED
(about how particular things behave or work, so apply to special cases under special conditions)

- Examples of principles (Fig 18) include the heuristic principle “do as you would be done by” and the scientific principle that “energy is conserved in all causal interactions”. Historically, principles start out as heuristics, and over time some become more scientific. As principles become more scientific, they become more useful for making apt judgements or taking effective action. By “more scientific” principles we mean principles that more strongly reflect the scientific approach, that is, use clear and precise concepts, express qualities and relationships that can be subject to measurement, quantification, empirical verification or falsification, and so on. In this sense scientific principles can arise in philosophy, science, engineering and operational/service contexts. The scientific enterprise can be viewed as aimed at making principles across these domains increasingly scientific. All domains that seek to develop or employ such principles can be considered to be scientific disciplines, becoming more scientific over time as their principles become more so.

- Note that we make a distinction between “scientific principles” in the sense just explained and “science principles”, i.e., the principles underpinning science. It is a separate question whether the principles underpinning disciplines such as sociology, anthropology, economics, politics or psychology are scientific or not.

- Both heuristic and scientific principles can be either general (applying universally, for example conservation of energy) or specialised (applying only in specific contexts, for example the principles of disease prevention).

- The effectiveness of science depends on having strong principles underpinning scientific research methods, and the progress of science at a fundamental level (such as the discovery of new substances or new laws of nature) depends on having strong general principles. For example, specialized laws of nature, for example Boyle’s Law that states the balancing relationship between pressure and volume in an ideal gas, are instances of general principles such as that energy is always conserved or that effects have sufficient causes. General principles are powerful guides for exploring phenomena for which adequate theories do not yet exist.

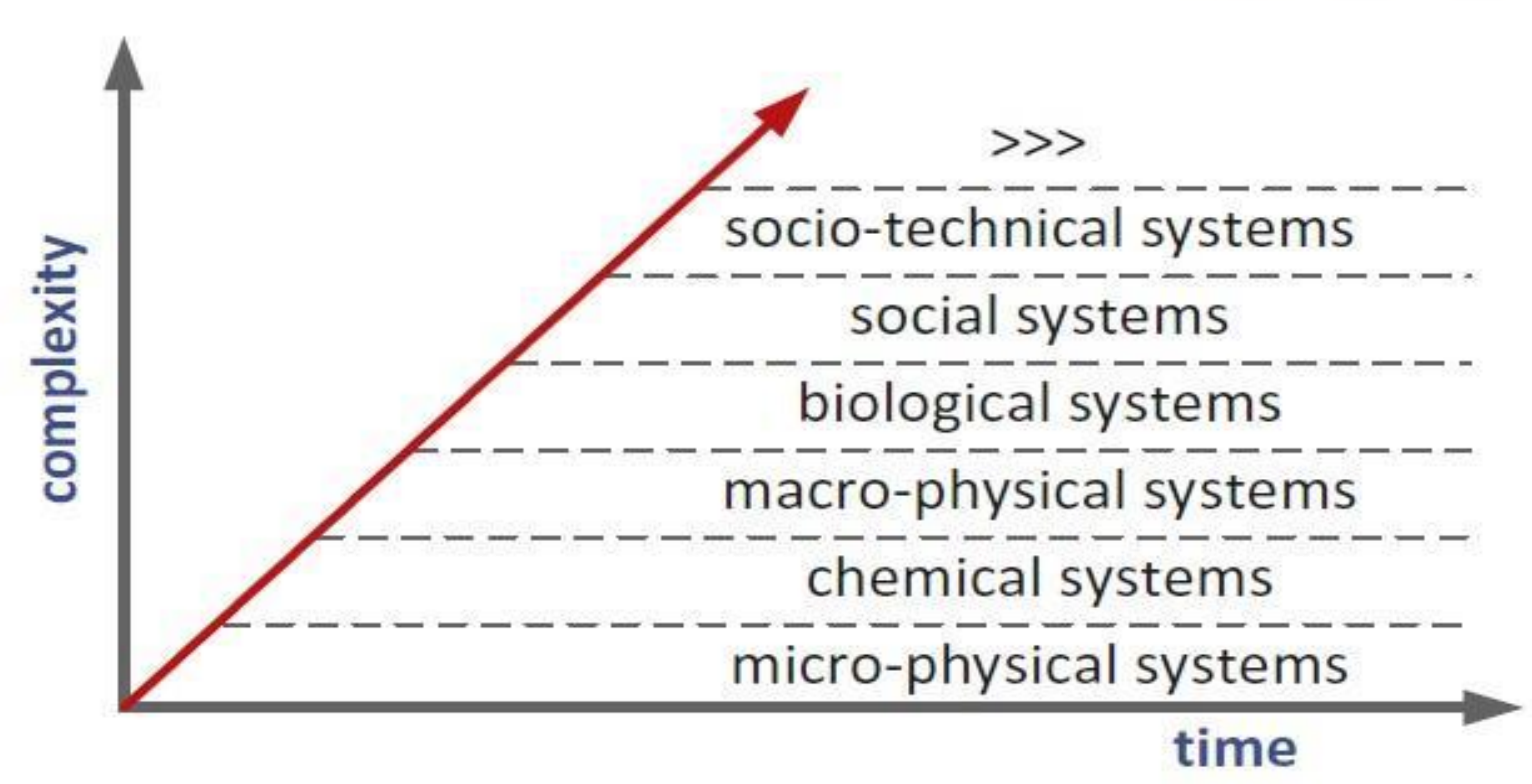
8.1.2- What Are Systems Principles?

- From the understanding of the nature of principles just presented we can now say that *systems* principles are fundamental rules, beliefs, ideas or insights about the nature or workings of systems, and hence systems principles guide judgment and action in systemic contexts. Systems principles will therefore exist in both heuristic and scientific forms, and in both general and specialised forms. Moreover, general scientific systems principles will have the same relevance for systems laws, and for exploratory systems research, as the relationship just described for the sciences more broadly.

8.1.3- Systems Science and Its Relationship to Principles

- A starting point for thinking about Systems Science is the view that every concrete thing is a system or part of one, and that natural systems can be arranged into a "complexity hierarchy", in which every level corresponds to some kind of system and the 'levels' represent increasingly complex systems embedding systems from the 'lower' levels, as shown in a simplified way in Fig 19.
- The system levels in the complexity hierarchy correspond to the subjects of concern of the mainstream specialised scientific disciplines, so it can be said that every specialised scientific discipline studies some kind of system. Note however that this does not make these disciplines systems sciences, since it is only trivially true that their subjects are systems. These specialised disciplines do not have as their subject matter systems *as systems* but rather they seek to understand instances of kinds of systems.

Fig 19


>>>
socio-technical systems
social systems
biological systems
macro-physical systems
chemical systems
micro-physical systems
complexity
time

- The idea of a science of systems arises from three reflections on the complexity hierarchy:

  1. First, given that systems occur on every level of the complexity hierarchy, a science of systems must be about what is true of or possible for systems across all the levels. This is the insight behind the claim that System Science will be a transdiscipline, having relevance across the disciplinary spectrum, and will comprise theories that are scale-free and composition-independent. At a minimum,such a science must involve concepts and principles that allow systems to becharacterised as a category of analysis distinct from things that are *not* systems, to enable instances of systems to be identified in the real world, and to explain/predict the behaviour and potential of systems as *systems*.

2. Second, when looking across the levels we find similar patterns recurring across multiple levels, for example spiral forms in certain tropical storms, sea shells, flowers and galaxies. Speaking metaphorically, these patterns represent solutions to Design problems that nature must solve in order to create enduring complex structures. The existence of these isomorphically recurring patterns across changes in scale and composition entails that there must be transdisciplinary specialized systems principles reflecting the nature of these ‘solutions’. In principle each of these patterns can be ‘decoded’ to establish a theory that explains the nature and function of the observed pattern, and to identify the relevant explanatory principles. Each such theory would then be a specialized systems science theory, and we have several of these already (for example Control Theory, Hierarchy Theory, Network Theory, Communication Systems Theory, Theory of Dissipative Structures etc.). There are still many patterns in nature we do not theoretically understand. Moreover, it is likely that there are further patterns we have not yet identified.

3. Third, the isomorphically recurring patterns arise independently in multiple contexts involving different scales, compositions and developmental histories. This suggests that there are general systems principles that provide for the possibility of the *emergence* of these systemic patterns across contexts. Speaking loosely, these would be general principles about how Nature 'finds' solutions, rather than (as above) specialised principles about how specific kinds of solutions work. We have very limited knowledge of such general systems principles,2 but in principle they hold the promise of a general theory of systems that would explain both the emergence of specialized patterns and the relationships between them. Such a 'general systems theory' (GST*) would be very valuable not only for unifying the body of specialised systems knowledge but also for opening up new routes to discovery.

8.1.4- The Role of General Principles in a Scientific Discipline

- There are multiple terminologies and perspectives in science and in philosophy on the nature of the relationships between general principles, laws, theories and models. For present purposes, we will follow a perspective called Scientific Realism, which is presently the dominant view amongst metaphysicians of science, is well matched to the working practice of practicing scientists and is consistent with the General Systems Worldview as discussed earlier. Briefly, Scientific Realism posits that a concrete world exists independently of our mental states, that the truth of our theories depends on the nature of the world, and that our best scientific theories are approximately true of the world. Within the framework of Scientific Realism we propose following a model known as the "Principles Laws-Theories" (PLT) model of modern science. For present purposes we will focus only on its notion of principles.

- The PLT model represents an early attempt (1996) in the modern resurgence of metaphysics to show how modern science depends on metaphysical principles and how such principles relate to scientific laws and scientific theories. The metaphysics of science has advanced rapidly in the last two decades, but in our view the basic structure of the PLT model is still the most practically useful framing we have of these relationships. We will however, expand the model to make the dynamics of scientific developments and the connection to worldviews more explicit.

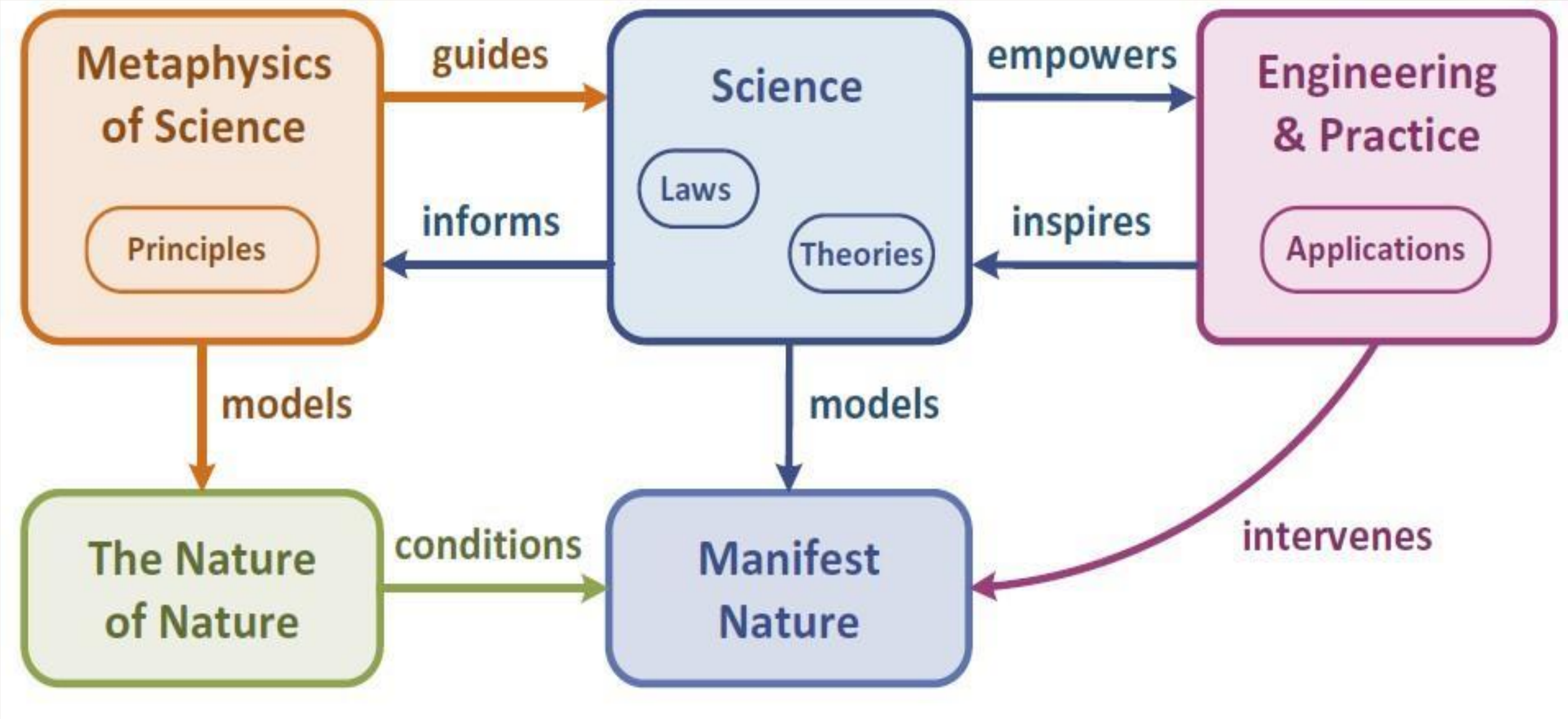
- In science, general principles articulate the most fundamental assumptions we make about the nature of the world. They represent what we take to be true in general, and hence fulfil a number of orienting functions, including:
  (a) Encapsulating what is deemed ontologically or metaphysically possible or inevitable (for example, the "Principle of Sufficient Reason", which claims that effects have proportionate causes, is a presumption against the occurrence of miracles);
  (b) Setting bounds of scientific forms of reasoning (for example the "Principle of Uniformity of Nature", which claims that under the same conditions the same causes always produce the same effects, presents one way in which evidence can be linked to conclusions or predictions);

(c) Providing guidelines for doing science (for example the “Energy Conservation Principle” provides a way of checking that all the contributors to a given effect have been identified), and
(d) Defining basic concepts (for example, ‘energy’, ‘force’ and ‘atom’).

- The principles of science are grounding *assumptions* and hence not provable by science. However, they are provisional and can be challenged and amended. Nevertheless, they are regarded as representing deep truths about the nature of the world, and their formulation and evolution is informed by progress in science. They express what we take to be the conditions for the possibility of the empirical phenomena observed by sentient beings. In this way the principles of science represent the invisible reality underlying the phenomenal one, and form part of metaphysics rather than science.

- Taken together, the principles of science characterize the nature of Nature, so we might say that our image of the nature of Nature is the gestalt that reconciles the joint entailments of the principles (rather like the elephant image that reconciles the observations of the seven blind men). These relationships are illustrated in a simplified way in Fig. 20. Changes in the principles can have dramatic consequences for the scientific paradigm, as for example occurred when the Newtonian notion of “mass” was redefined by Einstein’s General Relativity theory.

Fig 20


Metaphysics of Science
Principles
guides
Science
Laws
Theories
informs
empowers
Engineering & Practice
Applications
inspires
models
models
intervenes
The Nature of Nature
conditions
Manifest Nature

- Principles generally start out as qualitative heuristic principles based on limited observations, and later on (typically with great difficulty) become exact, quantifiable and profound. For example, the (heuristic) Aristotelian notion of a force defined a force simply as a push or a pull, while the (scientific) notion from Newton was quantitative and carried profound implications, triggering the “Mechanical Revolution”.

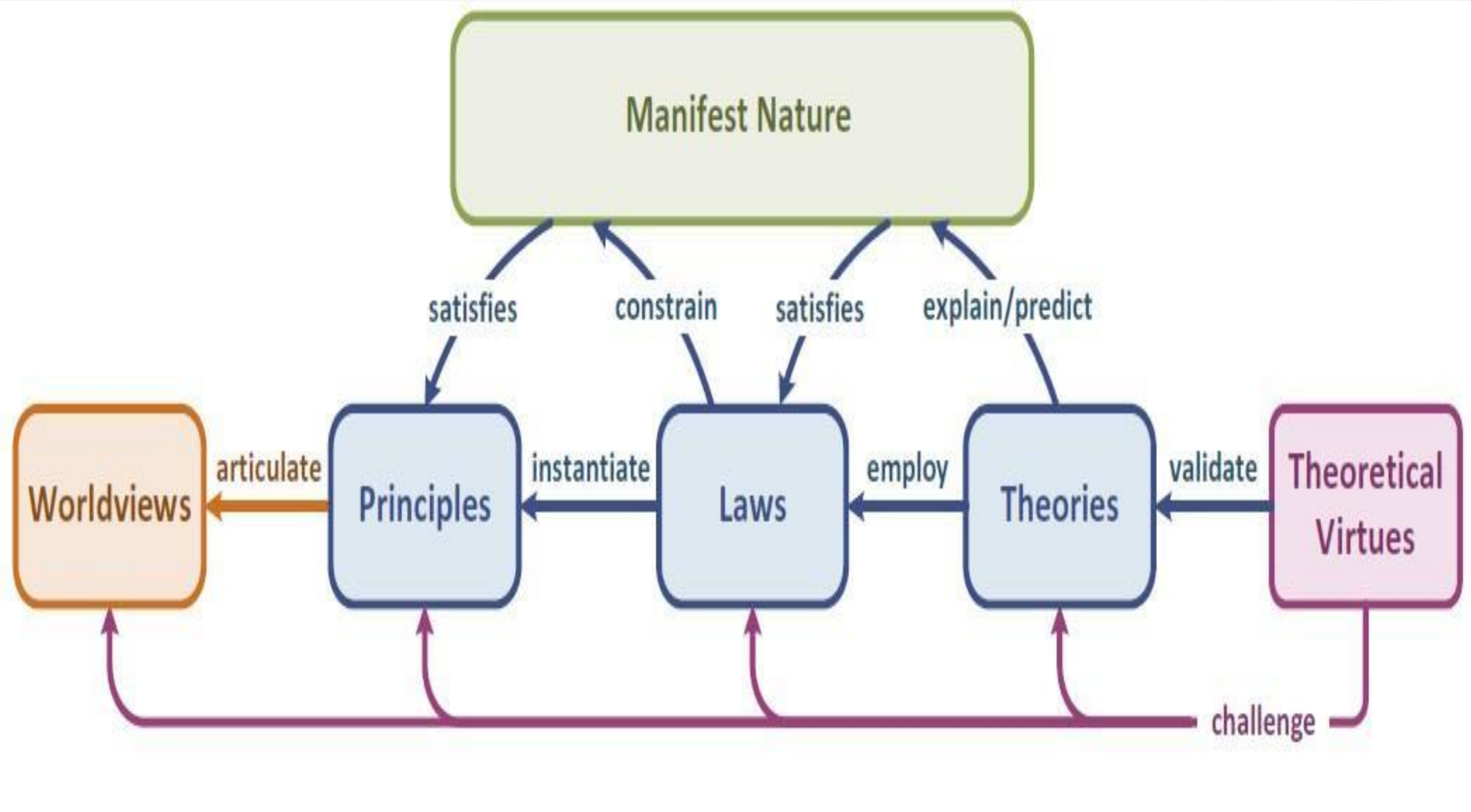
- Note that principles as stated here typically do not explicitly take the form of a guideline, framed as for example “if you want x in context y then do z”. However, if the principle is understood it can be interpreted as a guideline and hence be applied in taking action or making a judgement. For example, the principle that energy is conserved in all causal interactions is equivalent to a guideline that says if we wish to scientifically explain an effect, we can identify the causes by tracing the flows of energy along space-time tracks towards the final state. The same can be said for those *concepts* that are treated as principles. For example, the concept ‘force’ as defined by Newton is equivalent to a guideline that says if you want to explain something’s state of motion you have to identify the balance of forces acting on it.

8.1.5- The Interdependence of Principles, Laws and Theories

- Principles, laws and theories interdepend systemically, and this conditions how they are discovered, used and evolve. The “PLT model” mentioned earlier captures these relationships well, as illustrated in Fig. 21 and explained below.

- The guiding principles for doing science (for example that similar causes produce similar effects) express general assumptions or accepted general insights about the nature of the world, and therefore the general principles jointly form the most succinct expression we have of our worldview. Conversely, if we can describe our worldview we can distil general principles from it.

Fig. 21


Manifest Nature
satisfies
constrain
satisfies
explain/predict
Worldviews
articulate
Principles
instantiate
Laws
employ
Theories
validate
Theoretical Virtues
challenge

- Once we can state the principles we can apply them to observations of causal interactions to discover laws of nature, which are exemplars of the principles in specific contexts. For example, Boyle’s Law specifies how an increase in the pressure of an ideal gas will cause it to proportionately expand in volume, in conformance with the general principle that all effects have proportionate causes (under given conditions). Conversely, laws can be generalised to suggest new principles, for example Kepler’s second law, which states that planetary orbits sweep out equal areas in equal time, can be generalised to suggest the Principle of the Conservation of Angular Momentum.

- By applying laws we have derived in this way to observations of previously poorly understood phenomena we can develop models and theories that explain or predict those phenomena. For example, we can apply Newton's laws of motion of massy objects to data from astronomical observations to build a theory that explains why we have two ocean tides per day, or to build a model that predicts the return of specific comets.
- An interesting nuance is added by the fact that in practice there are often multiple ways of explaining the same phenomenon. To choose between them, competing theories or models are judged as to how "good" they are by evaluating them against "theoretical virtues" such as explanatory power, predictive power, simplicity, falsifiability, coherency, empirical adequacy, consistency with well-established theories. Philosophy of science has shown that theories that are 'good' in this sense are 'better' because they tend to last longer before they are superseded, are more likely to lead to new insights, are more likely to evolve into even more powerful theories rather than just be discarded, and so on.

- If we cannot develop “good” theories about a given phenomenon, we must question the adequacy of the laws they employ: perhaps these need additions or refinements, or we need extra ones. To discover new or improved laws we have to reflect on our principles, because laws are special cases of how the principles play out under specific conditions. By making further careful observations of the puzzling phenomena, and then carefully applying our principles, we might find better or further laws, which we can then use to develop more powerful theories and models. If despite these efforts we still cannot devise ‘good’ theories, we must then cast doubt on our principles. We generally refine or extend them by generalising from laws we already have, or by distilling them from the assumptions entailed by our worldviews, so if we are questioning our principles, we have to consider both possibilities.

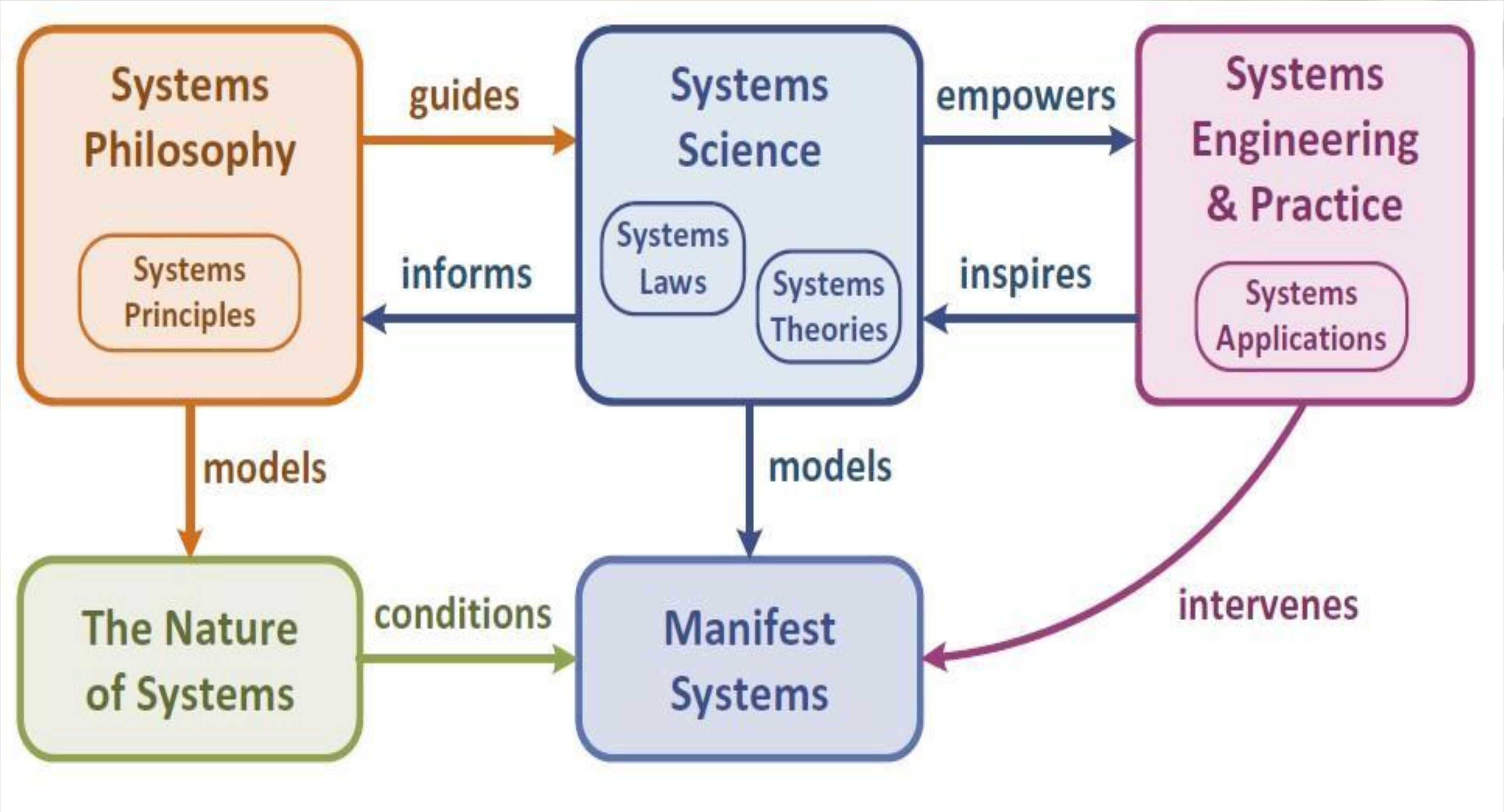
- As a first step we could review our current stock of laws and reflect on whether there are opportunities for hitherto unforeseen generalizations that could help us build the better theory we need. In general, discovery often works this way, for example Kepler's second law was discovered before the generalized principle it instantiates (conservation of angular momentum) was known. However, if new or improved principles cannot be found in this way, or what we do find does not help us to improve/extend our laws such that we can build good theories, then we must question our worldviews, reflecting on how we balance between knowledge, experience and intuitions to find the core beliefs that ground our basic judgements and actions, and hence we must try to form an adjusted worldview from which we can then adjust or extend our principles, laws, theories and models.

- In this manner, assessments against the theoretical virtue criteria help to drive the evolution of theories, laws, general principles and worldviews in a systemic way. If Systems Science is a scientific endeavour then it will follow the same pattern of discovery and evolution as we search for scientific systems principles, laws and theories, so it is helpful for systemists to understand these interrelationships in our quest to find routes to discovering them.
- It may be useful to note that in order to effectively leverage this insight it is advisable to adopt the methods and language already in use in science and philosophy to model this process and capture its outcomes, so that we can maximise the lessons we can learn from established science and the metaphysics of science, and minimise the effort needed to integrate the findings of Systems Science back into the established body of science. For example, accepting “scientific principles” as denoting our most general assumptions about the nature of the world, then entails that scientific “systems principles” express our most general assumptions about the systemic nature of the world.

8.1.6- The Nature and Significance of General Systems Principles

- The content of Systems Science is distinct from that of the specialized sciences, but the structure of Systems science is likely to be no different from that of the rest of science. From this brief review we can thus form some idea of the scope and potential of systems principles. We can directly paraphrase the above discussion for the systems case as illustrated in Fig. 22.
- The correspondence between these two diagrams lies in the observation that Systems Philosophy models the systemic nature of the nature of Nature, and Systems Science models the systemic nature of manifest systems. Paraphrasing what was said above about our image of Nature, we can now propose the following:

Fig. 22

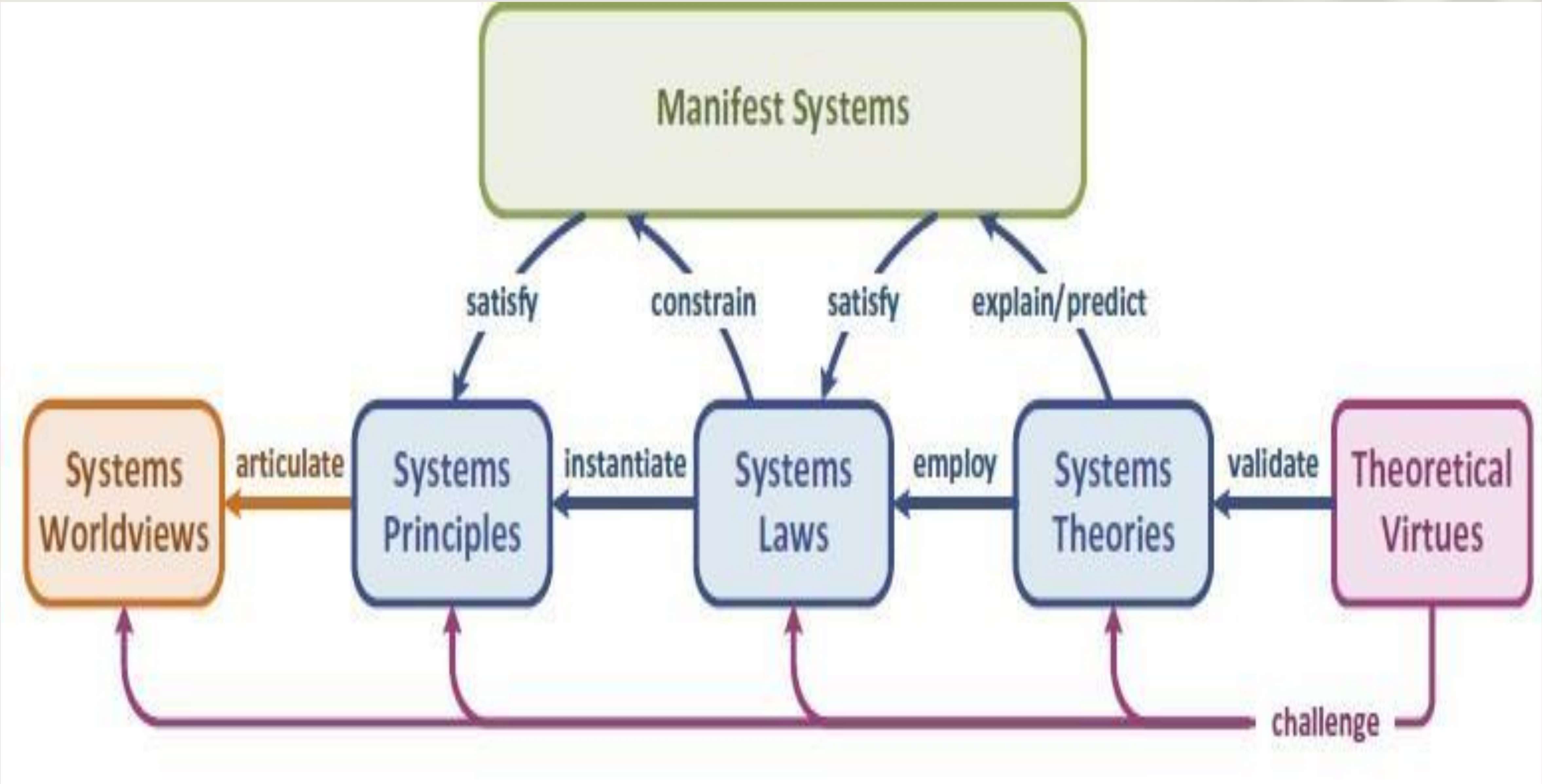

Systems Philosophy
Systems Principles
guides
Systems Science
Systems Laws
Systems Theories
empowers
Systems Engineering & Practice
Systems Applications
informs
inspires
models
models
intervenes
The Nature of Systems
conditions
Manifest Systems

- General systems principles are the grounding assumptions of systems science, and hence not provable by systems science. However, they are provisional and can be challenged and amended. Nevertheless, they are regarded as representing deep truths about the systemic nature of the world, and their formulation and evolution is informed by progress in systems science. They express what we take to be the conditions for the possibility of the empirical systemic phenomena observed by systems thinkers. In this way the systems principles represent the systemic nature of the invisible reality underlying the systemicity of the phenomenal one, and form part of systems philosophy rather than systems science.

- Taken together, the systems principles characterize the nature of systemness, so we might say that our image of the nature of ‘system’ is the gestalt that reconciles the joint entailments of the systems principles. A set of coherent and scientific systems principles would form the core of a foundational general systems theory (GST*), and changes in the systems principles could have dramatic consequences for the systems worldview.

- Once we have some principles in place for a scientific GST*, we would be able to execute a cycle of discovery, progress and refinement in the context of systems science, in the same pattern as discussed above for the PLT model more general. We illustrate this in Fig. 23.

Fig. 23

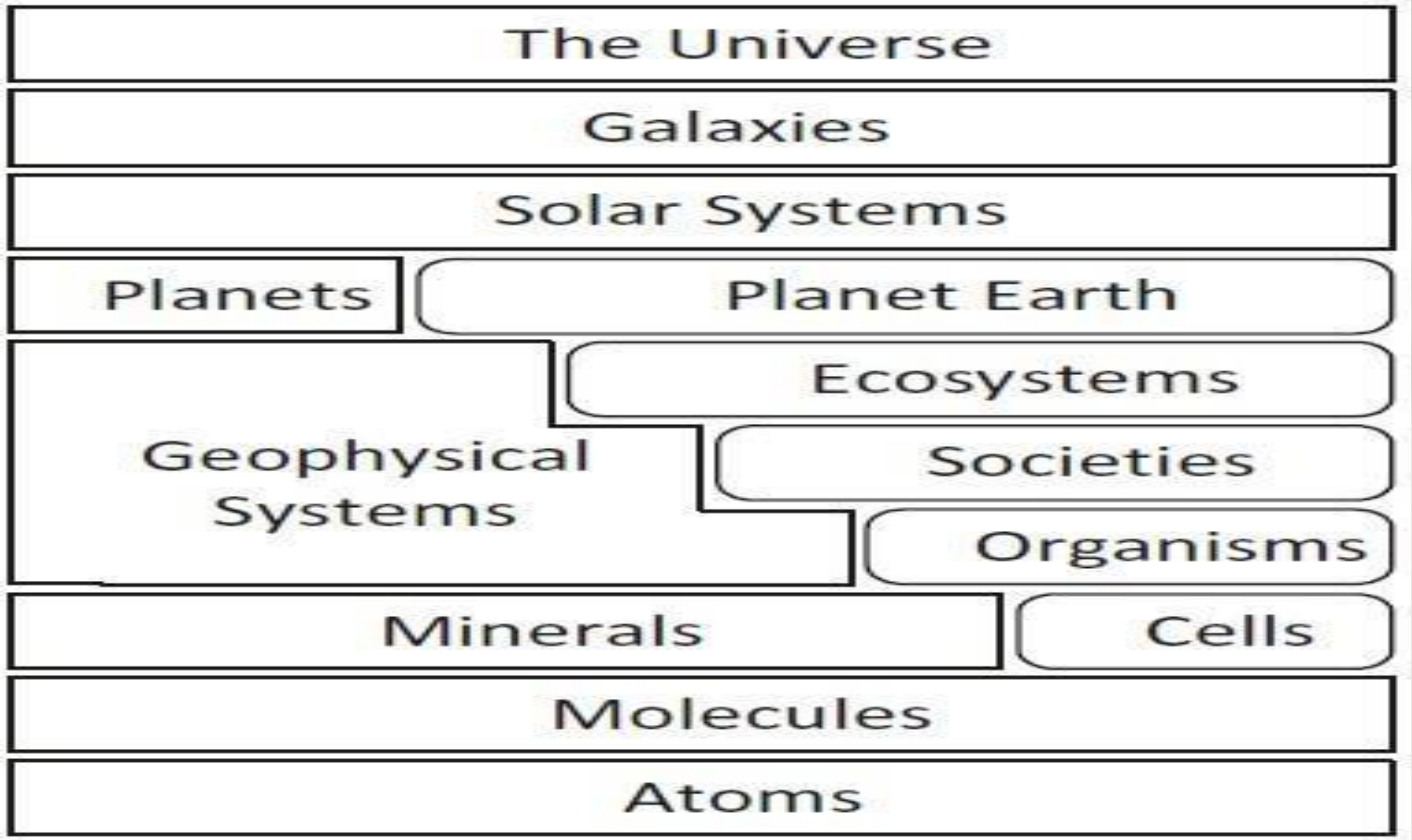

Manifest Systems
satisfy
constrain
satisfy
explain/predict
Systems Worldviews
articulate
Systems Principles
instantiate
Systems Laws
employ
Systems Theories
validate
Theoretical Virtues
challenge

8.2- Foundations for Discovering General Scientific Systems Principles

8.2.1- Grounding Concepts for a Search for General Scientific Systems Principles

- A common idea in systems thinking is that we can arrange naturalistic systems into a hierarchy by sorting things into kinds based on properties that are essential to being members of that kind, and then ranking them in order of complexity. One way of looking at this arrangement is to note that the things in every layer are composed of things that exist autonomously at the ‘lower’ level as shown in Fig. 24.

Fig. 24


The Universe
Galaxies
Solar Systems
Planets
Planet Earth
Ecosystems
Geophysical Systems
Societies
Organisms
Minerals
Cells
Molecules
Atoms

- Systems differ from heaps in that the properties of heaps are merely the sum of the properties of the parts, whereas systems have new kinds of properties their parts do not have. These are called “emergent properties”, and it is this emergence of new kinds of properties that establishes new kinds of systems. One definition of “system”, due to Anatol Rapoport, is that a system is a whole that functions as a whole in virtue of the relationships between its parts. When the systems at stake are naturalistic ones, as shown in the complexity hierarchy in Fig. 24, then the inter-part relationships that establish the whole must be concrete, and therefore must be due to lawful causal interactions between the parts. In this light we can say that emergent properties are new kinds of causal powers that arise at the level of the whole due to kinds of causal interactions between parts.

- Systems can have a multiplicity of kinds of parts, and a multiplicity of inter-part relationships, leading to a multiplicity of kinds of interactions between the parts. As the diversity of parts, relationships and interactions increases systems are said to become more “complex”. However, it is important to note that interactions between parts do not always produce new kinds of systems – in fact for the most part interactions just create new states in existing systems.
- It is important to note that one of the challenges in trying to explain emergence comes from the fact that science’s approach is predominantly reductionistic, taking new kinds of things to be largely explicable in terms of special states of collections of lower-level entities and so on ‘all the way down’ to fundamental particles (quantons). Systems thinkers are typically skeptical about such a narrow reductionism, because living systems exhibit properties that are categorically different from physical ones, such as subjectivity and anticipation, and context can powerfully influence developmental processes, as seen in cultural inheritance. However, it has proved an enduring challenge to formulate a scientifically profound systemic alternative to reductionism, despite a vigorous philosophical debate on this subject.

8.2.2- Derivation of Three General Scientific Systems Principles
8.2.1- Emergence and the Conservation of Energy

- As a first investigation, let us begin by considering the notions of properties and interactions firstly from a metaphysics and then from a systems perspective. On the metaphysics of science side it can be seen that scientific principles, and the laws that instantiate them, model changes in substances in terms of the sources and consequences of change, and the proportionalities between changes in different substances in different contexts. These models depend on the notions of causal powers, concrete properties, and exchanges or transfers of energy, using ideas we can briefly summarize as follows:

1. 'Real' (non-imaginary) things are called 'concrete' if they have causal powers, and causal powers are properties that make interactions between things turn out in a specific way;

2. In interactions, changes occur in the interaction partners, so causal powers can be understood as the power to cause or undergo change;

3. If the changes are proportionate (i.e., effects are proportional to their causes) then the interactions are ‘naturalistic’;

4. The ability to cause change is the ability to do work, and the doing of work requires transfer or transformation of energy;

5. This implies that to have concrete causal powers is to have energy and the ability to exchange it; and

6. In this way, there is a clear and direct connection between the notions of concrete properties, causal powers, change, and energy.

❖ Under Scientific Realism the concept of energy has a precise meaning, and empirically energy can be quantified in an exact way. This opens up an opportunity to make the notions of causally effective properties and empirical change exact and quantifiable too, as follows. If ‘having causal powers’ can be represented by ‘having energy’, then:

1. The kinds of causal powers something has can be represented by the kinds of energy it has;

2. The strength of a kind of causal power something has can be represented by the amount of the relevant kind of energy it has;

3. Causal interactions transfer and/or transform kinds of energies, and hence causal interactions can be viewed as changing the strengths of the interacting things’ causal powers, and thus their concrete properties; and

4. If causal interactions are naturalistic then energy is conserved during interactions.

- If we now turn to naturalistic systems, we might be able to speak of the emergent properties arising though interactions between parts in these terms involving causal powers and energy. To see how this might go, let us first consider a simple case, i.e., where the complexity of the interactions is low but they nevertheless produce an emergent property. A convenient example is provided by atom formation, the process whereby protons and neutrons combine to form an atomic nucleus, as happens in stars and supernovae, and then combine with electrons to form atoms. The atom has properties the parts did not have – it is a stable structure that has different causal powers to those of the fundamental particles, and different quantities and arrangements of such parts will result in different levels of atomic stability. This stability is a new system-level property that emerges as the atom is formed. It is a concrete property, making a difference in causal interactions, and therefore is a causal power.

- However, as explained earlier causal powers can be represented in terms of kinds of energy, so this entails that atoms have special kinds of energies that unbound fundamental particles do not. Now, we know from the principle of conservation of energy that ‘emergent’ energy must have come from somewhere. Given that the emergent property exists due to the interaction of the parts, it seems likely that the parts have given up some of their energy and hence have undergone a reduction in their own properties and causal powers. This is not an unreasonable supposition – many systemists have pointed out that systems are not only more than the sum of their parts but also *less* than the sum of their parts, due to parts being constrained by their systemic context. There is even a term for such loss or reduction of parts’ powers: “submergence”.

- A suggestion that emergence is accompanied by submergence is therefore not in itself new. However, the insight emerging here goes further in two important ways.

First, submergence is now *expected*, on principled grounds, rather than just being observed. This is called “retro-diction” in science, where we find a theoretical way of predicting something which was already known to be the case but only by observation, not via scientific arguments. Achieving retro-diction is an important step towards building a theory with predictive powers.

Second, because this claim is being made in a scientific way it can be empirically checked in a precise way. In effect we have replaced a qualitative aphorism, that emergence is accompanied by submergence, with a precise quantifiable scientific proposition, namely that the energy gained as the emergent stability property of the atom will be exactly matched by some kind of energy lost to the particles through property submergence.

- This proposal is empirically testable, and when it is checked for atoms the expected result is indeed found: the mass of an atom is less than the sum of the masses of its particles in their unbound states. This phenomenon is well known in nuclear chemistry, where it is called the “mass defect”. Einstein’s famous law $E=mc^2$ relates mass to energy, and we thus calculate an amount of energy this lost mass represents. When this is done it is indeed found to be the exact amount knownas the “binding energy” of the atom, which is the energy that would be needed to break the atom up again.

- It is suggested that this illustrates a general principle applicable to all systems, and hence to call it the '*Conservation of Properties Principle (CPP)*'. CPP states that "*the energy associated with an emergent property in system formation is exactly matched by the sum of the energies lost by the parts participating in that systemizing interaction*". More colloquially, this can be stated as "emergent properties are exactly paid for by submerged ones".
- This principle presents a valuable insight for systems research, system design and systemic intervention. It provides an empirical standard for demonstrating that an observed system property is an emergent one, by connecting it with submergence. This is important because it casts suspicion on the common practice of calling any property noted at the system level but not seen in the parts an emergent one. CPP suggests that if the balancing interplay between emergence and submergence cannot be demonstrated, then the analysis is incomplete or wrong.

- For example, the boundary of the system may have been drawn incorrectly, and the supposedly emergent system-level behaviour is actually due to the action of parts unwittingly left out of consideration but which are in fact contributing that power to the whole in a summative way. Alternatively, the parts may have been mischaracterised, and have properties not currently attributed to them, and once again the system level property is actually summative rather than emergent. Either way research investigating the nature of a supposed emergent property will proceed differently from how this might be done without knowledge of CPP.

- A further value is suggested via the idea that systems are dynamic structures, and so there is a constant interplay between emergence and submergence. This implies that when a system is suffering degradation due to loss of parts or weakening of inter-part interactions then we should be concerned not only about the loss of functionality but also about the re-emergence of previously inhibited behaviours of the remaining parts. This explains why it is so difficult to conserve or restore degraded or degrading complex systems (for example ecosystems). In systemic interventions both emergence and submergence have to be managed, and lack of control in this management might imply that the wrong boundaries have been managed, or the boundaries and/or parts have been mismanaged. In this way systemic interventions and also the design of resilient systems might now proceed differently from the way they would have been done without knowledge of CPP, and in particular this may help to reduce the occurrence or severity of unintended consequences.

- It is not possible at this time to show that CPP applies across all systems types in the exact way the principle states, because we do not yet have a quantifiable scientific understanding of all the kinds of properties systems exhibit. This is especially notable in the case of living systems exhibiting mental or psychological properties. However, the principle does seem valid in a qualitative way, for example teams or families can achieve things the individual members cannot do by themselves, but members of such social units are also constrained in their behaviour compared to what they are able or willing to do in isolation. Some kind of balancing interplay seems to be in play here, as the willingness of an individual to accept constraints on their personal freedom seem to be dependent on the value they place on the benefits they gain though the powers of the social unit.

- Although CPP cannot be applied in an exact way in such complex scenarios, because of the incompleteness of certain specialized sciences, CPP may still be useful in those contexts, because insights into systemic behaviour we gain by studying quantifiable cases could be translatable into metaphors providing effective new heuristic principles we can apply in more complex situations. As the sciences advance these metaphors can be improved, and become more scientific in the guidance they suggest.

8.2.2- Emergence and Super-Systems

- By knowing the first systems principle we can immediately suggest another one, as follows. Systems hierarchy diagrams of the sort shown in Fig. 30 illustrate how system levels scale with size and complexity, but this somewhat obscures the fact that it represents a containment hierarchy, so that the systems at every level not only contain parts from the lower levels ("sub-systems") but are also themselves embedded as parts in higher-level systems ("super-systems"). A core concept of systems thinking is that things not only have environments but they are systemically connected into their environments, so every concrete thing short of the universe is a part in at least one super-system.

- In this light it is obvious that, in accordance with CPP, it must be that case that system properties are not only emergent over the properties of the parts, but are themselves subject to submergence as a result of their integration into their super-systemic context. This entails then that in fact systemic properties are determined by a balancing act between the bottom-up influence due to the parts and the outside-in influence of the super-systemic context. This provides a second systems principle, which is called the "*Principle of Universal Interdependence*", and paraphrases as "*system properties represent a balance between bottom-up emergence and outside-in submergence*".

- It is worth noting that this principle reflects a different idea from the statement often made for systems that they cannot be explained reductionistically because they involve an interplay between “bottom up” causation and “top-down” causation. That view is about how emergent properties can act back onto the parts, for example mental properties might emerge ‘bottom up’ via brain complexity can then influence processes within the body via will-power and bio-feedback. This kind of claim is not to do with a system’s environment but is rather just a more sophisticated view about the goings-on within the system boundary.

- The Principle of Universal Interdependence has significant implications for science. It entails that to model a system's real potential one has to look not only at what the parts contributed (bottom-up causation) but also what was deducted by the super-systemic context (out-side in causation). It means the explanatory arrows go both ways, both down and up from the system boundary. From a philosophy of science point of view this replaces classical "down-ward only" reductionism with a type of holistic interdependence perspective. For scientific research, this then suggests that for a theory about any new phenomenon the explanatory burden is expanded to now include both bottom-up and outside-in influences, and to do so in a balancing way. This principle also has significance for planning interventions and system designs, because it implies that there are two interconnected kinds of leverage points for changing system behaviour, namely via modulation of either the bottom-up or the outside-in influences.

- In addition, this principle makes a contribution to epistemology, by adding a new theoretical virtue: theories and designs will be "better" if they are (more) holistic. An interesting prediction follows from this suggestion, namely that all the specialised disciplines will become more holistic as they mature. This is already happening in several fields, most notably at this time in cosmology, biology and medicine. It is therefore likely that a future systems engineering will not only be holistic itself but will increasingly be able to draw on holistic specialised sciences for support.

8.2.3- Emergence and Complexity

- Consider a super-system (W) consisting of two sub-systems, one of high complexity (S1) and one of low complexity (S2). The interactions between S1 and S2 bind them into the super-system (W). As a new system W has emergent new properties, and by the Conservation of Properties Principle (CPP) both S1 and S2 must undergo some degree of submergence. The binding interaction that links the two subsystems together is the same for each, but the relative impacts are unequal. A simple example will make this evident. Take for example the impact of gravitational attraction between a very small body and a large one, such as a meteoroid passing a planet. They form a system and each falls towards the other in accordance with Newton's Law of Gravity, but the effect on each is very different: the meteoroid's behaviour is strongly conditioned by the nearby planet, but the planet is hardly affected.

- The interaction force is the same for each of the interaction partners, so it follows that they each give up the same amount of (gravitational potential) energy, so they contribute equally to the emergence of the new whole. In terms of CPP, we can say, speaking colloquially, that they each pay the same amount towards the emergent property of the whole, but the complex subsystem can afford that payment more easily, so is less affected by it. In a simple subsystem like S2 the few parts each have to give up a lot of their energy to make up their contribution to the total, but in a complex subsystem like S1 the many parts each give up a relatively small amount to make up their contribution. In line with the energy conservation aspect of CCP this conclusion can be generalised by saying that in systemizing interactions complex parts pay proportionately less towards emergent properties of the whole than simpler parts do. This amounts to a new systems principle, which Rousseau has called the "Principle of Complexity Dominance". It states that the impact of submergence on a part is proportional to the complexity differential between the part and the whole, and can be paraphrased as "complexity buffers autonomy".

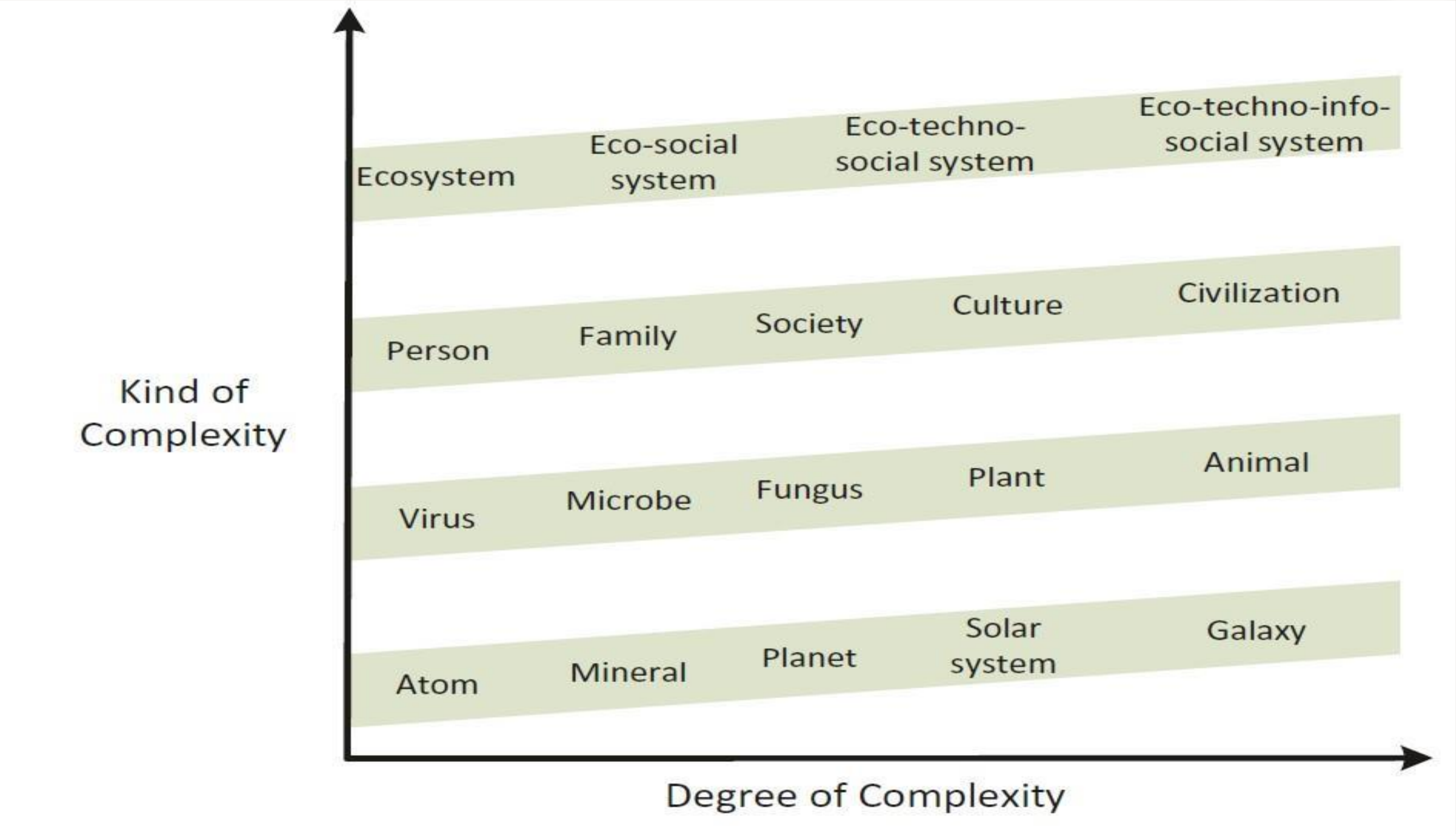
- This principle has relevance for scientific research, because it implies that when modelling the nature and potential of a given system the two explanatory arrows (‘bottom up’ and ‘outside in’) differ in weight in proportion to the relative complexity of the target system compared to the other systems making up the super-system it is systemically interlinked with. This is an important consideration in the study of naturalistic systems, because they cannot be completely shielded from systemizing interactions. This principle also applies to the behaviour and performance of designed systems, as they, like natural systems, are always parts in super-systems.

- This principle is also relevant for planning systemic interventions, because the two inter-related leverage points for modulating system behaviour would be unequally weighted if there are complexity differentials involved. One corollary of this is that a target system can be efficiently controlled by a more complex one, as suggested by Ashby’s so-called “Law of Requisite Variety”.
- Application of this principle however requires some care, because ‘complexity’ has multiple dimensions. The distinctions between these dimensions are far from sorted out, but we can separate them to some extent. Two important distinctions are between what we might call (for want of better terms) ‘degree of complexity’ and ‘kind of complexity’. Systems are nature’s way of creating complex enduring structures, and the two mentioned complexity dimensions reflect two aspects of nature’s innovation process, one hallmarked by increases in scale and one hallmarked by increases in variety of behaviours. The two factors interdepend, with advances in the former (scale) often opening up opportunities for advances in the latter (behaviour).

- We previously discussed how different kinds of systems can be grouped into a levels hierarchy. This represents a type of complexity hierarchy, where the systems at each higher level have a new kind of behavioural property that emerges due to their higher level of organizational complexity. These levels represent not just an increase in complexity but shifts to new *kinds* of complexity. On this view biological systems thus appear ‘higher up’ in the system levels hierarchy than chemical systems because their increased behavioural variety is due to their having a radically different kind of complexity.

- There is also another aspect to complexity where an increasing ‘degree of complexity’ enables the establishment of ever larger enduring structures by combining smaller assemblies of a similar kind in special ways. Large-scale systems of a certain kind are thus distinguished from small scale systems of the same kind by having a higher *degree* of complexity. This is the case for systems of all kinds, so we can illustrate the interplay between these two dimensions of complexity as shown in Fig. 32. Note that both dimensions of complexity are involved in the evolution of new system types, as is suggested by the sloping levels. An increase in scale does entail some increase in the level of behavioural complexity, but not of such a radically different kind as is required for producing a wholly new kind of system behaviour.

Fig. 25


Ecosystem
Eco-social system
Eco-techno-social system
Eco-techno-info-social system
Person
Family
Society
Culture
Civilization
Kind of Complexity
Virus
Microbe
Fungus
Plant
Animal
Atom
Mineral
Planet
Solar system
Galaxy
Degree of Complexity

- With this distinction in mind we can now see that in the example considered earlier, presented to expose the principle of complexity dominance, we only looked at a differential in the degree of complexity and not differentials in kinds of complexity. This might be taken to imply that the principle would only apply within system levels (that is, between systems sharing the same kind of complexity), but it can indeed be applied when interactions *across* system levels are at stake. However, in this case the principle has to be used carefully in order not to conflate the different dimensions of complexity in play. One way to do this is to consider kinds of complexity as conferring kinds of emergent properties on systems, and to recognize that kinds of interactions are exchanges between kinds of properties. We can thus treat complexity dominance as playing out relative to the emergent properties the inter- acting systems have in common, irrespective of the overall complexity of each of those systems.

- For example, a bull is overall a more complex system than a fence, in the sense that the bull has a greater variety of parts, states, process and emergent properties. However, when the bull tries to get out of the field the relevant interaction is between the physical-system-level properties of each party, and here the fencing system outperforms the bovine system, entraining more mass and leverage into a more enduring structure. The bull has to stay inside or risk suffering more damage than the fence would in a forceful interaction between them. An intelligent bull might nevertheless escape by identifying and exploiting a weakness in the design, build quality or management of the containment system, but in this case the complexity differential involved is between the intelligence and experience of the bull, the fencing system designer and the farmer.

- This however involves interaction within a higher systems level, involving a different kind of complexity, so it has to be considered separately from the former case when trying to apply the principle of complexity dominance. The general lesson we can learn from this is that to fully model how the interaction between complex systems might turn out we have to identify, for that scenario, all the kinds of (emergent) properties between which interactions can take place, and identify for each possible interaction not only the interaction magnitude, activation probability and triggering conditions, but also the complexity differential. In such a model the principle of complexity dominance, applied across all these causal relationships, will give us insight into the overall ‘possibility space’ of the total interaction outcome, even if the kinds of systems involved are very different from each other.

تم بحمد الله