



A Knowledge Component Framework for Enhancing Transdisciplinary Knowledge Assimilation

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Research shows that generating new knowledge is accomplished via natural human means: mental insights, scientific inquiry process, sensing, actions, and experiences, while context is information which characterizes the knowledge and gives it meaning. Transdisciplinary research literature clearly argues for development of strategies that transcend any one given discipline and that enhance research collaboration. A new framework, coined *Recombinant kNowledge Assimilation (RNA)*, was constructed in this research. The framework was successfully applied recursively to abstracts from research manuscripts. Using RNA, disciplinary and transdisciplinary knowledge components and context were systematically discovered creating a mechanism to interact with dynamically changing research knowledge and assimilating it to form explicit new knowledge while simultaneously retaining the causal pedigree captured during manuscript processing.

Keywords: recombinant, knowledge, context, recursion, transdisciplinary research.

1 Introduction

Definations. Six important terms consistently used

within this paper are defined as follows.

Recombinant: Establishing new relationships between any two or more pieces of information to create new knowledge.

Knowledge: A relationship between any two or more pieces of information which has crossed the importance threshold to become established in the mind of the stakeholder.

Context: Information which characterizes knowledge and gives it meaning.

Recursion: Repeated application of functions on information and knowledge to create new knowledge; continuous input.

Knowledge Components: Discrete logical groupings of various granularity of information content, upon which effort of thought has been expended to understand.

Transdisciplinary Research: Collaborative research within many disparate disciplines working together to develop strategies and implements to dissolve the hardened discipline silos of knowledge to solve common problems that transcend any one discipline.

1.1 Knowledge

Nonaka and Takeuchi [1], when describing how Japanese companies innovate as knowledge creating organizations, described two types of knowledge: tacit and explicit. Tacit knowledge is personal and context-specific. Explicit knowledge is knowledge codified in books, journals and other documents for transmittal. Additionally, Nonaka [2] prescribed how dynamic organizational creation of knowledge needs to be strategically collected, understood, and managed across the entire company's organizational structure as intellectual capital. Knowledge theorist Polanyi and Sen [3], in describing what he called the "Tacit Dimension," used the idea of tacit knowledge to solve Plato's "Menos paradox," that deals with the view that the search for knowledge is absurd, since you either already know it or you don't know what you are looking for, whereby you can not expect to find it. The author argued that if tacit knowledge was a part of knowledge then "we do know what to look for and we also have an idea of what else we want to know," therefore personal and context-specific knowledge must be included in the formalization of all knowledge. Renowned fuzzy logic theorist Zadeh [4], described tacit knowledge as world knowledge that humans retain from experiences and education, and concluded that current search engines with their remarkable capabilities do not have the capability of deduction, that is the capability to synthesize answers from bodies of information which reside in various parts of a knowledge base. More specifically Zadeh, describes fuzzy logic as a formalization of human capabilities: the capability to converse, reason and make rational decisions in an environment of imprecision, uncertainty, and incompleteness of information. Tanik and Ertas [5] described, knowledge as generated through mental insights and the scientific inquiry process, usually stored in written form, assimilated through mental efforts, and disseminated through teachings and exposure in the context of a disciplinary framework. Kim et al. [6] used a case study to develop an organizational knowledge structure for industrial manufacturing. Specifically, a methodology was developed for capturing and representing organizational knowledge as a six-step procedure, which ranged from defining organizational knowledge to creation of a knowledge map for validation. The defined knowledge was extracted from the process as three types: prerequisite knowledge before process execution, used knowledge

during execution, and produced knowledge after execution. Spender [7] stated that universal knowledge true at all times is the highest grade that knowledge can attain. Gruber [8] when describing social knowledge systems on the web and their relationship to semantic science and services, defined knowledge as "collective knowledge" that is collaborated upon. When describing how science integrates with information theory, Brillouin [9] defined knowledge as resulting from a certain amount of thinking and distinct from information which had no value, was the "result of choice," and was the raw material consisting of a mere collection of data. Additionally, Brillouin concluded that a hundred random sentences from a newspaper, or a line of Shakespeare, or even a theorem of Einstein have exactly the same information value. Lastly, Engelbart [10] when describing the needs of the optimal workplace, depicted what he called the "knowledge workshop," where a knowledge worker performed work, and that knowledge represented integrated domains of knowledge which were natural and specialized [11].

1.2 Context

Dourish [12] expressed that the scientific community has debated definitions of context and its uses for many years. He discussed two notions of context, technical, for conceptualizing human action relationship between the action and the system, and social science, and reported that "ideas need to be understood in the intellectual frames that give them meaning." Hence, he described features of the environment where activity takes place [13]. Torralba [14] derived context based object recognition from real-world from scenes, described that one form of performing the task was to define the 'context' of an object in a scene was in terms of other previously recognized objects and concluded, that there exists a strong relationship between the environment and the objects found within, and that increased evidence exists of early human perception of contextual information. Dey [15] presented a Context Toolkit architecture that supported the building of more optimal context-aware applications, because, he argued, that context was a poorly used resource of information in computing environments and that context was information which must be used to characterize the collection of states or as he called it the "situation abstraction" of a person, place or object relevant to the interaction between a user

and the application. When describing a conceptual framework for context-aware systems, Coutaz et al. [16] concluded that context informs recognition and mapping by providing a structured, unified view of the world in which a system operates. The authors provided a framework with an ontological foundation, an architectural foundation, and an approach to adaptation, which they professed, all scale alongside the richness of the environment. Graham and Kjeldskov [17] concluded that context was critical in the understanding and development of information systems. Winograd [18] noted that intention could only be determined through inferences based on context. Hong and Landay [19] described context as knowing the answers to the “W” questions (e.g. Where are the movie theaters?). Similarly, Howard and Qusibaty [20] described context for decision making using the interrogatory 5WH model (who, what, when, where, why and how). Lastly, Ejigu et al. [21] presented a collaborative context aware service platform, based upon a developed hybrid context management model. The goal was to sense context during execution along with internal state and user interactions using context as a function of collecting, organizing, storing, presenting and representing hierarchies, relations, axioms and metadata.

1.3 Transdisciplinary Research

Rosenfield [22] argued for transdisciplinary research as a process where members of different fields work together over time to develop novel concepts and frameworks with potential to produce new approaches which transcend inter- and multidisciplinary research. Ertas et al. [23] described transdisciplinary research and education in context of addressing large-scale, modern engineering systems to prepare engineers, designers, and researchers of the future. Described are three critical attributes, namely, clarification of theoretical issues involved in crossing disciplinary boundaries, development of a more comprehensive understanding of large-scale problems, and integration of concepts and methods from other disciplines which share similar levels of analysis. Pohl [24] stated that an aim of transdisciplinary research is to get natural and social scientists to collaborate, so as to achieve an integrated view subjects that go beyond the viewpoints offered by any one particular discipline. Stokols et al. [25] described a two decade surge of interest and investment in transdisciplinary research and

described a framework for understanding and evaluating transdisciplinary research. Finally, Nicolescu [26] described transdisciplinary research as a “transdisciplinary model of nature which must integrate all new knowledge of emergent characteristics of the universe.” Additionally, he concluded that there are three major aspects of nature that follow the transdisciplinary model of reality: Objective Nature, the natural properties of the transdisciplinary object, Subjective Nature, the natural properties of the transdisciplinary subject, and Trans-nature, the similarity in nature between the object and subject.

1.4 Organization of Knowledge and Context

In 1957 Newell et al. [27] and Simon [28] together developed models of human mental processes and produced General Problem Solver (GPS) to perform “means-end analysis” to solve problems by successively reducing the difference between a present condition and the end goal. GPS organized knowledge into symbolic objects and related contextual information which were systematically stored and compared. Almost a decade later Sternberg [29] described a now well-known paradigm called the Sternberg Paradigm where, observations of participants were taken during experiments to determine how quickly the participants could compare and respond with answers based upon the size and level of understanding of their knowledge organized into numerical memory sets. Sternberg Paradigm is known for (1) organizing knowledge and modifying context while using a common process for describing the nature of human information processing and (2) human adaptation based upon changes in context. Similarly, Rowley and Hartley [30] described the development of knowledge as the organization and processing required to convey understanding, accumulated learning, and experience. Object Oriented Design (OOD), as defined by Booch [31] and Rumbaugh et al. [32], organized knowledge and attributes describing details of objects in the form of general objects of information, using a bottom-up approach, iteratively building its components and attributes through a series of decisions. Boochs more generalized design decisions occurred via five basic phases which he described as part of the macro processes of OOD: Conceptualization which established the core requirements, analysis which developed the desired behavior via a model, design which included various architectural artifacts,

and evolution which was the core component responsible for iterative bottom-up development, and lastly maintenance which managed the spiral delivery of functional capability. The details Booch described in the micro processes of his definition of OOD were the critical design mechanisms which fleshed out design details to take the conceptualization phase requirements to an implementable solution. The micro process components were, namely, identify and classify the abstraction of objects, identify the semantic representations of the objects and classes which define them, identify via specialized OOD notation the relationships between the objects, and finally the specification of the interfaces, the physical implementation of the defined classes and runtime objects. More recently, Gruber [8] described the collection of knowledge and context on the web as “collective intelligence.” Gruber based his opinion on Elgelbart’s [11] principle which stated the need for creating combined human-machine interactive systems which can boost the collective intelligence of organizations and society via automated harvesting of collected knowledge for collective learning. Specifically, Gruber added that true collective intelligence can emerge if aggregated information from the people is recombined to create new knowledge. Van Ittersum et al. [33] organized knowledge and context as individual stand-alone knowledge components in agricultural systems which can be linked using a software infrastructure. Finally, Ejigu et al. [21] defined the organization of knowledge and context as a process of collection and storage. Their work proposed what they described as a neighborhood based context-aware service platform which was user collaborative in nature, that managed the reusability of context resources and reasoning axioms, and shared computational resources among multiple devices in the neighborhood space. They used a semantic ontology based hybrid model known as EHRAM as the core data source from which they systematically collected and stored information content, reasoned upon with their reasoning engine and then disseminated via their interface manager to the user. The main components of EHRAM context model were used to model the information content sources as a set of hierarchies (H), set of entities (E), set of entity relations (Re), set of attribute relations (Ra), set of axioms (A) and set of metadata (M). Hence, the information data source content was collected and stored as the EHRAM layered context representation

structure.

1.5 Presentation of Knowledge and Context

Trochim [34] described Concept Maps to present knowledge and context as structured conceptualization used by groups to collaborate thoughts and ideas. Described was the typical case in which concept maps are developed via six detailed steps: the “Preparation,” which included the selection of participants and development of the focus for conceptualizing the end goal, such as brainstorming sessions and developing metrics, (e.g. rating the focus), the “Generation” of specific statements which reflected the overarching conceptualization, the “Structuring” of statements which described how the statements are related to one another, the “Representation” of statements in the form of a presented visual concept map, which used multidimensional scaling [35] to place the statements in similar proximity to one another and cluster analysis [36] which determined how to organize the presentation into logical groups which made sense, the “Interpretation” of maps which was an exercise in consensus building once the representation had been created; and finally the “Utilization” of maps which was described as a process by which the groups within the process collectively determine how the maps might be used in planning or evaluation of related efforts. Stated was that concept mapping encouraged groups to stay on task which then resulted relatively quickly into an interpretable conceptual framework. It also expressed the framework entirely in the language of the participants and finally yielded a graphic or pictorial product. The product simultaneously presented all major ideas and their interrelationships and often improved group or organizational cohesiveness and morale. Graph theory, was shown to be used within many disciplines as an approach to visually and mathematically present knowledge and context relationships, [37]. In Software Engineering, many traditional tools exist: Entity Relationship Diagrams (ERD), Sequence Diagrams (SD), and State Transition Diagrams (STD) which each present different knowledge and context about database, and systems [38]. More recently, Universal Modeling Language (UML) [39] and semantic and ontology based software development tools, as well as, descriptive Resource Description Framework (RDF) language [40], and Web Ontology Language (OWL) [41] were used extensively to create, store, and present knowl-

edge and context, using shapes, lines, and text as relationships between objects of information. However, Ejigu et al. [21] argued that ontology tools were only good at statically presenting knowledge of a domain and that they were not designed for scalable capturing and processing dynamic information in constantly changing environments.

1.6 Representation of Knowledge and Context

Dourish [13] concluded that representation of knowledge and context is an ethno methodological problem of encoding and representing social motivation behind action and that translating ideas between different intellectual domains can be exceptionally valuable and unexpectedly difficult. One reason is that ideas need to be understood within the intellectual frames that give them their meaning, and therefore need to be sensitive to the problems of translation between the frames of reference. Additionally, he describes four assumptions which represent context in systems, first, context as a form of information which can be encoded and represented in software systems just as other information content, second, context is delineable and therefore for a set of requirements, context can be defined as activities that an application supports and it can be done in advance, third, context is stable and hence can vary representation from one software application to another but does not vary from instance to instance of an event, it was specific to an activity or an event. Lastly, Dourish concluded, that most importantly context is separable from the action or activity, since context described the features of the environment where the activity takes place, separate from the activity itself. Dourish proposed an interactional model of context, where the central concern with representing context was with the questions, “how and why” during interactions, do people achieve and maintain a mutual understanding of the context for actions. Polyn and Kahana [42] described that cognitive theories suggest that recall of a known item representation is driven by an internally maintained context representation. They described how neural investigations had shown that the recall of an item represented in the mind is driven by an internally maintained context representation that integrated information with a time scale. Howard and Kahana [43] stated that by linking knowledge items and context representations in memory, one

could accomplish two useful functions. First, one could determine whether a specific item occurred in a specific list (episodic recognition). Second, one could use a state of context to cue item representations for recall (episodic recall). Konstantinou et al. [44] concluded that a common knowledge representation formalism ought to allow inference extraction, and proposed “Relational.OWL,” based tool to automate structural representation of knowledge ontology to database mapping. Additionally, Ejigu et al. [21] made the argument that context was missing from systems and is in the “head” of the user, and proposes an ontology based structure using RDF representation of knowledge and context with metadata attributes. Zouaq et al. [45], concluded that Natural Language Processing (NLP) enabled structured representations of documents. They proposed a knowledge puzzle approach using ontology based learning objects, semantic maps, and grammatical maps, which represented structure of context on the basis of using text relations. Similar to Trochim [34], Novak and Canas [46] described the structure of concept maps as a mechanism for structural representation of knowledge and context.

2 Motivation

Ertas et al. [23] described a need to address complexities whereby important knowledge within one discipline can be systematically discovered, and recombined into other disciplines to solve common problems and for enhancing and augmenting other fields of study. Stokols [51] noted that there was a need to achieve a more complete understanding of prior research collaborations and sustain future ones and their content, and Fry [52] described the importance of integration between subject disciplines, Llinas et al. [53] described a challenge, to harness actionable knowledge from complex interrelated cross-domain data. Konstantinou et al. [44] concluded that a lack of a generally accepted, unified, and common knowledge representation impedes data exchange, interoperability and collaboration. Dourish [13] concluded that, presentation of context is extremely problematic since context is continually renegotiated and redefined. Nicolescu [26] concluded that a transdisciplinary model must integrate the emerging characteristics of the physical universe and that a need exists to use tools in physics describing reality with mathematical formalization. Torralba

[14] indicated a need to represent the strong relationships which exist in the environment with the objects found within. Finally, motivation was drawn from a need as described by Ejigu et al. [21] for providing collection, organization, storage, presentation, and representation of knowledge and context, together which addressed the significant challenge of quality context and by Liao et al. [47], who indicated the need for representing context in a knowledge management framework for enabling transition from data, information, and knowledge to new knowledge. Therefore, the goal of this research was to develop implements for effective transdisciplinary research, and to develop mechanisms to dissolve the knowledge barrier between hardened discipline silos of knowledge. The literature clearly argues for strategies, methodologies, tools, frameworks to further the development and quality of transdisciplinary thought and practice. This research aimed to answer the question, "Can a framework be developed to enhance transdisciplinary research knowledge?" This question was focused intentionally and exclusively on the research and development of a framework. This research proposed the exploration of the framework's application to journal abstracts rich in discipline specific research information content for enhancing the meaning and/or relevance of discovered knowledge and context.

3 Scope and Methods

The scope of work involved the development of three specific aims: the organization of knowledge and context, the presentation of knowledge and context, the representation of knowledge and context and the ultimate framework including each independent organization, presentation and representation aim. The Organization of knowledge and context involved development of a common process which was derived from five major components: (1) General Problem Solver, (2) Sternberg paradigm, (3) concepts in Computer Science, (4) concepts in transdisciplinary research, and (5) the concept of organization as collection and storage of knowledge and related information content known as context, and then explored, via application of the process, to rich discipline specific abstracts. The Presentation of Knowledge and Context involved for this aim was to develop an independent approach to enhance the presentation of knowledge and related information content known

as context constructed from four major concepts: (1) Ejigu et al. [21] separation of context data and context knowledge, (2) Dourish [13] concept, presenting knowledge and context as consistent, continual renegotiation, when matching action to state, (3) extending the presentation components, lines, spheroids, and edges, for representing relationships in graph theory [37], Entity Relationship Diagrams (ERD), Sequence Diagrams (SD), and State Transition Diagrams (STD) [38], and lastly, (4) an analogy to the concept of relating the motion of two particles as a frame of reference is measured differently by different observers [54]. The presentation of knowledge and context were then validated through application of the process to rich discipline specific abstracts. The Representation of Knowledge and context involved development of an independent approach to enhance representation of knowledge and related information content known as context derived from Newton's law of gravitation. The approach is explored via application to knowledge and context found within discipline specific abstracts rich in domain specific content. The Framework for Knowledge and Context is constructed by combining three independent components: (1) organization of knowledge and context, (2) approach for presenting knowledge and context, and (3) an approach for representing knowledge and context. The framework's application is subsequently explored via application to two independent discipline abstracts rich in domain specific knowledge and context.

4 Results and Discussions

4.1 Organization of Knowledge and Context

4.1.1 Introduction

This approach presented organization of knowledge and context and was constructed from three discrete components to collect and store knowledge and context per Ejigu et al. [21]. Collection and storage together are considered analogous to the term assimilation, in this section. First, a new knowledge and context assimilation equation known as knowledge assimilation equation was developed. Second, a new concept map diagram comprising natural discipline knowledge formation was developed. Third, a collection and storage diagram representing the knowledge assimilation equation was developed and applied to

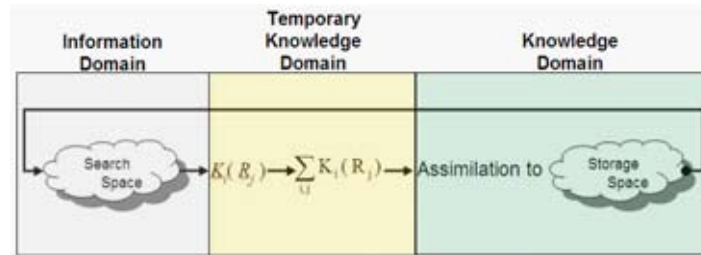


Figure 1: Recombinant kNowledge Assimilation Equation.

an abstract rich in domain specific knowledge and context.

4.1.2 Collection of Knowledge and Context

Llinas et al. [53], observed that the synthesis of combining two bits of information into knowledge fusion requires knowledge and pedigree/historical information, which was context. Rowley and Hartley[30] describe knowledge as learning accumulation, hence, to accumulate knowledge and context “collective intelligence” was used as described by Gruber [8]. Therefore, not only is effort required to observe, select, and physically take hold of information, but also necessary is the understanding that collected knowledge and context has a historical relationship to existing information. Gruber [8] states that collective intelligence emerge if data collected from all people is aggregated and “recombined” to create new knowledge. To form an understanding of the relationship between different knowledge and contexts when assimilating knowledge, the associated relationships can be written symbolically as knowledge K_i and the associated context relationship R_j where, $K_i(R_j)$ represents a recombination of knowledge and context and finally represents the assimilation storage into the core domain repository. This is depicted in knowledge assimilation Figure 1. Figure 1 depicts a conceptual search space where a user would search for discipline specific knowledge and context within the Information Domain. The combined knowledge and context is then assimilated in the Temporary Knowledge Domain into a storage space shown on the right of the equation, the Knowledge Domain, to store knowledge and context which has reached a threshold level in the mind of the assimilator.

4.1.3 Storage of Knowledge and Context

Today, existing databases housing vast bits of information do not store the information content of the reasoning context used to determine their storage [21]. The knowledge collection and storage formula was therefore developed to include and store relationship context along with knowledge, recursively. This means that, each act of knowledge and context pairing shown as in equation shown in Figure 1, $\sum_{i,j} K_i(R_j)$, recursively examined all of the previous relationships as they were recombined into storage since they were all related and dependent on each other. Recursive refinement then occurred, per iteration of relationship pairing. Recursive refinement occurred when the user found what was looked for shown as $K_i(R_j)$, using interrogatives, (e.g. who, what when, where, why and how) [19-20]. The information content contributing to finding the answer then has significant value and therefore, a higher degree of permanence in the mind of the stakeholder [55]. Therefore, the information content has reached a threshold where retaining the knowledge and context has become important. The assimilation to storage can take physical and virtual form. Virtual storage can be described as the caching of a collection of temporary knowledge in the mind of the user per Ausubel et al. [56] along with a set of historical pedigree of preconceived/tacit or explicit knowledge and context per Nonaka [2] used to solve an issue at hand. Physical representations of assimilated stores are well known (e.g. libraries, databases, coin or philatelic collections.) However, whether virtual or physical, each unit of storage has a series of reasons or pedigree as to why it was collected and stored, or in the case of knowledge and context assimilation, why a knowledge and context relationship was created. For this result it is assumed that while knowledge and context are contemplated in the mind of the user [56], that knowledge and context

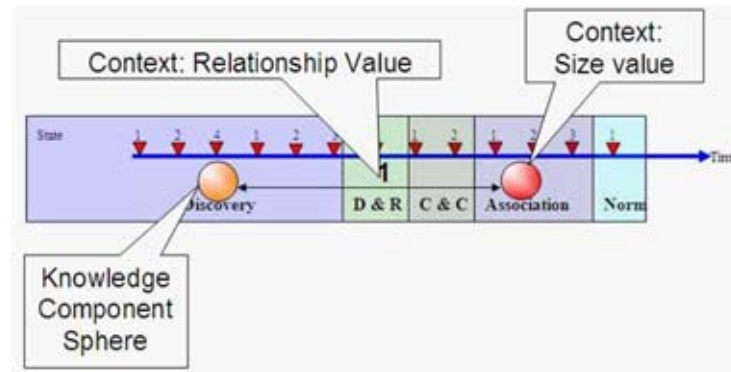


Figure 2: Knowledge Relativity Thread.

are stored virtually until the point in time the user reaches the threshold where it is believed the virtual knowledge is of enough quality to become stored in a physical repository for someone else to see or use, or that a virtual memory constraint has been reached and thus the memory needs to be saved physically so that it might not be lost if not captured.

4.2 Presentation of Knowledge and Context

Figure 2 represents a KRT. This approach for presentation of knowledge and context and was constructed to present five discrete attributes, namely, time, state, relationship distance, relationship value, and event sequence. In this figure, the timeline represented by the blue arrow from left to right, shows the events or state transitions in sequence and captures the decision points. During each iteration of presentation of knowledge and context, intrinsic values were captured and placed close to each colored knowledge component. In Figure 2, these are represented as words under the cycles. The Basic Sentence Decomposition depicts how a KRT looks when it represents a sentence decomposed into pieces; in this case words. The red triangles, added next, depict a particular state for each iteration in the KRT development cycle. For emphasis, each colored sphere was built into the depiction and added in sequence to represent the fact that each word follows the other. Each icon represents each word of the sentence. The relative values in this Basic Sentence Decomposition between each sphere are perceived to be of the same value to each other. Therefore, the lines are the same distance as well. Since, this base representation depicted in Figure 2 can present time,

state, and sequence, as well as, relationships, the challenge was addressed as described by Dourish [13] to create presentation of context which can visually capture and manage a continually renegotiation and redefinition of context as development of knowledge occurs over time. Figure 3 shows a KRT presentation approach to comparing the knowledge and context between two distinct discipline abstracts. Specifically, for this example, Bioscience 1 abstract and Video Processing 1 abstract were compared to each other to find similarities, per the need as prescribed by Habermas [57] to have an original set of criteria to meet and by Ertas et al. [23] to find and integrate concepts and methods from other disciplines which share similar levels of analysis and finally by Trochim [34] which described the need to present knowledge and context so different groups can collaborate their different thoughts and ideas in a structured conceptualized manner. Therefore, a systematic approach was taken comparing and presenting the knowledge and context of each aggregated object to the other. As part of this enhanced systematic approach, each aggregated object in each abstract is compared to each of the other aggregated objects in the other abstract. As this comparison occurred, the user captured each event in a log for every action and related reason which transpired during the systematic comparison. The details of the log are explained later in this paper. This logged information was used to help subsequent users gain a more complete understanding of the knowledge and context and thereby interpret a previous KRT collaboration presentation blueprint. The KRT visualization of this comparison shown in Figure 3 depicts the sequence of the aggregated objects that were compared. An important distinction about the observation of each comparison

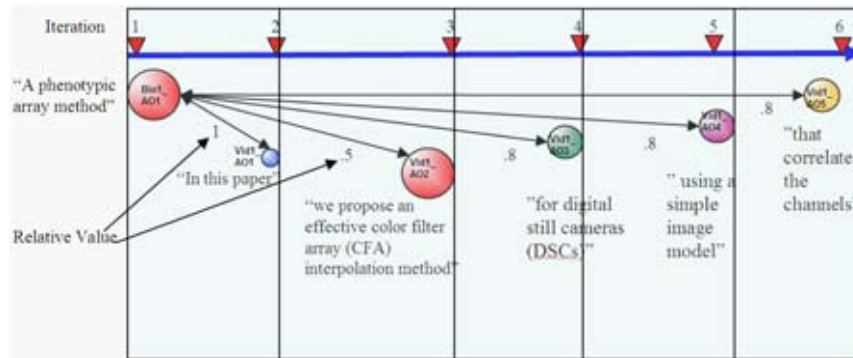


Figure 3: Comparing Abstracts using KRT.

is that each was made from the perspective of the aggregated object being compared. This is defined conceptually as an analogy to Hibeller [54] where the concept of relating the motion of two particles is as a frame of reference and is measured differently by different observers.

Figure 3, is a snapshot in time, using simple length measures to show relative distance of a relationship which is described later in paragraph 3.3, for comparison of aggregated object 1 in the Bio-science 1 domain abstract or Bio1_AO1 compared to each aggregated object from Video Processing abstract 1 or Vid1_AO1 to Vid1_AO5. Iteration 1 shows Bio1_AO1=“A phenotypic array method” solo. Iteration 2 shows Bio1_AO1 being compared to Vid1_AO1=“In this paper.” The relationship is not similar and therefore has little value and is presented by the smaller spheroid and distant relationship set namely to L1. By contrast, iteration 3 shows an equal size red spheroid showing an overlapping match was found (e.g. the word “array”). Meaning Bio1_AO1 has the word “array” in the text as does Vid1_AO2, thus presenting a change in relationship shown as a different length L2 as compared to Bio_AO1 and Vid1_AO1 (1). The reason why the relationship between Bio1_AO1 and Vid1_AO2 is not closer than L2 is that though the relationship has been found to be textually similar, until additional information content is gathered and understood as per Brillouin’s [9] assertion that information has no value until it has been thought about, a final assertion can not be made that these two aggregated objects are exactly the same. Iteration 4 shows Bio1_AO1 compared to Vid1_AO3=“for digital still cameras (DSCs).” The green spheroid is larger than the blue spheroid Vid1_AO1 because, at

initial look, substantive information such as “digital still camera” presents additional information which might be relative to Bio1_AO1=“A phenotypic array” when additional comparisons and knowledge and context are obtained. The distance of the relationship is therefore currently a bit further than that of Vid1_AO2 (L2), but closer than Vid1_AO1 which has little to no similarity, at this point, to Bio1_AO1. Lastly, Vid1_AO4 and Vid1_AO5 have similar attributes as Vid1_AO3 and therefore their knowledge and context relationship settings are similarly set.

4.3 Representation of Knowledge and Context

The representation of knowledge and context formula is introduced here and is presented by Equation (2). The independent results which follow are mathematical evaluations extended from Newtons law of gravitation shown in Equation (1). Newtons Law of Gravitation formula is,

$$F = G \frac{(M_1 M_2)}{r^2} \quad (1)$$

where,

F is the magnitude of the gravitational force between the two objects with mass,

G is the universal gravitational constant,

M_1 is the mass of the first mass,

M_2 is the mass of the second mass, and

r is the distance between the two masses.

This equation was used as an analogy for the derivation of mathematical relationship between a basis made up of two objects of knowledge.

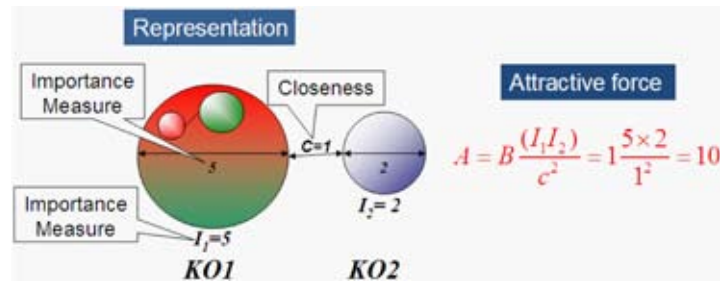


Figure 4: Representation of Knowledge Object and Context.

Abstracting Newtons Law of Gravitation

An analogy of Equation (1) that represents relationships between two objects of knowledge using context is written as Equation (2) shown below, which describes the components of the formula to represent relationships between two objects of knowledge using context:

$$A = B \frac{(I_1 I_2)}{c^2} \quad (2)$$

where,

- A is the magnitude of the attractive force between the two objects of knowledge,
- B is a balance variable,
- I_1 is the importance measure of the first object of knowledge,
- I_2 is the importance measure of the second object of knowledge, and
- c is the closeness between the two objects of knowledge

Comparing the parameters of Equation (1) and Equation (2) F and A have similar connotations except F represents a force between two physical objects of mass M_1 and M_2 and A represents a stakeholder magnitude of attractive force based upon stakeholder determined importance measure factors called I_1 , and I_2 . As an analogy to F in Equation (1), As strength or weakness of attraction force was also determined by the magnitude of the value. Hence, the greater the magnitude value, the greater the force of attraction and vice versa. The weighted factors represented the importance of the objects to the relationships being formed. The Universal Gravitational Constant G is used to balance gravitational equations based upon the physical units of

measurement (e.g. SI units, Planck units). B represents an analogy to G 's concept of a balance variable and is referred to as a constant of proportionality. For simplicity, no units of measure were used within Equation (2) and the values for all variables only showed magnitude and dont represent physical properties (e.g. mass, weight) as does G . Therefore, an assumption made here is to set B to the value of 1. For simplicity, all of these examples assume the same units and B was assumed to be one. The parameter c in Equation (2) is taken to be analogous to r in Equation (1). Stakeholder perceived context known as closeness c represented how closely two knowledge objects (KO) are related. Lines with arrows are used to present the closeness of the relationships between two pieces of knowledge presented as spheroids.

The representation of knowledge and context approach depicted in Figure 4 is a representative structure of knowledge and context as a snapshot in time for Bioscience 1 abstract. The first word of Bioscience 1 abstract is the word "A." "A" by itself has little meaning. However, it was still considered part of this abstract and was therefore marked as object of knowledge 1 (KO1) within the abstract. As the abstract was read and more information content was gained and understood, "A"'s knowledge value changed. Currently, all that is known at this juncture is that "A" described a singular entity and has foreshadowed that something will follow. Hence, that has some small value and creates cognitive structure in the mind of the "learner" per Ausubel et al. [56]. It is depicted in Figure 4 as knowledge object 1 (KO1) (e.g. red spheroid with the number 1) and mentally place only a small value on it for now because of our lack of knowledge. Next, as reading the abstract continued, the second word is found and marked as knowledge object 2 (KO2), "phenotypic." Figure 4, representing the knowledge and context of the mind of the learner now depicts KO1 and KO2, as related

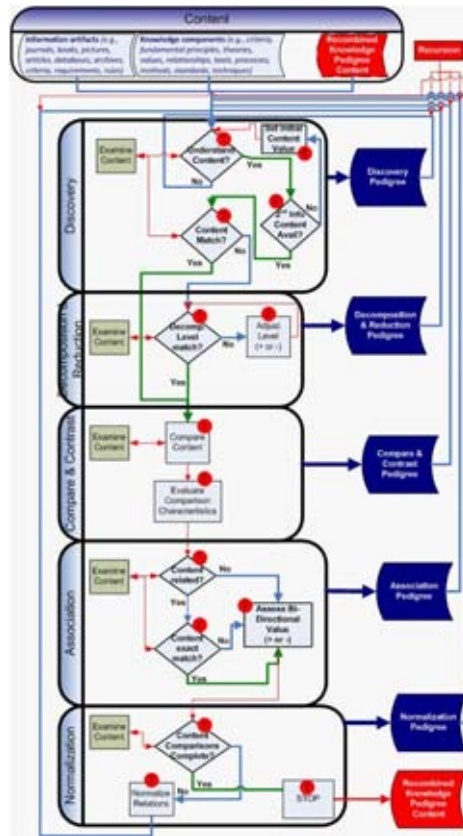


Figure 5: RNA Flow Diagram.

to each other. The word “A,” or KO1 has a smaller spheroid than KO2, and therefore, structurally represents a smaller context of importance measure shown as a diameter, $I_1 < I_2$. The line distance between KO1 and KO2 structurally represents “closeness” or how closely related the objects are perceived to be to each other. The word “A,” KO1 has small relationship to KO 2. Hence, KO1s relationship to KO2 was characterized simply as residing within the same abstract and one of order sequence. Therefore, the knowledge objects remain further apart, shown as closeness or “c.” Therefore, the snapshot in time shows a structural representation of knowledge relationship between two knowledge objects along with the context of magnitude importance value shown as the arrows representing the diameter magnitude of each knowledge object.

Using Equation (2), the value of the attraction force $A_{1 \rightarrow 2} = 5 \times 2$ divided by the relative closeness/ perceived distance² = 1. Hence, the attraction force A in either direction was 10. The value of 10 is context which can be interpreted in relation to the scale. The largest possible value for attraction

force A with the assumed important measure 1-10 scale is 100, therefore a force of attraction value of 10 was relatively small compared to the maximum. This means that the next stakeholder/ researcher understood that a previous stakeholders conveyance was of small relative overall importance. However, the closeness value of 1 showed that the two objects were very closely related. Figure 4 therefore shows that when using Equation (2), if relationship closeness and/or perceived importance measure of the knowledge objects change value, as new knowledge or context is added and evaluated, then it follows that relationship force of attraction will change.

4.4 Framework to Enhance Knowledge and Context

The framework developed in this research to enhance knowledge and context is shown in Figure 5 and was referred to as the Recombinant kNowledge Assimilation (RNA). RNA and is made up of a combination of the organization of knowledge and context, the presentation of knowledge and context, and the representation of knowledge and context [21]. The three

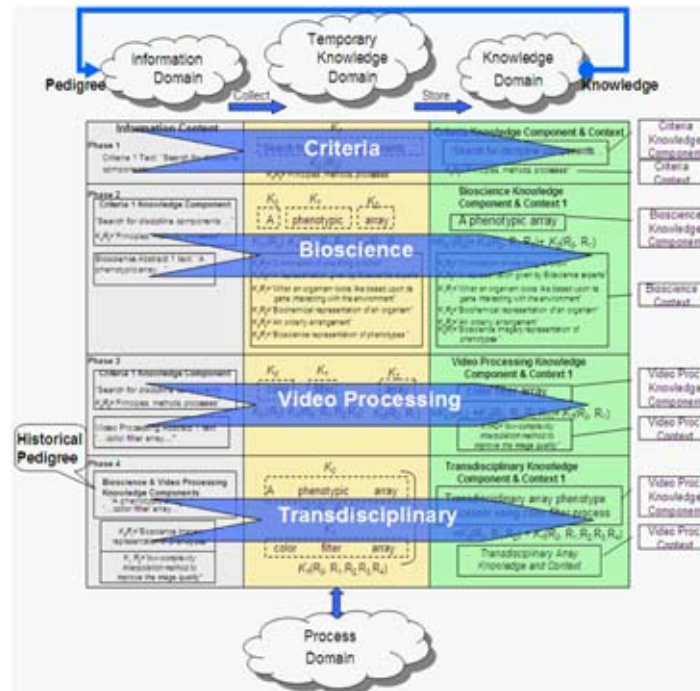


Figure 6: Knowledge and Context Processing.

components make up the core pieces essential for building a knowledge and context framework [21, 47]. Cross discipline domain research [28-29, 31, 33, 58] shows clearly that although all researchers use their own flavor of unique rules, methodologies, processes and frameworks, they use a core set of components for gathering, analyzing, organizing and disseminating their work. Recently Liao et al. [47] and Ejigu et al. [21] defined these processes as: collection, storage, presentation and representation.

4.4.1 RNA Flow Diagram

The RNA Flow Diagram shown in Figure 5 is shown to describe the flow of the processes within the framework [21]. It is similar to the Liao et al. [47] framework that collects, stores, presents and represents knowledge and context. The RNA flow diagram comprised three major, discrete parts. First, “Content,” which represents all information content input into the flow diagram. Second, “Sub-Processes” for synthesizing knowledge and context. Third, storage repositories known as pedigree bins, where knowledge and context was stored during compilation. Compilation is a path beginning from basic information content in the Information Domain, to the Knowledge Domain, as described by Brillouin [9], where a set of initially “useless” information is

“thought about” and turned into knowledge. This knowledge becomes the collected pedigree knowledge and context, just as Gupta and Govindarajan [48] collected knowledge flow for measurement, for the next researcher, as shown by the blue arrow leaving the Knowledge domain and feeding back into the Information Domain in Figure 6. In the RNA flow Diagram shown in Figure 5, each diamond shaped box represents a decision point. This is a critical point where a stakeholder of the process contemplates the decision to be made using any previous knowledge components acquired prior to making the decision as defined by Kim et al. [6]. Each red spheroid represents a sub-step within each of the larger components of the RNA process. These red spheroids are used to identify an important portion of the process. Red arrows signify action and green arrows represent “Yes” answers to a decision, hence the red lines represent a stakeholder of the process performing an action such as, collecting more information content known as used knowledge during process execution [6] for the eventual goal of establishing a more complete understanding of knowledge and context during processing at a decision point. All other blue arrows, represent either “No” answers or neutral transitions to a subsequent step in the process to track the flow of the process and thus

continually collect information content used to make the “No” decision.

The RNA process flow begins when a reason or need was established to ask a question and to want to search for an answer. This causes the establishment of a set of criteria or rules which govern what was to be discovered [57]. These criteria govern the activity performing the bottom-up processing and recursively evolving the building of knowledge and context. Once the criteria has been established and understood passing from the Information Domain thru the Temporary Knowledge Domain and finally captured in the Knowledge Domain, the RNA sub-processes begin processing based upon the defined rules. RNA processes criteria just as other information content. Each is collected from the Information Domain, “thought about” [9] in the temporary Knowledge Domain and subsequently placed into the Knowledge Domain for use as shown in Figure 6.

The upper rounded box labeled “Content” represents all information content which can potentially be used when performing the steps of the RNA process to build knowledge components. This is the set of initially “useless” information built into knowledge, as described by Brillouin [9], and is represented by the information content under the Information Domain search space in Figure 6. Hence, when a stakeholder begins the process of examining information, it is the information content which was initially observed, using the senses, and then subsequently “thought about” and understood, via collecting, representing, presenting, and storing, until the stakeholder satisfies the desired threshold of understanding defined by the initiating criteria. The criteria were considered information content as well, since a set of criteria was established to setup rules to compare against until satisfied. The gathering and comparisons, shown by the red arrows in Figure 5, occur to the point where a stakeholder believes an understanding has been reached during each step in the process, just as Brillouin [9] defines knowledge as resulting from a certain amount of thinking. Therefore, the developed sub-Processes: Discovery, Decomposition and Reduction, Compare & Contrast, Association, and Normalization process information content based upon a set of initial criteria.

4.4.2 RNA Synthesis Sub-processes

The RNA common process contains five functional sub-processes, labeled Discovery, Decomposition and Reduction, Compare & Contrast, Association, and Normalization. These sub-processes synthesize knowledge and context within the framework down the left side of Figure 5. These sub-processes operate in the process domain [59] as shown in Figure 6. Discovery encompasses the review and understanding of existing knowledge and /or in the case of disciplines, the review of a discipline’s fundamentals and/or First Principles. Decomposition & Reduction decomposes the domain knowledge into “bite size” digestible bits of information and reduces the representative domain knowledge to a core capability. Compare & Contrast, a cognitive examination process assimilating facts and information, comparing each to the other, looking for evolving associations, Association for establishing and assigning relationships between any two objects of information, and Normalization for functionally combining commonalities into a normalized form and validating the result. Finally, recursion is depicted as the blue domain knowledge feedback loops, which represents the iterative recursive refinement taking the knowledge gathered during each iteration and using it as input into the next iteration of the RNA process.

Since RNA’s synthesis tasks, depicted in Figure 5, extend concepts from mature disciplines including Software Engineering. Specifically, recursion is shown by the feedback loops from each of the processes [31] [32]. Recursion is well suited for the goal of creating objects of information using a bottom-up approach, iteratively building its components and attributes through a series of decisions. Hence, RNA implements the mature bottom-up approach for developing knowledge and context as discipline components, derived from discipline domain abstract readings and the recursive nature of the process shown by the feedback loop in Figure 5 which recombines knowledge and context.

4.4.3 Discovery

In the Discovery sub-process, the stakeholder must gather at least one additional piece of information content to make a comparison. During the comparison process, the stakeholder was asking questions and developing answers, just as in the Sternberg Paradigm [29]. However, the difference was that

RNA developed and retained empirical information during each specific step. Each question and answer was developed and captured at each step. All thoughts regarding reasoning and the information content used to develop the comparison were also captured at each step. Consequently, the value the stakeholder placed upon each piece of information content, shown in Discovery step 4, can be temporarily saved mentally or stored physically to retain the context of the thoughts being developed. This was designated by all the dark blue arrows and boxes labeled (e.g. Discovery Pedigree). After the first piece of Information Content has been observed, the flow diagram shows that a stakeholder must have at least one other piece of information content in order to form a comparison. Hence, the RNA process flow expands using a red arrow to depict the setting of an initial value property for the first piece of content and then continues back to Discovery step 1 to observe a 2nd piece of information content in order to form a comparison. Finally, if the stakeholder has found two pieces of content that was believed to be an exact match and was exactly what has been searched for, then the flow diagram resumes in the Association building block where a determination was made as to the bi-directional value of force attraction of matching relationship pairs. If there was not an exact match then the next Decomposition and Reduction building block in the flow diagram was used to assist in determining whether there was simply an inequality in the comparison, and the Decomposition and Reduction flow block assists in rectifying that issue.

4.4.4 Decomposition & Reduction

The next step in the RNA Process was Decomposition and Reduction. This phase extends and expands GPS [27, 60], used to solve problems by successively reducing the difference between a present condition and an end goal. This was important because this section of the flow diagram was built so the stakeholder can establish a comparison level by which one can create comparisons more easily. Therefore, decomposition expands the RNA flow diagram as shown in box 2, and constitutes the act of slicing the contextual bonds of a relationship between two pieces of information and comparing the logical context level to assess whether information content should be further sliced or whether information content should be aggregated instead. The

process of decomposition and reduction to practice based upon knowledge and context is similar to the concept of graduated/granulated in fuzzy logic [4]. As expressed in the Decomposition definition above, a document can be sliced into paragraphs and paragraphs can be sliced into sentences.

However, this Decomposition and Reduction decision spot in the flow diagram is built so words can also be aggregated together into sentences, or so characters can be aggregated into words. Thus, the red arrow from the box labeled “Adjust Layer Up or Down” was created showing that the stakeholder decides whether the content being compared was at the same logical context level/OEA. As before, the capture of the reasoning and meanings behind the decisions to aggregate or decompose was gathered and the dark blue pedigree repository box was created to depict the pedigree storage. The flow diagram then was built to feed back, all pedigrees from all phases, into the information content repository each time new context, knowledge or information content is generated as output from the flow diagram.

The reasoning captured during decomposition can give valuable insight into stakeholder context. For example, it is well known that words can have multiple definitions, and when aggregated together into sentence form they can portray different emphasis and different meanings just by their sequence. Therefore, capturing this as pedigree provides the next evaluator of this information valuable reasoning context, which could otherwise easily be misinterpreted. A detailed log file is then created to act as a pedigree container as the abstracts are processed. The log file describes details of state, sequence, and events. These details give insight into how the process was used to generate knowledge components and related context from the information content contained within abstracts. Specifically, a Bioscience paper and a Video paper were processed. The high-level process flow and a portion of the labeled pedigree are shown in detail in Figure 6, Knowledge and Context Processing. The specific examples show that the capture of the relationship pedigree along with the stakeholder weighting of relative relationships. Thus, providing valuable insight into (e.g., who, what, when, where, how and why) relationships were developed and how the process contributed to the benefit of subsequent researchers evaluating the previously conveyed thoughts. Once the knowledge objects are equated at the same contextual level of

understanding, the OEAs can be passed to the next stage, Compare & Contrast.

4.4.5 Compare and Contrast

The Compare & Contrast building block was then added to capture the specific characteristics of the OEA relationship through a series of interrogatories. At this stage, simple interrogatories such as, Who, What, When, Where, How, and Why as well as more detailed questions can be asked based upon the context to determine relationship specifics. Hence, the box for comparing content was added to the flow diagram and then the “Evaluate Characteristics” box was added to designate the need to perform an analysis of the characteristics captured such that the next building block can be added called Association.

4.4.6 Association

The building block Association is where the critical analysis was performed for determining the value of the relationships formed during RNA. The decision box is added to designate the need to determine if, based upon the analysis captured during Compare and Contrast, the objects are related to one another. The flow diagram box is then added to designate the need to assess the value strength or weakness of the relationship bi-directionally. A value assessment of each object to the other is performed, based upon the context of the analysis. As in all the previous sub-processes, the iterative decisions and reasoning is captured in the created blue pedigree boxes for ultimate feed-back into the content repository box.

4.4.7 Normalization

The next building block added to the RNA flow diagram is the Normalization box representing evaluation of the overall content of the relationships developed under a set of rules governing what to discover. This is analogous to an automobile which is made up of many parts. Each part has an independent function. Each set of parts is related to each other based upon some specific context (e.g. Rim and Tire). However, the sum of all valued parts equals a car, but each part has a perceived value to the overall value of the car as well. An engine might be perceived as having more importance than the radio. Therefore, the Normalization building block was added to designate the need to evaluate

all relationships created under the guise of a given criteria context to each other bi-directionally. If all comparisons are complete, then the RNA process flow diagram process stops and the Normalization pedigree is added to the content repository through the blue feedback pedigree box. The pedigree reasoning which was derived from normalizations of the all the relationships created under a certain criteria are related to each other to achieve a cohesive overall value chain of the relationships to each other and their importance to the overall context of the criteria.

In summary, the new RNA Common Process depiction in Figure 5, describes a process which can be generalized for use in a domain where knowledge assimilation is desired, by extending a bottom-up approach in OOD and applying concepts the natural language interrogatives found in 6WH. Therefore, RNA follows a path of creating knowledge and context in a natural manner combined with techniques described herein, for collecting, representing, presenting and storing.

4.4.8 Application of RNA to Journal Abstracts

The RNA common process was applied to research journal abstracts in Bioscience [61] and Video Processing [62]. The elements of the constructed RNA framework and sub-processes were applied to each journal abstract, yielding criteria knowledge component and context, knowledge component and context, and transdisciplinary knowledge component and context. This is depicted in by the four phases in Figure 6.

Additionally, the snapshot in time shown in Figure 6 depicts how the framework combined the use of RNA as a common process, the presentation approach for knowledge and context, and the representation approach for knowledge and context. Together the framework constructed and refined a sustainable blueprint of knowledge and context from abstract excerpts in Bioscience and Video Processing. Thus, via the log files and pedigree bin storage mechanisms, it was shown how a cohesive user collaborative [50] dependency trail of knowledge and context was created. The collaborative nature of the process showed how “collective intelligence” was created as defined by Gruber [8]. Therefore, the outcome satisfied the objective of locating reliable and relevant information out of an environment of rich domain specific Bioscience and Video processing abstracts.

Finally, upon comparison of the two abstracts using the framework comprised of organization, presentation, and representation, of knowledge and context, the outcome showed creation of transdisciplinary knowledge component and context.

5 Conclusion

A framework was constructed from the organization, presentation, and the representation of knowledge and context. The organization was derived from the concept of collection and storage, general problem solver, derived from Newell et al. [27] and Simon [28] who together developed models of human mental processes. Sternberg paradigm [29], and tenets of transdisciplinary engineering as defined by Tanik and Ertas [5]. The presentation was constructed from five discrete attributes, namely, time, state, relationship distance, relationship value, and event sequence from computer engineering and mathematics. The representation was derived by using Newton's law of gravitation as an analogy. Finally, the framework was applied to abstracts from research manuscripts and extracted disciplinary and transdisciplinary knowledge and components and therefore was able to as described by Ertas et al. [23], discover important knowledge within one discipline can be systematically discovered, and recombined into another, and via combined engineering visualization mechanisms and collaborative KRT blueprints satisfied Stokols [51], need to achieve a more complete understanding of prior research collaborations and sustain future ones. Finally, the framework satisfied the need as described by Liao et al. [47], enabling transition from data, information and knowledge to new knowledge.

Therefore, using RNA, disciplinary and transdisciplinary knowledge components and context were systematically discovered from tacit and explicit knowledge and context, allowing future generations a mechanism to dynamically interact with ever changing research knowledge, assimilating it to form explicit new knowledge while retaining the causal pedigree. Thus, RNA was able to enhance transdisciplinary research knowledge and context.

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