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GENERATING INTEGRATION AND COMPLEX UNDERSTANDING:

Exploring the Use of Creative Thinking Tools within Interdisciplinary Studies

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Abstract: The following paper examines the links between the interdisciplinary process and the creative process and reviews the potential for the literature on creativity to propose and advance tools for promoting interdisciplinary understanding. By comparing the steps involved in the interdisciplinary model proposed by Newell (2001a) to the steps involved in each of the creativity models proposed by Wallas (1926), Treffinger, Isaksen, & Dorval, (2000), and Rossman (1964) as well as to the definition of creativity proposed by Torrance (1988), this paper aims to uncover clues to the techniques and methods found to be useful in producing synthesis and creative understanding. These tools are not the sparks that arise mysteriously from the mind of genius. On the contrary, they are tools that are known and that may be learned and honed; they include, but may not necessarily be limited to: observing, imaging, abstracting, recognizing patterns, forming patterns, analogizing, body thinking, empathizing, dimensional thinking, modeling, playing, transforming, and synthesizing (Root-Bernstein & Root-Bernstein, 1999).

Introduction

The interdisciplinary process, as it is generally conceptualized (Newell, 2001a), is intimately related to the creative process and may be fruitfully understood as a distinct form of creativity. As such, nuggets of insight into the interdisciplinary process may be mined from the professional literature on creativity. Newell and Green (1998) state that “certainly there is a creative component to synthesis” (p. 32), but what techniques and skills are needed in order to develop the ability to generate complex and synthetic understanding? The following paper examines the links between the interdisciplinary process and the creative process, as well as the potential for the literature on creativity to propose and advance tools for promoting interdisciplinary understanding. This discussion presumes that creativity and interdisciplinarity are themselves two complicated and abstract concepts which warrant explication.

Interdisciplinarity/Interdisciplinary Studies

Interdisciplinarity is an approach to studying an issue, problem, or question that is inherently complex (Newell, 2001a). Interdisciplinarity draws critically on disciplines and integrates their insights. One of the more compelling definitions of interdisciplinary studies characterizes it as:

> a process of answering a question, solving a problem, or addressing a topic that is too broad or complex to be dealt with by a single discipline or profession. Whether the context is an integrated approach to general education, a women’s studies program, or a science, technology, and society program, IDS draws on disciplinary perspectives and integrates their insights through construction of a more comprehensive perspective. (Klein & Newell, 1998, p. 3)

The Interdisciplinary Process

The interdisciplinary process has the goal of eliciting understanding and solutions to complex problems by setting out the necessary steps that lead to the “pulling together and synthesizing of disparate disciplinary insights into a coherent whole…” (Newell, 1998, p. 113). Both Klein (1990) and Newell (2001a) have outlined what are generally agreed upon models (as claimed by Newell, 2001a) that specify the necessary steps for accomplishing this process. There is, nevertheless, some disagreement among interdisciplinarians as to whether the steps are "linear and sequential or looped and flexible" (Newell, 2001a, p. 14). Newell's (2001a) version of the interdisciplinary process is outlined below:

A. Drawing on disciplinary perspectives.

- *defining* the problem [question, topic, issue];
- *determining* relevant disciplines [interdisciplines, schools of thought];
- *developing* working command of relevant concepts, theories, methods of each discipline;
- *gathering* all current disciplinary knowledge and *searching* for new information;
- *studying* the problem from the perspective of each discipline;
- *generating* disciplinary insights into the problem.

B. Integrating their insights through construction of a more comprehensive perspective.

- *identifying* conflicts in insights;
    - using disciplines to illuminate each other's assumptions;
    - looking for different terms with common meanings, or terms with different meanings;
- *evaluating* assumptions and terminology in the context of the specific problem;
- *resolving* conflicts by working toward a common vocabulary and set of assumptions;
- *creating* common ground;
- *constructing* a new understanding of the problem;
- *producing* a model [metaphor, theme] that captures the new understanding; and
- *testing* the understanding by attempting to solve the problem. (p. 15)

Creativity, Discovery, Invention, and Innovation

Various terms are often employed to describe creative activity; for instance, "Hamlet was created, the telephone was invented, and the structure of DNA was discovered" (Ottino, 2000, p. 2750) which may lead to the impression that the underlying creative processes involved in each case somehow differ. However, as Dunbar (1999) states, "most researchers see scientific creativity as being composed of the same mental processes that guide all other forms of creativity" (p. 525). It follows then that instead of the choice of term being a strict categorization of specific types of creative processes, it appears largely to be a function of the discipline with which one is associated; typically, for example, *creativity* in the arts, social sciences, and humanities; *discovery* in the natural sciences; *invention* in the applied sciences; and *innovation* in business and high-technology (Cropley, 1999; Root-Bernstein, 1999; Hertz, 1999; West & Rickards, 1999, respectively). Nevertheless, it should be noted that certain individual authors may at times specify idiosyncratic distinctions among these terms.

Although a variety of definitions and words are used to describe creative activity (Davis, 1992; Parkhurst, 1999), there does seem to be agreement on some basic requirements necessary for an act or product to be considered creative irrespective of discipline (Benack, Basseches & Swan, 1989). Characteristics that are most commonly mentioned are *novelty*, *usefulness*, and *harmony* or *elegance*, with the caveat that no one criterion is in itself sufficient for the product to be considered creative (Voss & Means, 1989). Most definitions are sufficiently broad to encompass each of the disciplines, whether they are characterized as artistic or scientific; for example, there is considerable consensus on the following definition (Vernon, 1989):

> creativity… [is the] capacity to produce new or original ideas, insights, restructurings, inventions, or artistic objects, which are accepted by experts as being of scientific, aesthetic, social, or technological value. In addition to novelty as our major criterion, we must incorporate in our definition the acceptability or appropriateness of the creative product, even though this valuation may change with the passage of time. (p. 94)

The Creative Process

Creativity research is typically conducted in one of four strands: *person* (personality traits, cognitive abilities and biographical traits), *process*, *product*, or *environment* (Barron, 1988; Brown, 1989; Cropley, 1997; Rhodes, 1987). In the past, creativity research has tended to emphasize the person (traits) or the products resulting from creative endeavors. However, it is generally accepted that it may be more useful for researchers to characterize creativity as "a process which leads to the production of something that is both new and useful" (Houtz & Patricola, 1999, p. 1) and to focus on the steps, tools, and environments that foster this process (Spooner, 2001).

The creative process typically refers to (1) steps or stages, (2) perceptual changes or transformations, or (3) techniques and strategies that are used to inform or to produce the creative act (Davis, 1992). One of the earliest and perhaps best known creative process models is the four-stage configuration proposed by Wallas (1926). To account for the process by which "the making of a new generalization or invention, or the poetical expression of a new idea… was brought about" (p. 79), Wallas (1926) proposed the following stages: *preparation*, *incubation*, *illumination*, and *verification*. Briefly explained, (a) *preparation* involves observing a need or deficiency as well as clarifying the precise problem followed by a period of "reading, discussing, exploring, and formulating many possible solutions, and then critically analyzing these solutions for advantages and disadvantages" (Torrance, 1988, p. 45); (b) *incubation* involves a period of preconscious, offconscious, or unconscious mental activity, and, from this, activity flows; (c) *illumination* entails a flash of insight that is characterized as "a sudden change in perception, a new idea combination, or a transformation that produces a solution" (Davis, 1992, p. 101); and, finally, (d) *verification* consists of selecting a solution and testing it.

Wallas's model has served as the basis for, or is quite similar to, a wide range of subsequent models (Torrance, 1988), for instance, most notably, the creative problem-solving model attributed to Osborn (1963) which originally consisted of three stages, (1) fact-finding, (2) idea-finding, and (3) solution-finding. It was later adopted and expanded by Parnes (1981) and more recently by Treffinger, Isaksen, Dorval (2000) and now comprises six specific stages (see Treffinger, Isaksen, Dorval below). Using the Wallas model as a guide, a variety of theorists have added, amalgamated or somehow modified the various stages of the creative process (e.g., Basadur, 1987; Davis, 1992; Parnes, 1981; Treffinger, Isaksen & Firestien, 1982; etc.); however, to an extent these models remain closely related to the original.

The six flexible stages of the Treffinger, Isaksen, Dorval (2000) Creative Problem Solving model (CPS) are divided into three major process components: (a) *understanding the challenge,* which consists of constructing opportunities, exploring data, and framing problems*;* (b) *generating ideas*; and (c) *preparing for action,* which consists of developing solutions and building acceptance. According to the model: (1) *constructing opportunities* involves identifying and selecting a challenge or goal to be pursued; (2) *exploring data* involves investigating the various aspects of the task and then focusing on the principal goal for one's CPS efforts; (3) *framing problems* is the stage in which as many alternative problem statements as possible are generated and a specific problem statement is selected; (4) *generating ideas* consists of "generating many, new and unusual, or varied ideas to respond to the problem statement, [and] then identifying the most promising possibilities" (Treffinger, Isaksen, Dorval, 2000, p. 14); (5) *developing solutions* consists of analyzing and evaluating the possibilities and then shaping the most promising ones into potential solutions; and, finally, (6) the *building acceptance* stage involves putting the solution(s) into action by considering sources of resistance and acceptance as well as formulating plans to implement and evaluate the actions. One should note that each step may be followed in sequence or in a more concurrent style, the emphasis here being on improving the likelihood of finding a solution. Further, each stage consists of a divergent phase, where many ideas are sought, and a convergent phase, where only the most promising ideas are selected for further exploration. These stages are reflected by Torrance's (1988) definition of creative thinking as:

> the process of sensing difficulties, problems, gaps in information, missing elements, something askew; making guesses and formulating hypotheses about these deficiencies; evaluating and testing these guesses and hypotheses; possibly revising and retesting them; and finally communicating the results. (p. 47)

Correspondingly, after questioning over 700 inventors, each holding an average of 39.3 patents, about the process of invention, Rossman (1964) proposed the following steps to the inventive process:

1. Observation of a need or difficulty
2. Analysis of the need
3. A survey of all available information
4. A formulation of all objective solutions
5. A critical analysis of these solutions for their advantages and disadvantages
6. The birth of the new idea – the invention
7. Experimentation to test out the most promising solution, and the selection and perfection of the final embodiment by some or all of the previous steps. (p. 57)

It should be clarified that, for Rossman (1964), and as previously argued in this paper, the term *invention* is "not necessarily limited to developments in the physical sciences or in the industries, as it is ordinarily assumed. The term *invention* embraces all new developments in the social, administrative, business, the technical, scientific, and aesthetic fields" (p. 8).

Creativity and Interdisciplinarity

Comparing the interdisciplinary process model proposed by Newell (2001a) to each of the creative process models reviewed above reveals many links and common elements. As the creative process models are mapped onto Newell's model, it becomes quite evident how closely these two processes are linked. However, as can be expected when dealing with observations and descriptions of complex phenomena, steps in each process are not always conceptualized or defined in precisely the same manner or sequence; nor may each step in the creative process models previously discussed be mapped discretely into each step of the interdisciplinary process as identified and defined by Newell. Therefore, by no means is it suggested that there is a perfect fit between interdisciplinary and creative processes. There is not. Nevertheless, clear similarities between the two processes may be observed.

For instance, one will immediately notice that both interdisciplinarity and creativity are characterized as processes. Moreover, a key first element in the interdisciplinary model proposed by Newell (2001a) and in each of the creative process models proposed by Wallas (1926), Treffinger, Isaksen, Dorval (2000), and Rossman (1964) as well as in the definition proposed by Torrance (1988) is the identification or sensing of a problem. For Newell, this is a necessary precursor to *defining* a problem; for Wallas, it is included in *preparation*; for Treffinger, Isaksen, Dorval (2000), it is an overt goal of *constructing opportunities* where one considers a challenge; for Rossman, it is evident with the identification of a need or a difficulty which subsequently involves defining the problem, and, finally, for Torrance, it is where the process begins with the "sensing [of] difficulties, problems, gaps in information, missing elements, something askew" (1988, p. 47).

The next two steps in the interdisciplinary model proposed by Newell (2001a) are to *determine* the relevant disciplines and to *develop* a working knowledge of those disciplines. *Determining* is a step that is mirrored by Wallas's *preparation* which involves clarifying the precise problem, Treffinger, Isaksen, Dorval's *exploring data* where one identifies what is known about the problem, and Rossman's *analyzing the need.* Developing a working command of any discipline to generate a solution is not an overtly stated separate step within the creativity models examined; however, Wallas's *preparation* stage does incorporate a period of reading, discussing and exploring, and it is implied in Treffinger, Isaksen, Dorval's *exploring data* which explicitly demands that sources be considered from many points of view. In the case of Torrance's creative process definition, *determining* or *developing* are not included as steps to the creative process; rather, these steps are assumed to take place as is determined necessary for achieving a solution. For Ghiselin (1963) there are two qualitatively distinct forms of creativity: a lower level creativity which simply "extends some known concept into a new area of application" (Brown, 1989, p. 12) and a higher level creativity which "alters the universe of meaning itself, by introducing into it some new element of meaning or some new order of significance, or more commonly both[;]… the new insight may supplant all or part of some strongly established area of vision" (Ghiselin, 1963, p. 42). This distinction between levels of creativity is interesting since creative offerings appear to lie on a continuum – in one direction, an originality that occurs within the constraints of a given tradition; and in the other, an originality that involves an alteration of some aspects of the constraints themselves. Interdisciplinarity, it would appear, by definition, necessarily requires the latter form of creativity.

Newell next proposes *gathering* disciplinary knowledge and *studying* the problem from each perspective (2001a). These two steps are most closely mirrored by Wallas in *preparation* where one is to formulate many possible solutions after a period of reading, discussing and exploring, by Rossman who proposes surveying all available information, by Treffinger, Isaksen, Dorval who posit *framing the problem* through listing alternative problem statements, and finally, indirectly within Torrance's definition, through making guesses and formulating hypotheses about the problem. Ensuing for Newell is *generating* disciplinary insight similar to Wallas's *preparation* stage in which one formulates many possible solutions, to Treffinger, Isaksen, Dorval's *generating ideas* which involves generating as many alternative ideas as possible as potential solutions, to Rossman's formulation of all objective solutions, and to Torrance's making guesses and formulating hypotheses.

Identifying conflicts in insights and *evaluating* assumptions in the context of specific problems are the steps which, according to Newell (2001a), follow in the interdisciplinary process. Within the creativity process models examined, these steps correspond with Wallas's *preparation* and Rossman's fifth step where solutions are critically analyzed for advantages and disadvantages, Treffinger, Isaksen, Dorval's *developing solutions* where considering advantages, limitations, and unique qualities of solutions often involves developing an evaluation matrix to judge the ideas generated, and in Torrance's definition by evaluating and testing guesses.

Newell's *resolving* conflicts, *creating* common ground, and *constructing* a new understanding of the problem are somewhat reflected by: Wallas's *illumination* stage described as a sudden change of perception, new idea combination or transformation, by Rossman's sixth stage *birth of a new idea – the invention*, by Treffinger, Isaksen, Dorval's *developing solutions* which often requires one "to draw on several … pathways, not just one… [and] narrow or compress a number of possibilities and then analyze and refine the cluster that emerges" (Treffinger, Isaksen, Dorval, 2000, p. 52), and by Torrance's testing of guesses and hypotheses stages.

Finally, Newell's *producing* and *testing* steps are mirrored by Wallas's *verification*, which involves testing the solution, Treffinger, Isaksen, Dorval's *building acceptance* which involves making sure that good ideas become useful solutions, Torrance's revising and testing and communicating the results, and Rossman's "experimentation to test out the most promising solution and the selection and perfection of the final embodiment using some or all of the previous steps" (Rossman, 1964, p. 57).

It is of interest to note that, with their emphasis on testing and retesting, the preceding creativity models and definition imply greater trial and error, whereas the interdisciplinary model proposed by Newell (2001a) is more detailed and naturally places more emphasis on integrating disparate disciplinary knowledge. Creativity models appear to take integration of disparate disciplinary knowledge for granted. The creativity literature also stresses the fact that, in practice, the steps and techniques of the creative process are to be applied as the need arises with the primary emphasis being on improving the likelihood of finding a solution. The creative process is characterized as an iterative and heuristic endeavor, whereas, initially, Newell's (2001a) outline of the interdisciplinary process gives the impression that it is linear, rigid, and step-dependent. However, in Newell's subsequent reply (2001b) to various comments and critiques of his model, he asserts that:

> there is an element of arbitrariness in the width and order of the steps in my theory… interdisciplinarians follow the interdisciplinary process about as closely as scientists follow the scientific method. … Both abstract, for example, from the human tendency to jump ahead for a while and then return to fill the missing steps or to figure out what went wrong. (p. 140)

Newell's elaborated characterization of the interdisciplinary process,

TABLE 1

Steps in Interdisciplinary and Creativity Processes, as Suggested by Models Discussed

Newell (2001a)	Wallas (1926)	Treffinger, Isaksen, Dorval (2000)	Torrance (1988)	Rossman (1964)
	Preparation (observing a need or deficiency)	*Constructing opportunities*	Sensing difficulties, problems, gaps in information, missing elements, something askew	Observation of a need or difficulty
Defining	*Preparation* (clarifying the precise problem)	*Exploring the data*		Analysis of the need
Determining	*Preparation* (reading, discussing, exploring)	*Exploring the data*		
Developing				
Gathering and searching	*Preparation* (formulating many possible solutions)	*Framing problems*		A survey of all available information
Studying				
	Incubation			
Generating	*Preparation* (formulating many possible solutions)	*Generating ideas*	Making guesses and formulating hypotheses about these deficiencies	A formulation of all objective solutions
Identifying conflicts		*Developing solutions*		A critical analysis of these solutions for their advantages and disadvantages

Newell (2001a)	**Wallas (1926)**	**Treffinger, Isaksen, Dorval (2000)**	**Torrance (1988)**	**Rossman (1964)**
Evaluating assumptions	*Preparation* (evaluating solutions for advantages and disadvantages)		Evaluating and testing these guesses and hypotheses	A critical analysis of these solutions for their advantages and disadvantages
Resolving conflicts				
Creating common ground	*Illumination*	*Developing solutions*	Making guesses and formulating hypotheses	The birth of the new idea – the invention
Constructing				
Producing				Experimentation to test out the most promising solution, and the selection and perfection of the final embodiment by some or all of the previous steps
Testing	*Verification*	*Building acceptance*	Possibly revising and retesting them	Experimentation to test out the most promising solution, and the selection and perfection of the final embodiment by some or all of the previous steps
			Communicating the results	

together with the one which follows, suggests that the two processes may be even more similar than they initially appeared. As Mumford and Porter (1999) remind:

> …most significant creative efforts represent solutions to highly complex problems – problems that include a host of relationships, multiple restrictions, and a number of different types of knowledge. As a result, the construction of viable mappings and useful new relational systems will be an unusually demanding activity calling for substantial cognitive resources over long periods of time. Moreover, in grappling with multiple potential relationships, and a variety of sometimes contradictory constraints, one cannot expect coherent solutions will appear immediately. Instead, multiple integrations of relational mappings will be built up over time, with these mappings, and their coherence, improving as a function of ongoing elaboration and extensions to related phenomena. This pattern of progressive refinement and extension seems to characterize creative efforts across the arts and sciences as witnessed by the efforts of both Darwin and Monet. (p. 75)

The preceding examination and comparison of the steps involved in the interdisciplinary model proposed by Newell (2001a) to each of the steps or stages in the models proposed by Wallas (1926), Treffinger, Isaksen, Dorval (2000), Rossman (1964) as well as to the creative process definition proposed by Torrance (1988), reveal many links and common elements. For clarity, a comparison of the steps involved in each model is presented in Table 1, which can be found on pages 94-95. Here, as before, the reader should keep in mind that several of the steps used to describe the creative process are exceptionally broad, encompassing more than one discrete element of the process yet grouped under the same step; for instance, a term like "preparation" as defined by Wallas is problematic as one attempts its categorization for comparison purposes. Therefore, the chart is intended as a useful and time-saving visual summary only; it should not leave the reader with the impression that the two processes are a perfect fit which can be neatly overlaid.

In fact, links between the interdisciplinary and creative processes have been identified and examined in the past. For example, Sill (1996) has previously pointed out that creativity often involves synthesis and integration, fundamental goals for interdisciplinarians. In a similar vein, many have defined the creative idea as a "combination of previously unrelated ideas, or looking at it another way, a new relationship among ideas" (Davis, 1992, p. 44). However, it would appear more useful in future initiatives for interdisciplinarians and educators to characterize the creative process more broadly than integration, and to move the discussion beyond a focus on non-observable, "non-logical and non-linear thought" (Sill, 1996, p. 135).

Examinations of interdisciplinarity and creativity must include more detailed discussions of how insight and creative understanding are generated and achieved; or, stated another way, what happens within the process of creating common ground, or between the *incubation* and *illumination* stages. In the case of interdisciplinary studies, while it is recognized that creating common ground requires creativity (Newell, 2001a), the mental processes and tools by which it is generated have not been given much attention beyond a few useful techniques for fostering interdisciplinary integration, including redefining terms, extending meanings, transforming disciplinary axioms, and rearranging sub-systems (Newell, 2001a). A close examination of the literature on creativity may turn up clues to the techniques and methods that can be of use in producing synthesis and creative understanding.

There may be good reason why creative individuals are often creative in more than one discipline (Root-Bernstein & Root-Bernstein, 1999). For example, Root-Bernstein has spent over a decade studying the skills and tools employed by some of the world's most creative individuals, including among many others, Albert Einstein, Jane Goodall, Amadeus Mozart, and H. G. Wells (Root-Bernstein & Root-Bernstein, 1999; see also, Root-Bernstein, 1987, 1996, 1997). In fact, when the world's most creative thinkers are questioned, we find a basic set of tools that in various combinations are at the root of their creative understanding and that guide their creative endeavors. These tools are not the sparks that arise mysteriously from the mind of genius. On the contrary, they are tools that are known and that may be learned and honed; they include, but may not necessarily be limited to: *observing, imaging, abstracting, recognizing patterns, forming patterns, analogizing, body thinking, empathizing, dimensional thinking, modeling, playing, transforming, and synthesizing* (Root-Bernstein & Root-Bernstein, 1999; see discussion below).

Before it is possible to examine applications for each thinking tool within an interdisciplinary framework, an important distinction must be clarified between the tools people use to think creatively and the ones they use to express their innovations. Unlike Howard Gardner (1988, 1993), who tends to characterize creative individuals by the mode or specific domain in which they express themselves, and, contrary to Sill's (1996) characterization of the creative process "as modeled one way when looking at the activities of painting and sculpting, another when looking at inventing a new business enterprise" (p. 136), research by Root-Bernstein and Root-Bernstein (1999) and Spooner (1999, 2003) suggests there is an important distinction to be made between the mental tools and skills people use to think creatively and the ones people use to communicate their novel ideas. For instance, Einstein relied heavily on visualization, body thinking, and empathy to help generate creative understanding, yet communicated his findings and theories through mathematical formulae (Root-Bernstein & Root-Bernstein, 1999). It appears more likely that the underlying thinking tools involved in the creative process are the same regardless of domain or discipline of application (Amabile, 1983, 1990), albeit in varying degrees of emphasis (Root-Bernstein, 1987, 2000; Root-Bernstein & Root-Bernstein, 1999).

These creative thinking tools may be added to the techniques at the disposal of interdisciplinarians, thus improving their chances of developing creative, integrated, and synthetic responses to complex problems. Each thinking tool may enter into the interdisciplinary process at various steps and make a useful contribution to the end goal of developing interdisciplinary integration and synthesis. For example, in order to draw on various disciplinary perspectives, *observation* and *abstracting* are useful skills. Likewise, in order to integrate disciplinary insights, the ability to *recognize patterns*, to *form patterns*, to *analogize*, to *think dimensionally*, to *develop models*, to *transform,* and finally to *synthesize* information is very valuable. As well, it is not a stretch to see how having a playful attitude contributes to the flexibility that is often required when entertaining alternative points of view and attempting to integrate the insights they produce. The same may be said for *imaging*, *body thinking*, and *empathizing* which, depending on the disciplines involved, may contribute to the drawing of connections among disparate disciplines. An awareness of each of the creativity tools and a conscious attempt to target these skills may help to foster the end goal of interdisciplinary integration.

It is worth noting that interdisciplinary interactions tend to increase the likelihood for creativity to occur because, as Root-Bernstein and Root-Bernstein (1999) have demonstrated, each tool brings its own unique and valuable addition to the process of creative understanding. As interdisciplinarians are aware, within disciplines certain thinking styles are emphasized or downplayed in a variety of combinations. For example, research by Sagarin and Gruber (1999) has identified *ensembles of metaphors* – "figures of thought as images, symbols, allegories, and analogies" (p. 678) – that tend to cluster within various disciplines. While disciplines open doors to experience and provide an organizing structure for "knowing," they also form a type of disciplinary prism analogous to the screens or filters used in photography which act upon perception. Therefore, as interdisciplinary teams assemble, or as students are exposed to interdisciplinary environments, the variety of differing *ensembles of metaphor* and *metaphors in a field* are more likely to clash and/or complement one another, thus facilitating the discovery of preconceptions and habits of thought (Bohm, 1998), and in turn leading to the extension, modification, and variation of thinking styles and ultimately to a better understanding of complex questions. Interdisciplinary collaborations and integrated learning opportunities afforded through the interdisciplinary process promote new ways of observing and create an awareness of both old and novel patterns (Root-Bernstein, 2000). Interdisciplinary teams and training facilitate seeing not only what others have seen, but also what they have missed, and therefore foster learning to perceive in new ways; as disciplinary metaphors and forms of envisaging vary, so too do perspective and insight.

Discussion

Applying the Creative Thinking Tools to Interdisciplinary Studies

Interdisciplinary understanding and synthesis might fruitfully be re-examined in light of the literature on creativity. It is proposed that interdisciplinarians who consciously target the development, use, and interaction of the thinking tools previously identified are constructing paths that are optimal for generating synthetic (and creative) solutions to complex problems. In this context each thinking tool plays a role in the promotion of synthesis and interdisciplinary integration. One should keep in mind that the thinking tools operate in concert with one another and are presently examined individually solely for clarity. Due to length considerations, only the creative thinking tools proposed by Root-Bernstein and Root-Bernstein (1999) will be discussed here; however, to the extent that the interdisciplinary and creative processes are analogous, it would appear highly likely that a wide variety of insights may be gained by future examination of the literature on creativity.

Observing

Learning to perceive the world in a variety of ways contributes to effectively developing the ability for complex understanding. The keenest observers employ and assimilate sensory information from each of the senses. Creative artists and scientists spend years training to "see" (in the fullest sense of the term and through each of the senses) even the most mundane details. As Osborn (1963) states, "observation capitalizes inspiration" (p. 330); one must learn to be alert in order to take advantage of leads. Both artist and scientist should practice breaking out of perceptual habits by learning to rely on all the senses rather than concentrating on only a few (Root-Bernstein & Root-Bernstein, 1999). Perception is enhanced in creative individuals who use all senses in observing (Davis, 1992, p.72). One manner in which individuals may learn to become more observant is by increasing the opportunities for art-science interactions. As Root-Bernstein and Root-Bernstein (1999) state, "Art improves scientific observation as science can improve artistic observation" (p. 47). The following anecdote by Bohm and Peat (2000) eloquently describes the process by which perspective shapes one's sensory awareness:

> A group of people walking through the forest, for example, see and respond to their environment in different ways. The lumberjack sees the forest as a source of wood, the artist as something to paint, the hunter as various forms of cover for game, and the hiker as a natural setting to explore. In each case the wood and the individual trees are perceived in very different ways which depend on the background and expectations of the walker. (p. 65)

Imaging

The ability to imagine, see, hear, smell, taste, and touch with the mind's eye is an important thinking tool common to many fields and has been found to be significantly correlated with creative success (Root-Bernstein & Root-Bernstein, 1999). This is further supported by Ward, Smith and Finke (1999) who state "there is little doubt from historical and anecdotal accounts that imagery plays a central role in creative functioning…" (p. 204). Imagery is described "as schematic representations of thought… They can occur spontaneously or be deliberately generated and manipulated by conscious effort" (Houtz and Patricola, 1999, p. 2). According to Houtz and Patricola (1999), several ways in which this skill may be targeted include: (a) allowing the use of imagery when attempting to solve a problem, (b) elaborating on images by manipulating or making changes to an image, (c) using guided imagery as a practice activity, or (d) performing three-term series problems;

for example, “if Grace is taller than Carol, and Carol is shorter than Nessa, is Nessa taller than Grace?” (p. 2).

Abstracting

The ability to remove all but essential elements from one’s observations and thinking, to reduce complex visual, physical, emotional, or analytic ideas to bare, stripped form, often reveals non-obvious properties and hidden connections. Abstracting may take on many variants as different fundamental aspects are explored (Root-Bernstein & Root-Bernstein, 1999). As Mumford and Porter (1999) explain, “...abstract relational mappings may provide a particularly useful way of identifying viable relationships when people must work with diverse concepts” (p. 74). As will be discussed, this skill is also an important element of modeling. Interdisciplinarians should consider the use of modeling software as well as other informational database applications as additional tools that may contribute to one’s ability to abstract and to reduce complex visual, physical, emotional, and analytic ideas into simpler, abstracted forms. An alternative technique, mind mapping, is a visual procedure that “facilitates recording thoughts and associations through a connected nodal structure” (Proctor, 1999, p. 301). Such a structure may be illustrated manually or with the aid of computers and is quite useful in helping with the reconstruction and sorting of views on a problem, or mapping ideas and connecting interrelated problems with one another (Proctor, 1999). (See also discussion below under *Modeling*).

Recognizing Patterns

Discovery occurs when observations do not fit into expected patterns, or when one perceives new patterns and connections between what were previously thought to be unrelated things or ideas: “We derive from patterns that we recognize general principles of perception and action and base our expectations on those patterns. Then we try to fit new observations and experiences into these expectations” (Root-Bernstein & Root-Bernstein, 1999, p. 94). This view is supported by Loehle (1994) who maintains that pattern recognition is central to the discovery process and that “such a skill is particularly useful for finding relationships in phenomena…” (p. 241). Root-Bernstein and Root-Bernstein (1999) suggest several ways to improve the ability to recognize patterns and perceive relationships including: learning the pattern biases of other cultures by exploring the manner in which they view order, by inventing and solving puzzles, and by exploring a variety of musical patterns. The possibility is intriguing that interdisciplinarians may also wish to seek and target intercultural insight as an additional resource for constructing and developing increasingly comprehensive perspectives. Cultural exchanges could potentially become a great source of insight and dramatically alter the manner in which interdisciplinarity is conceptualized and practiced.

Forming Patterns

Forming patterns helps to create new knowledge and a richer understanding. Juxtaposing simple patterns often yields strikingly complex ones with surprising properties. Newly created patterns often reveal patterns that occur naturally but that have been overlooked (Root-Bernstein & Root-Bernstein, 1999). Discussing scientific discovery, Loehle (1994) argues that:

> It is far closer to puzzle solving or mechanical work. That is, a pattern or mental structure or understanding does not necessarily come all as a piece and in a flash, but rather may be built up slowly and piecemeal as one links facts together and builds and rearranges a mental framework for the problem. It involves tinkering, puttering, patience, and stubbornness. That is, we may say that the scientist is involved in constructing patterns. These patterns consist of networks of relationships between fact, assumptions, mathematical relations and methods, measurement techniques, rules of thumb, and hunches. (p. 242)

Interdisciplinarians should actively target pattern recognition and pattern formation in order to promote the development of discovery and problem solution.

Analogizing

To think metaphorically or to create analogies is to recognize a "correspondence of inner relationship or function between two (or more) different phenomena or complex sets of phenomena" (Root-Bernstein & Root-Bernstein, 1999, p. 142). Often these comparisons will reveal unsuspected shared properties. Ironically, in many instances "it is the inexact, imperfect nature of the analogy that allows it to bridge the gap between the known and the unknown" (p. 143). Research by Harrington (1980) suggests "the possibility that creative problem-solving skills might be incremented by teaching the conscious use of analogy-encouraging representational modes" (p. 21). This viewpoint is further supported by Gordon (1961) who argues problem-stating and problem-solving "…mechanisms are to be regarded as specific and reproducible mental processes, tools to initiate the motion of creative process … and by definition subject to conscious and deliberate use…" (p. 36). Synectics, as Gordon (1961) has coined them, have played an important role in "strip[ping] from the creative process the aura of sheer accidental intuition"(Gordon, 1976 p. 255) by devising a teachable strategy for employing their use. Among the techniques recommended by Gordon (1976) to help people think unhabitually and that contribute to the creative problem-solving process are *direct analogy*, *personal analogy,* and *compressed conflict* (symbolic analogy). Briefly reviewed : *direct analogy* is characterized by comparing one thing with another; Darwin, for example, comparing evolution in nature to the controlled breeding of livestock farms; *personal analogy* is characterized by the empathetic identification with something outside oneself, such as a scientist imagining him or herself as a lightbeam – also included as a technique for empathizing; and *compressed conflict* or *symbolic analogy* is characterized by a process of resolving seemingly contradictory concepts, as in close-coupled statements where the ideas "fight" each other as occurs in the oxymoron "gentle toughness."

Body Thinking

Insights may take the form of various types of muscular expression. As Gardner (1993) has demonstrated, the body harbors an intelligence; proprioception may take the form of a visceral, emotional, or kinesthetic feeling (Root-Bernstein & Root-Bernstein, 1999). This tool highlights the need to further explore alternative pedagogies and ways of knowing. Research has demonstrated that kinesthetic representations can sometimes "play significant roles in the creative problem-solving activities of some adults" (Harrington, 1980, p. 14-15). Clues as to how this technique may be usefully applied to IDS are not evident; however, preliminary research by Harrington (1980) appears to suggest "kinesthetic modes of representation tend to facilitate creative thinking by encouraging or demanding analogical/metaphorical transformations of information…" (p. 21). The use of role-playing may help by simultaneously incorporating body thinking as well as several of the other thinking tools proposed by the Root-Bernsteins, including empathizing.

Empathizing

To become "other" is distinguishable from simple imaging or proprioceptive thinking; it allows the individual to gain insight by entering a problem in such a way that one becomes a part of, one with, the problem – that is, it allows the individual to develop a sympathetic intuition and understanding (Root-Bernstein & Root-Bernstein, 1999). For instance, Einstein described using personal fantasy thought processes as he entered a problem which led to "the development of the special and general theories of relativity" (Harrington, 1980, p. 15). Gordon (1961) explains how the personal analogy technique may be useful:

> Personal identification with the elements of a problem releases the individual from viewing the problem in terms of its previously analyzed elements. A chemist makes a problem familiar to himself [or herself] through equations combining molecules and the mathematics of the phenomenological order. On the other hand, to make a problem strange the chemist may personally identify with the molecules in action. (p. 37)

Dimensional thinking

Dimensional thinking involves the ability to move from one dimensionality to another and may be useful for interdisciplinarians in their attempt to understand and synthesize often disparate disciplinary insights by helping to create a common level for comparison or juxtaposition. This ability may take one of several forms, including, *mapping,* the ability to transform information provided in one set of dimensions to another set; *scaling,* being capable of altering the proportions of an object in any given dimension; or *conceptualizing* dimensions beyond space and time as we know it (Root-Bernstein & Root-Bernstein, 1999).

Modeling

Modeling combines several tools at once, for example, abstracting, analogizing, and dimensional thinking, and is the ability to create one or all of the following: *representational models* which display physical characteristics of a real object; *functional models* which capture the essential operations of an object or mechanism; *theoretical models* which embody the basic concepts governing the operation of any given process; or *imaginary* *models* which display the features of an object or process that cannot be observed directly (Root-Bernstein & Root-Bernstein, 1999). Again, like dimensional thinking, modeling may help interdisciplinarians compare and juxtapose disciplinary information in a succinct format that may help reveal unseen properties, thus increasing the likelihood for insight to occur. For instance, Savolainen and Cantamessa (1995) contend that "building several models of the problem area from different viewpoints increases the knowledge, insight, ownership of the problem and motivation to find a solution" (p. 302); while, "having the models in representations, which have powerful tools of the 'side-meanings' to 'play' with the information and make information transformations, even 'illegal' [ones], increases the probability of innovative 'accidents' or associations" (p. 302). Discussing computer-simulated modeling, Meyer, Swanson and Williams (2000) note that "whereas computers made peripheral impact in the past, they are likely to be central to every aspect of research in the future, even – or especially – the creative aspects" (p. 120). The use and integration of computer-simulation models by interdisciplinarians may, ironically, prove to be an exciting and fruitful new specialization within the field of interdisciplinarity.

Playing

Playing is more than just being playful in exercising other thinking tools; it is a tool in and of itself. Playing involves the ability to retain a sense of humor, an almost childlike curiosity, and a playful attitude toward one's life and one's work which contributes to the breaking of normal habits of action, thought, and perception (Root-Bernstein & Root-Bernstein, 1999). Playfulness is a well-documented trait of many creative people (Davis, 1992). Interdisciplinarians who are playful, or encouraged or permitted to be playful, may well find that adopting such an attitude allows them the flexibility required to consider various viewpoints. Adopting a playful attitude provides a great freedom to "play" with concepts in a risk-free framework and environment. Interdisciplinarians may find it useful to play with disciplinary boundaries, distinctions, or "truths" that are taken for granted.

Transforming

Transforming is "the serial or simultaneous use of multiple imaginative tools in such a way that one (set of) tool(s) acts upon another (set)..." (Root-Bernstein & Root-Bernstein, 1999, p. 273). As concepts are transformed from one form to another, they often yield unexpected properties and new discoveries (Root-Bernstein & Root-Bernstein, 1999). Moreover, as previously discussed at the beginning of this section, in order to communicate solutions, ideas and insights must be transformed “through many tools for thinking and translated into one or more expressive languages” (p. 273). Transforming concepts or insight from one domain to another may be facilitated by ignoring disciplinary constraints (Boden, 1994). A graphic example of the power and use of this technique is provided by Root-Bernstein and Root-Bernstein (1999) who discuss the innovation of musical urinalysis which involves the transformation of typically numerical and graphical data into musical form, a representational form that allows researchers greater acuity to recognize chemical differences than through traditional light wavelength analysis. Other similar transformations include musical DNA which allows researchers to be able to hear similarities in sequences more quickly than visually scanning them. As Root-Bernstein and Root-Bernstein (1999) argue, “the more unexpected the transformation, the greater the likelihood that a surprising insight will result” (p. 285).

Synthesizing

Inevitably transformational thinking leads to a synthetic understanding, a multimodal understanding stemming from the fusion of multiple-sensing of the world. According to Flowers and Garbin (1989), “Theorists and artists long have recognized the correspondences, interrelationships, and interdependencies of the senses as they are used to capture information about the world” (p. 157). In order to generate complex and interdisciplinary understanding, the “integrated use of thinking tools [must be] such that, first, we synthesize sensory impressions and feelings and, second, we fuse our sensory synthesis with the abstract knowledge that exists in our memories as patterns, models, analogies, and other higher-order mental constructs” (Root-Bernstein & Root-Bernstein, 1999, p. 298).

The preceding section has provided an initial look at the possibility of incorporating, within an interdisciplinary context, thinking tools that have been found to be useful for promoting insight and creative understanding. Due to space limitations, it is not possible to provide an exhaustive list of how each of these tools may be applied within interdisciplinary studies; nor have other, and possibly numerous, additional insights been drawn from the literature on creativity. This section was, however, intended to open the possibility and to provide a brief aperçu to how the parallels between these two processes may be fruitfully re-examined in order to harness the full potential of interdisciplinary practice and study. Future research will not only need to examine the utility of each tool, but also how, and at what stage, it may be best applied in order to maximize the potential for interdisciplinary integration and to generate solutions to complex problems. We have only begun to scratch the surface.

Conclusion

Exploring a variety of links between the interdisciplinary and creative processes may help to enhance the interdisciplinary process by suggesting a variety of creative thinking tools that could prove to be instrumental in developing creative and synthetic understandings of complex problems.

Future research will need to examine more precisely how each of the creative thinking skills or tools factor into the interdisciplinary process and play a role in the development of knowledge integration and synthesis. In addition, initiatives in the design and delivery of interdisciplinary programs will need to take these creative thinking skills into account and consciously highlight and target them to the extent that they are found to be effective tools for fostering creative insight and synthesis. Finally, it should be made abundantly clear that this paper represents but one early exploration; future explorations should continue to investigate the feasibility of incorporating other useful tools and insights from the extant literature on creativity.

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