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THESIS

APPLYING SYSTEMS ENGINEERING METHODOLOGIES TO THE CREATIVE PROCESS

by

Adam H. Stone

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Thesis Advisor: Gary O. Langford
Second Reader: Brigitte T. Kwinn

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13. ABSTRACT (maximum 200 words)

The application of systems engineering methodologies to the creative process provides opportunities to improve the creative capabilities of individuals and organizations. Through creativity and systems engineering research, the creative process is equated to the systems engineering process. This allows creativity itself to be defined as a system. Defining creativity as a system permits the analysis of the creative process and the construction of a systems engineering based process model for creativity. Process based creativity theories are decomposed and reformulated into a process flow that acknowledges the iterative and recursive nature of the creative process. The derived process flow is then integrated with systems engineering process elements to construct a process model for creativity. The production of a systems engineering derived process model for creativity allows future opportunities to improve that process model by incorporating new creativity research and/or additional influences on creativity, increasing the fidelity of the model. The proposed process model also invites future research into the efficacy of the model. Through the use of systems engineering, creativity research may be incorporated and refined to build an evolving process model for creativity.

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APPLYING SYSTEMS ENGINEERING METHODOLOGIES TO THE CREATIVE PROCESS

Adam H. Stone
Commander, United States Navy
B.S., University of Florida, 1995

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Author: Adam H. Stone

Approved by: Gary O. Langford
Thesis Advisor

Brigitte T. Kwinn
Second Reader

Clifford Whitcomb
Chair, Department of Systems Engineering

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ABSTRACT

The application of systems engineering methodologies to the creative process provides opportunities to improve the creative capabilities of individuals and organizations. Through creativity and systems engineering research, the creative process is equated to the systems engineering process. This allows creativity itself to be defined as a system. Defining creativity as a system permits the analysis of the creative process and the construction of a systems engineering based process model for creativity. Process based creativity theories are decomposed and reformulated into a process flow that acknowledges the iterative and recursive nature of the creative process. The derived process flow is then integrated with systems engineering process elements to construct a process model for creativity. The production of a systems engineering derived process model for creativity allows future opportunities to improve that process model by incorporating new creativity research and/or additional influences on creativity, increasing the fidelity of the model. The proposed process model also invites future research into the efficacy of the model. Through the use of systems engineering, creativity research may be incorporated and refined to build an evolving process model for creativity.

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TABLE OF CONTENTS

LIST OF FIGURES

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LIST OF TABLES

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LIST OF ACRONYMS AND ABBREVIATIONS

EMMI	energy, matter, material wealth, and information
FFBD	functional flow block diagram
GQM	goal/question/metric
INCOSE	International Council on Systems Engineering
MOE	measure of effectiveness
SE	systems engineering
TOT	tip-of-the-tongue

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EXECUTIVE SUMMARY

The intensive study of creativity is a relatively recent phenomenon. Creativity refers to the production of something *novel* and *useful* (Dietrich 2004, 1011; Jung et al. 2013, 1; Sawyer 2012, 8). Creativity is essential to society, "…as a pathway to national prosperity and as a means for making the nation strong and safe" (Cropley and Cropley 2005, 170). Therefore, any advancement in creativity will have far reaching effects across multiple domains. The successful integration of systems engineering principles with creative theories to create a process model for creativity has the potential to provide a myriad of benefits.

The purpose of this thesis is to apply systems engineering methodologies to the creative process. This will allow individuals and organizations to be more creative through a systematic process. In order to do this, several research questions were asked and answered.

1. Is systems engineering applicable to the creative process?

This question addressed the theoretical aspects of applying systems engineering to creativity. Stage and componential process theories were shown to be most appropriate for conversion into a process model. As Kozbelt, Beghetto, and Runco (2010) state, stage and componential process theories of creativity "…attempt to understand the structure and nature of the creative process in terms of stages, which can be sequential or recursive, or underlying componential cognitive processes" (30). Sawyer's eight-stage creative theory was proposed and verified as the stage and componential process theory of creativity most readily convertible to a process model for creativity (2012).

The eight stages of Sawyer's (2012) creative process are: find and formulate the problem, acquire knowledge relevant to the problem, gather a broad range of potentially relevant information, take time off for incubation, generate a large variety of ideas, combine ideas in unexpected ways, select the best ideas applying relevant criteria, and externalize the idea using materials and representations (88–90). Component mechanisms from creativity literature were

integrated into individual context diagrams for each of Sawyer's eight stages in order to decompose each stage into component processes. Sawyer's eight-stage theory was then redrawn as a process flow, taking into account the iterative and recursive nature of creativity.

Creativity was shown to be a system. The systems engineering process was shown to be equivalent to the creative process in order to validate the application of systems engineering to creativity. Creativity was equated to systems engineering by mapping stage and componential process theories of creativity to generic systems engineering process models.

2. How can systems engineering be applied to creativity?

Using the theoretical groundwork laid by the first research question, the second question built a practical process model for creativity through the use of systems engineering. The selected creative process theory was integrated with elements from the systems engineering process in order to build this process model. Elements of the systems engineering process were selected, defined, and translated to a creativity context. These elements were then integrated into Sawyer's eight-stage creativity theory to build a process model for creativity.

The proposed process model was divided into two parts. The first part of the creativity system process model depicted the problem finding process. The second part depicted the idea generation process.

Acknowledgement that creativity is a system provides vast potential for study and improvement of the creative process. That acknowledgement allows the introduction of systems engineering and general systems thinking into the domain of creativity. Systems engineering provides a means to study creativity and improve understanding of the creative process. Systems engineering allows the construction of a process model for creativity, which can be continually refined as further research becomes available regarding various research aspects of creativity.

The process model for creativity proposed in this thesis provides a first step in applying systems engineering to the domain of creativity. Future work should include trials of the proposed model using a loss function to evaluate the results of those trials.

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I. INTRODUCTION

This chapter briefly describes the domain of creativity and the overall purpose of this thesis. The benefit of study of this thesis and the research questions posed are then discussed.

A. BACKGROUND AND PURPOSE

In order to examine how systems engineering can be applied to the creative process, this section provides background about the domain and study of creativity. The overall purpose of this thesis is then discussed.

1. The Study of Creativity

The intensive study of creativity is a relatively recent phenomenon, beginning in earnest in 1950 with an address by J.P. Guilford to the American Psychological Association. Guilford discussed the neglect of the study of creativity (Farooq 2008, 11; Sternberg and Lubart 1999, 3). Guilford reported that "…less than 0.2% of the entries in *Psychological Abstracts* up to 1950 focused on creativity" (Sternberg and Lubart 1999, 3). Even now, according to Kaufman and Sternberg (2010), "There are still debates, after more than six decades of intensive research, on how to measure, utilize, and improve it (creativity)" (xiii).

a. Roadblocks to Creativity Study

Sternberg and Lubart (1999) proposed that there have traditionally been at least six major roadblocks to the study of creativity (4). Systems engineering can be used to remove these roadblocks. A discussion of systems engineering terminology is contained in the Appendix of this thesis.

The first roadblock is that the origins of the study of creativity were steeped in "…mysticism and spirituality, which seems indifferent or even possibly counter to the scientific spirit" (Sternberg and Lubart 1999, 4). Systems engineering is a scientific and methodical approach to systems, which can be used to remove this first roadblock (Haskins 2011, 6).

Second, the elusiveness of a sound definition of creativity has, in the past, "…seemed to render the phenomenon either elusive or trivial" (Sternberg and Lubart 1999, 4). Through the decomposition of previously proposed creative process theories, systems engineering can be used to functionally define creativity. This will allow a verifiable process model to be produced and utilized.

Third, early creativity study was characterized by "…approaches that have tended to view creativity as an extraordinary result of ordinary structures or processes, so that it has not always seemed necessary to have any separate study of creativity" (Sternberg and Lubart 1999, 4). Howard Eisner, in *Essentials of Project and Systems Engineering Management*, defines systems engineering as "…an iterative process of top-down synthesis, development, and operation of a real-world system that satisfies, in a near optimal manner, the full range of requirements for the system" (quoted in Haskins 2011, 7). Using the top-down nature of systems engineering will result in a process model that incorporates the structures mentioned in the third roadblock. This will allow study of the entire scope of creativity, as well as the ability to incorporate future advances in creativity research into the creativity process model.

Fourth, early work on creativity was separated from mainstream psychology, resulting in its marginalization (Sternberg and Lubart 1999, 4). The fifth roadblock is that commercial approaches to enhancing creativity created an impression "…that its study lacks a basis in psychological theory or verification through psychological research" (Sternberg and Lubart 1999, 4). Lastly, many studies of creativity have tended to be unidisciplinary. These theories viewed a portion of creativity as the entire phenomenon, creating "…a perception that creativity is not as encompassing as it truly is" (Sternberg and Lubart 1999, 4). Systems engineering, by definition, is interdisciplinary, pulling knowledge and expertise from multiple disciplines (International Council on Systems Engineering [INCOSE] 2006; 2014). This interdisciplinary approach can be used to integrate mainstream psychology into creativity research, provide a testable creative process, and incorporate multiple domains into creativity research, addressing the fourth, fifth, and sixth roadblocks.

2. Purpose

According to Runco and Albert (2010), creativity studies continue to increase in scope and frequency (3). However, "…there is much to be learned about creativity, both by moving ahead with new research and theories and by looking back at what has been explored before" (Runco and Albert 3). This thesis attempts to use previous research in the domains of creativity and systems engineering to advance the execution of the creative process.

The purpose of this thesis is to apply systems engineering methodologies to the creative process in order to allow individuals and organizations to be more creative through the application of a systematic process. This thesis focuses on stage and componential process theories of creativity to build and elaborate a prescriptive process for creativity. As Kozbelt, Beghetto, and Runco (2010) state, stage and componential process theories of creativity "…attempt to understand the structure and nature of the creative process in terms of stages, which can be sequential or recursive, or underlying componential cognitive processes" (30). The other categories of creativity research will be discussed in Chapter II for background purposes.

B. BENEFIT OF STUDY

Creativity has broad applicability across multiple domains (some would argue all domains). As Cropley and Cropley (2005) state,

> The general argument is easy to summarize: In the face of rapid change that is biotechnological (e.g., communications, health), environmental (e.g., global warming, gene-modified crops), industrial (e.g., offshore manufacturing, globalization), demographic (e.g., breakdown of the family, aging of the population), social (e.g., adaptation of immigrants, integration of minorities), and political (e.g., terrorism, achieving fairness in international relations), societies will stagnate, even perish, unless their leaders in all fields

> become more creative. Thus, creativity is no longer seen as purely the domain of aesthetes and intellectuals concerned with questions of truth and beauty (as important as these issues may be), but also as a pathway to national prosperity and as a means for making the nation strong and safe. (170)

Creativity, therefore, is essential to society. In engineering fields, creativity is a cornerstone of engineering education in the United States, with 81 percent of employers believing that creativity is an important trait for workers to have (Ibrahim 2012, 6). According to Cropley and Cropley (2005), creativity "…is seen as essential for a successful career" (171).

Any advancement in creativity will have far reaching effects throughout multiple domains. Successful integration of systems engineering principles with creative process theories to create a process model for creativity has potential to provide a myriad of benefits, as outlined above.

C. RESEARCH QUESTIONS

This thesis will answer the research questions posed below. The questions posed in this section are somewhat general in nature and will be decomposed further in the methodology section.

1. Is systems engineering applicable to the creative process?
2. To which type of creativity theory can systems engineering processes be most successfully applied?
3. To which specific creative theory can systems engineering processes be most successfully applied?
4. How can systems engineering be applied to creativity?
5. Which systems engineering process elements are most applicable to creativity?
6. How can the selected systems engineering process elements be applied to the selected creativity theory to build a process model for creativity?
7. What expectations should one have if successful in applying the systems engineering process to the creative process?

D. METHODOLOGY

This thesis will answer the questions posed in the previous section. As questions are restated in the thesis body, creativity research, systems engineering research, or a combination of the two will be used to answer those questions.

In order to answer these research questions, numerous subquestions will be asked and answered. Those subquestions and the methods to be used to answer the questions and subquestions are presented in the following paragraphs.

1. Is Systems Engineering Applicable to the Creative Process?

This question will be answered in Chapter II. This question is designed to address the theoretical aspects of applying systems engineering to the creativity. In order to answer this question, the following subquestions will be asked and answered.

a. To Which Type of Creativity Theory Can Systems Engineering Processes Be Most Successfully Applied?

Different types of creativity research theories will be defined and discussed, in order to answer the following subquestions.

1. What are the different types creativity theories?
2. Which, if any, types of creativity theories are inappropriate for improvement by systems engineering processes? Why?
3. Which, if any, types of creativity theories are appropriate for improvement by systems engineering processes? Why?
4. Which is the most appropriate type of creativity theory for improvement by systems engineering processes? Why?

b. To Which Specific Creative Theory Can Systems Engineering Processes Be Most Successfully Applied?

The previous section will demonstrate that stage and componential process theories of creativity are the most appropriate for conversion into a process model. In this section, a specific creativity theory will be selected for further study. It will then be converted into a process flow that uses information derived from creativity research. To do this, the following subquestions will be asked and answered.

1. What are the key stage and componential process theories?
2. Which, if any, stage and componential process theories are inappropriate for improvement by systems engineering processes? Why?
3. Which, if any, stage and componential process theories are appropriate for improvement by systems engineering processes? Why?
4. To which specific stage and componential process theory can systems engineering processes be most successfully applied? Why?
5. What are the elements of that creativity theory? Are there any modifications that need to be made to it? Why?

Finally, a simple stage and componential process theory will be mapped to a systems engineering process model to demonstrate the applicability of systems engineering to creativity, answering the question presented at the beginning of Chapter II, "Is systems engineering applicable to the creative process?"

2. How Can Systems Engineering Be Applied to Creativity?

After the theoretical groundwork is set from Chapter II, a practical process model for the creative process will be built in Chapter III. The selected creative process theory will be integrated with elements from the systems engineering process in order to build this process model. To accomplish this, the following questions will be asked and answered.

a. Which Systems Engineering Process Elements are Most Applicable to Creativity? How Could Those Elements Be Used in the Context Of Creativity?

Systems engineering process elements that are applicable to creativity will be selected and defined. They will then be translated to a creativity context for later inclusion into the proposed process model.

b. *How Can the Selected Systems Engineering Process Elements Be Applied to the Selected Creativity Theory to Build A Process Model for Creativity? What Would A Process Model for Creativity Look Like?*

The selected systems engineering process model elements will be incorporated into the selected stage and componential process theory of creativity in order to build a process model for creativity. A walkthrough of the proposed process model will be conducted in order to fully explain it.

c. *What Expectations Should One Have if Successful in Applying the Systems Engineering Process to the Creative Process?*

This section will briefly describe potential methods to assess success or failure of the proposed process model for creativity. Subquestions that will be posed follow.

1. What should success look like?
2. What should failure look like?
3. How would one determine success or failure?

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II. IS SYSTEMS ENGINEERING APPLICABLE TO THE CREATIVE PROCESS?

This chapter is intended to address the theoretical aspects of applying systems engineering principles to creativity. Applicable creativity literature will be reviewed initially to gain an understanding of current creativity research and the creative process as described in that research. Applicability of systems engineering to creativity will be demonstrated by mapping a basic theory of creativity to a systems engineering process model. Finally, a creativity theory will be selected for later use in a proposed process model for creativity.

A. LITERATURE REVIEW

This literature review will provide a background of creativity research, allowing the eventual construction of a process model for creativity. Systems engineering process models will also be discussed. Further systems engineering concepts and definitions are contained in the Appendix.

1. Creativity Defined

Creativity refers to the production of something *novel* and *useful* (Dietrich 2004a, 1011; Jung et al. 2013, 1; Sawyer 2012, 8). Novelty refers to something new. Novelty alone is not sufficient for something to be called creative. Creative products must also be useful. For instance, a bridge or building that collapses could not be considered useful, no matter how novel the design is (Cropley and Cropley 2005, 173).

Ibrahim (2012) contends “Creativity has long been recognized as important in engineering design. Creativity in engineering design is often found as an area of emphasis in engineering textbooks” (3). Creativity is an essential element of all steps of a systematic design process (3).

Unfortunately, Ibrahim also states:

> Despite the fact that creativity is an important element in the engineering profession, engineering educators still face difficulties in assessing or quantifying creativity among their students. One reason could potentially come from the abstract nature of creativity itself and even now, there is no single definition of creativity that has been agreed upon among scholars. (2012, 3)

The requirement to accurately define creativity is essential to the construction of a process model for creativity. Sternberg and Lubart (1999) assert that "…creativity requires a confluence of six distinct but interrelated resources: intellectual abilities, knowledge, styles of thinking, personality, motivation, and environment" (11). Each of these resources is related to a stage of both Sawyer's eight-stage creative process theory (2012), which will be used as a basis for the proposed process model, and to the proposed process model itself. As each resource is described below, corresponding creativity concepts and proposed process model elements will be referenced.

a. Intellectual Abilities

Sternberg and Lubart (1999) further decompose the intellectual abilities required for creativity. The first of these three intellectual abilities is "…the synthetic ability to see problems in new ways and to escape the bounds of conventional thinking" (Sternberg and Lubart 1999, 11). This ability maps to the problem finding stage of both Sawyer's eight stages and the proposed process model (2012). The second of these abilities is "…the analytic ability to recognize which of one's ideas are worth pursuing and which are not" (Sternberg and Lubart 1999, 11). This ability maps to refinement and selection of the best ideas, both in Sawyer's eight stages and in the proposed process model. The third of these abilities is "…the practical-contextual ability to know how to persuade others of—to sell other people on-the value of one's ideas" (Sternberg and Lubart 1999, 11). This element is directly related to externalizing the idea, an element of both Sawyer's eight stages and the proposed process model.

Sternberg and Lubart (1999) describe the relationship between the three intellectual abilities:

> The confluence of these three abilities is also important. Analytic ability used in the absence of the other two abilities results in powerful critical but not creative thinking. Synthetic ability in the absence of the other two results in new ideas that are not subjected to the scrutiny required, first, to evaluate their promise and, second, to make them work. And practical-contextual ability in the absence of the other two may result in the transmittal of ideas not because the ideas are good, but rather because they have been well and powerfully presented. (11)

Though Sternberg and Lubart are discussing creative abilities (in contrast to the creative process), the above statement dictates a holistic approach to the creative process. A systematic approach to the creative process will ensure all of the required abilities, if present in the creator, will be utilized.

b. Knowledge

Sternberg and Lubart (1999) state:

> With regard to knowledge, on the one hand, one needs to know enough about a field to move it forward. One cannot move beyond where a field is if one doesn't know where it is. On the other hand, knowledge about a field can result in a closed and entrenched perspective, leading to a person's not moving beyond the way in which he or she has seen problems in the past. (11)

This relates to acquiring knowledge, a step in both Sawyer's eight stages and the proposed creative process model.

c. Thinking Styles

Sternberg and Lubart (1999) describe thinking styles as follows:

> With regard to thinking styles, a legislative style is particularly important for creativity, that is, a preference for thinking in novel ways of one's own choosing. This preference needs to be distinguished from the ability to think creatively: Someone may like to think along new lines, but not think well, or vice versa. To become a major creative thinker, it also helps if one is able to think

> globally as well as locally, distinguishing the forest from the trees and thereby recognizing which questions are important and which ones are not." (11)

This statement relates to problem finding, idea generation, idea combination, and idea selection and refinement, which are elements of both Sawyer's eight stages as well as the proposed creative process model.

d. Personality

Sternberg and Lubart (1999) address personality as follows:

> Numerous research investigations have supported the importance of certain personality attributes for creative functioning. These attributes include, but are not limited to, self-efficacy and a willingness to overcome obstacles, take sensible risks, and tolerate ambiguity. In particular, buying low and selling high typically means defying the crowd, so that one has to be willing to stand up to conventions if one wants to think and act in creative ways. (11)

Though the proposed creative process model does not specifically address the personality of the creator, personality will be addressed later in the thesis as an aspect of creative research.

e. Motivation

Sternberg and Lubart (1999) state that "Intrinsic, task-focused motivation is also essential to creativity" (11). They further suggest "…people rarely do truly creative work in an area unless they really love what they are doing and focus on the work rather than on the potential rewards" (11).

External motivation can also be used to spur creativity, but internal motivation has been shown to be superior (Huang 2005, 14-15). Task motivation is important, because "…without proper motivation and freedom from constraint, individuals with high levels of both domain-relevant skills and creativity-relevant skills will be unlikely to produce creative works or processes" (Freeman 2012, 24).

Study of creator motivation is, for the most part, beyond the scope of this thesis. Motivation will be briefly addressed when discussing emotional blocks later in this chapter. Constraints (which negatively affect motivation) will be discussed briefly as ambient risk. Neither of these elements is incorporated into the proposed creative process model.

f. Environment

Environment relates closely to motivation. The interrelationship between these elements is a component of systems theories of creativity (Kozbelt, Beghetto, and Runco 2010, 38). To quote Sternberg and Lubart (1999),

> …one needs an environment that is supportive and rewarding of creative ideas. One could have all of the internal resources needed in order to think creatively, but without some environmental support (such as a forum for proposing those ideas), the creativity that one has might never be displayed. (11)

Environment is an aspect of creativity research, and will be addressed later in this literature review. Environment is, for the most part, not addressed in the proposed creative process theory, with the exception of iterative externalizations.

2. Levels of Creative Magnitude

Creativity research breaks creativity into levels of creative magnitude in order to "…consider the scope and focus of theories, what may be missing, and what methods and measures might be most appropriate for exploring a theory's central proposition" (Kozbelt, Beghetto, and Runco 2010, 23). Big-C creativity refers to creativity on the largest scale, such as the work of Einstein. Occurrences of big-C creativity transform the domain (Sawyer 2012, 8, 11). Little-c creativity "…focuses on the creativity of everyday life" (Kozbelt, Beghetto, and Runco 2010, 23). An example of little-c creativity is "…the weekend watercolorist who dabbles for relaxation and enjoyment" (Kozbelt, Beghetto, and Runco 2010, 24). Mini-c creativity refers to "The creativity inherent in the learning process, when children discover something for the first time" (Sawyer 2012, 11). Pro-c creativity “makes room for professional level creators (like professional artists) who have not yet attained (or may never attain) eminent status, but who are well beyond little-c creators” (Kozbelt, Beghetto, and Runco 2010, 24).

This thesis addresses all levels of creative magnitude. A process model for creativity has the potential to enhance work conducted at each of the four discussed levels of creative magnitude.

3. Aspects of Creative Research

Creativity researchers divide creativity into areas of emphasis. These areas are known as the four Ps of creativity: process, product, person, and place (Kozbelt, Beghetto, and Runco 2010, 24). Process aspects of creativity “…typically specify different stages of processing or particular mechanisms as the components of creative thought” (Kozbelt, Beghetto, and Runco 2010, 24). These theories study “…the processes involved during creative work or creative thought” (Sawyer 2012, 11).

The product aspect of creativity focuses on “…the products judged to be novel and appropriate by the relevant social group” (Sawyer 2012, 11). These products may be “…works of art, inventions, publications, musical compositions, and so on” (Kozbelt, Beghetto, and Runco 2010, 24).

The person aspect of creativity focuses on “…the personality traits or personality types associated with creativity. Creative people are those identified with an individualist definition, or they are identified indirectly, as those people who have generated creative products” (Sawyer 2012, 11).

The place aspect of creativity, which is sometimes known as press (short for pressures), “…focuses on the external forces or ‘pressures’ acting on the creative person or process, such as the social and cultural context” (Sawyer 2012, 11). According to Kozbelt, Beghetto, and Runco, “Creativity tends to flourish when there are opportunities for exploration and independent work, and when originality is supported and valued” (2010, 25).

Of the above four Ps, the person aspect of creativity, relating to the selection or development of creative individuals, is beyond the scope of this paper, and as such will minimally addressed. The place aspect of creativity will be addressed in a limited fashion to raise awareness of possible prescriptive methods to enhance creativity. The product aspect of creativity will not be specifically addressed, but the intention of this thesis is to assist in the eventual genesis of more creative products. The primary focus of this thesis will be on the process aspect of creativity.

4. Systems Engineering Process Models

In systems engineering, "The overarching objective is to describe a *process* (as a frame of reference) that should be 'tailored' to the specific program need" (Blanchard and Fabrycky 2011, 49). To this end, systems engineers employ *process models*. Several systems engineering process models are examined.

a. SIMILAR

According to Bahill and Gissing (1998), "…the SIMILAR Process describes a logically consistent and effective means of planning and problem solving" (516). Bahill and Gissing (1998) assert, "…humans have a tendency to act in a disorganized way and need to be continually reminded about effective reasoning" (516). The SIMILAR process can be used to map processes in virtually any type of domain, be it technical or nontechnical (516). The SIMILAR process is endorsed by the INCOSE Fellows as an accurate representation of the systems engineering process (INCOSE 2006). The SIMILAR process can be summarized in seven steps, each of which will be briefly discussed.

(1) State the Problem

The problem should be stated in functional terms, divorced from proposed methods to achieve that function (Bahill and Gissing 1998, 516–517). The problem statement is based on the consequences of not satisfying the needs of a stakeholder. A problem exists if those consequences are significant enough to require action. Background and context of the problem are usually included in the problem statement (Langford 2012, 226).

(2) Investigate Alternatives

The investigation of alternatives could mean looking at multiple alternatives, or simply revising a single option until that option is acceptable. This investigation, particularly when working with unusual alternatives, can help to refine further the initial problem statement (Bahill and Gissing 1998, 517).

(3) Model the System

Models should be developed for the proposed alternatives. “Many types of system models are used, such as physical analogs, analytic equations, state machines, block diagrams, flow diagrams, object-oriented models, mental models, and computer simulations” (Bahill and Gissing 1998, 517). Analyzing the results of these models “…clarifies requirements, reveals bottlenecks and fragmented activities, reduces cost, and exposes duplication of efforts” (517).

(4) Integrate

Bring elements together so that they “work as a whole” (Bahill and Gissing 1998, 517).

(5) Launch the System

Begin using the system, allowing it to perform its intended purpose (Bahill and Gissing 1998, 517).

(6) Assess Performance

Measure and assess the performance of the system. Measures of effectiveness, as previously defined, are used to assess performance of functions. “Measurement is the key. If you cannot measure it, you cannot control it. If you cannot control it, you cannot improve it” (Bahill and Gissing 1998, 517).

(7) Re-Evaluate

Use feedback from the previous steps to determine the future course for the system. Course corrections can vary greatly in magnitude and may include

"…continue as is, make minor modifications, rework the entire project, or discontinue the project" (Bahill and Gissing 1998, 517).

The SIMILAR process is not sequential. It is parallel and iterative. The SIMILAR process is depicted in Figure 1 (Bahill and Gissing 1998, 517).

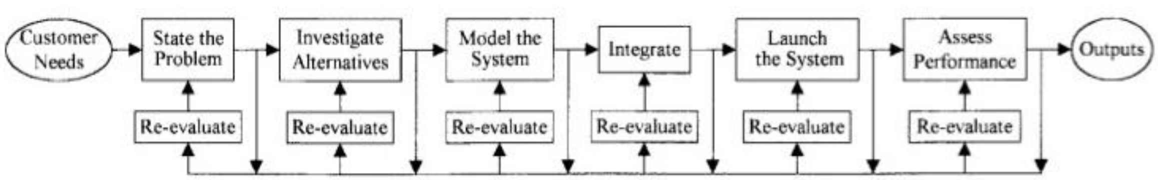

Figure 1. The SIMILAR Process (from Bahill and Gissing 1998, 518)

b. Vee Model

The systems engineering Vee model depicts the systems engineering process. A generic systems engineering Vee is shown in Figure 2.

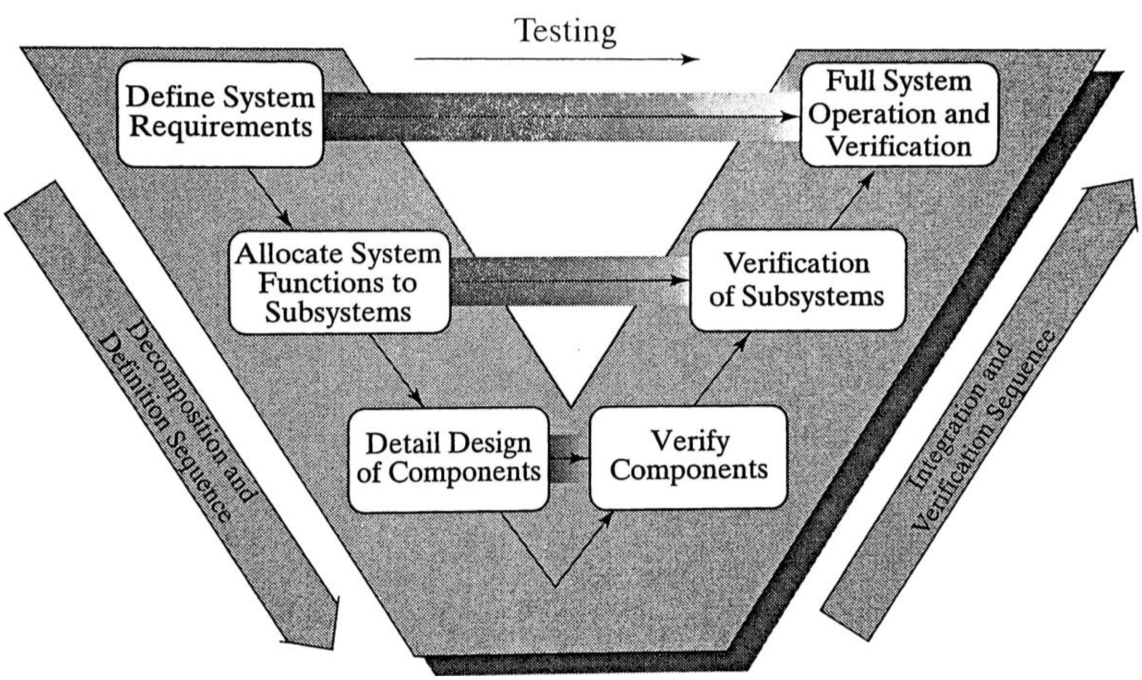

Figure 2. Generic Systems Engineering Vee (from Blanchard and Fabrycky 2011, 51)

The Vee model begins on the upper left of the model, progresses down towards the bottom of the Vee, and then moves up to the right, finishing in the upper right of the model. The Vee starts with user needs and finishes with an operating system that satisfies user requirements (Blanchard and Fabrycky 2011, 51).

Downward movement in the Vee corresponds to decomposition of systems functions and definition of requirements. Upward movement corresponds to integration of the system and verification that the system satisfies requirements. In other words, the Vee first breaks down a problem into its constituent elements, then finds solutions to those problems, and finally reconstitutes those solutions into a functioning, verified system that solves the initial problem (Blanchard and Fabrycky 2011, 51).

B. TO WHICH TYPE OF CREATIVITY THEORY CAN SYSTEMS ENGINEERING PROCESSES BE MOST SUCCESSFULLY APPLIED?

Creativity theories can be divided into different categories. Each type of theory brings a different perspective to creativity research (Kozbelt, Beghetto, and Runco 2010, 21). In the following sections, types of creativity theories will be outlined. The type of theory most capable of inclusion of systems engineering principles will then be selected.

1. What are the Different Types of Creativity Theories?

Creativity theory types are outlined below. When appropriate, creativity concepts will be introduced during the explanation of a creative theory type.

a. Developmental Theories of Creativity

Developmental creativity theories deal with how to encourage creativity in children so that they become more creative adults. It is based, to a large extent, on studying the backgrounds of extremely creative people. Developmental theories "…often suggest how to design environments so that the creative potentials of children will be fulfilled" (Kozbelt, Beghetto, and Runco 2010, 26).

b. Psychometric Theories of Creativity

Psychometric theories focus on the measurement of creativity. They "…are concerned, among other things, with the reliability and validity of assessment, which are issues in all scientific work on creativity" (Kozbelt, Beghetto, and Runco 2010, 29). This gives psychometric theories applicability through each of the other theory types.

c. Economic Theories of Creativity

Economic theories use, as the name would suggest, information from the domain of economics, which yields expected creative actions that can then be tested (Kozbelt, Beghetto, and Runco 2010, 30). Economic theories center on "buying low" and "selling high." As Sternberg (2006) explains, for the successful creator,

> Buying low means pursuing ideas that are unknown or out of favor but that have growth potential. Often, when these ideas are first presented, they encounter resistance. The creative individual persists in the face of this resistance and eventually sells high, moving on to the next new or unpopular idea. (87–88)

d. Stage and Componential Process Theories of Creativity

As Kozbelt, Beghetto, and Runco (2010) state, stage and componential process theories of creativity "…attempt to understand the structure and nature of the creative process in terms of stages, which can be sequential or recursive, or underlying componential cognitive processes" (30).

This paper uses stage and componential process theories to create a process model for creativity.

e. Cognitive Theories of Creativity

Kozbelt, Beghetto, and Runco (2010) explain, "Cognitive theories emphasize the creative process and person: process, in emphasizing the role of cognitive mechanisms as a basis for creative thought; and person, in considering individual differences in such mechanisms" (31). Individual cognitive theories can vary significantly in their focus and scope. Some focus on "…universal capacities, like attention or memory," (31) while others "…focus on individual differences" (31) in creative thought.

This paper leverages cognitive theories to further elaborate on the proposed creative process model.

(1) Threshold Theory

The threshold theory is a cognitive theory that relates to the individual's potential for creative thought. The threshold theory states, "…creativity and intelligence are correlated up to a certain threshold [around an intelligence quotient (IQ) of 120] after which they tend to vary independently" (Jung et al. 2009, 5319). Studies have attempted to test the threshold theory, and "...a study of college students using Magnetic Resonance Spectroscopy suggested that the threshold theory has neurobiological validity" (Jung et al., 5322). In other words, the threshold theory has been shown to accurately portray creative abilities based on intelligence from the perspective of the human nervous system.

f. Problem-Solving and Expertise Based Theories of Creativity

Problem-solving/expertise theories regard creativity "…as an essentially rational phenomenon" (Kozbelt, Beghetto, and Runco 2010, 34). These theories assert "…ill-defined problems can often be broken down into a set of well-defined problems, which can then be solved in familiar ways" (33). Many previously proposed creativity theories dictate that domain knowledge and expertise is a necessary element in creativity.

g. Problem-Finding Theories of Creativity

In contrast to the problem solving view,

> The problem-finding view holds that the traditional problem-solving view is inadequate to explain how creators come to realize that a problem exists in the first place, and how they are motivated to proactively bring their subjective experience to understand the problem. (Kozbelt, Beghetto, and Runco 2010, 34).

Problem-finding is an essential component of the creative process proposed in this thesis, and has strong parallels to the systems engineering process.

h. Evolutionary Theories of Creativity

Evolutionary theories propose that creativity is the result of blind, random generation and combination of ideas, followed by selective retention of those ideas. Those ideas are then refined consciously, and judged by other people (Kozbelt, Beghetto, and Runco 2010, 35–36). Evolutionary theories are a component of many cognitive theories. Evolutionary theories will be discussed in this thesis briefly to allow for greater knowledge of the mechanics of creative insight.

i. Typological Theories of Creativity

Typological theories attempt to divide creators into different types, "…who differ in systemic ways" (Kozbelt, Beghetto, and Runco 2010, 37). These different creative types are then typically used as the basis for theories.

j. Systems Theories of Creativity

Systems theories contend that "…creativity is best conceptualized not as a single entity, but as emerging from complex system with interacting subcomponents—all of which must be taken into account for a rich, meaningful, and valid understanding of creativity" (Kozbelt, Beghetto, and Runco 2010, 38).

2. Which is the Most Appropriate Type of Creativity Theory for Improvement by Systems Engineering Processes?

With each type, the question of whether or not that type of theory is appropriate for improvement by systems engineering processes and why will be addressed.

Elements from each creativity theory type can be combined in different theories (Kozbelt, Beghetto, and Runco 2010, 21). For the purposes of this thesis, stage and componential process theories of creativity are most appropriate, as they address the creative process. Because stage and componential process theories outline a process, they can be described and refined into a process model, incorporating other processes, both from the creativity domain and from other domains (including systems engineering). Where appropriate, principles and theories from other areas of creative research will be used to elaborate stage and componential process theories. For instance, cognitive theories and evolutionary theories will be used to explain the mental processes behind elements of stage and componential process theories. Additionally, problem-finding is a component of the stage and componential process theory that will be elaborated on in this thesis, and as such will be further discussed.

C. TO WHICH SPECIFIC CREATIVE THEORY CAN SYSTEMS ENGINEERING PROCESSES BE MOST SUCCESSFULLY APPLIED?

The previous section outlined why stage and componential process theories of creativity are most appropriate for conversion into a process model for creativity. This section discusses specific stage and componential process theories of creativity in order to choose one for conversion in Chapter III.

1. What are the Key Stage and Componential Process Theories of Creativity?

The explanation of several creative process models from creativity literature follows. The balloon model will be used to illustrate the concepts of divergent and convergent thinking. The Wallas model is significant because of its historical impact and contribution to the field of creativity. Sawyer's eight-stage theory of creativity incorporates many previous stage and componential process theories, and will serve as the basis for the process model to be constructed in Chapter III.

a. The Balloon Model

The balloon model is a very simple two-stage model that takes a high level look at the creative process. The balloon model is characterized by "…an expanding stage of *divergent thinking* where many possibilities are generated, followed by *convergent thinking* as you converge on the one best idea" (Sawyer 2012, 88). Divergent and convergent thinking are common elements in creative literature. The two concepts will be introduced at this time and referenced frequently throughout the thesis.

(1) Divergent Thinking

According to Cropley and Cropley (2005), divergent thinking "…involves branching out from the given to envisage previously unknown possibilities and arrive at unexpected or even surprising answers, and thus generate novelty" (170). Divergent thinking "…allows one to explore in different directions from the initial problem state, in order to discover many possible ideas and idea combinations that may serve as solutions" (Finke, Ward, and Smith 1992, 183). In short, divergent thinking allows one to generate unusual ideas rather than common ones (Finke, Ward, and Smith 1992, 184). Divergent thinking is associated with creativity (Cropley and Cropley 2005, 170).

(2) Convergent Thinking

According to Finke, Ward, and Smith (1992),

> In convergent thinking, one goes from an initial problem state through a series of prescribed operations in order to converge upon a single correct solution. Convergent thinking is ideal for well-defined problems for which there is only one allowable conclusion. (183)

Convergent thinking is thought that "follows the rules." As Cropley and Cropley (2005) explain, convergent thinking involves

> …acquiring factual knowledge, recalling it rapidly and accurately, reapplying it in a logical manner in order to find the single best answer to a problem, applying existing skills in a well-practiced, economical, and tidy way to new situations, having clearly defined and concretely specified goals, working quickly, resisting distractions, following instructions, and similar processes. (169–170)

b. The Wallas Model

In 1926, Graham Wallas published *The Art of Thought*. In one chapter of this book, Wallas proposed four “stages of control.” These four stages are a depiction of the creative process. The stages Wallas detailed are *preparation, incubation, illumination, and verification* (Wallas 1926). *The Art of Thought* is a book that was ahead of its time, and many of the concepts related to the creative process are present in modern creativity theories (Ellwood et al. 2009, 6).

c. Sawyer’s Eight Stages of Creativity Theory

Keith Sawyer proposed an eight-stage creative theory in his 2012 book, *Explaining Creativity: The Science of Human Innovation*. Sawyer’s eight-stage theory is something of a meta theory, which borrows from and builds upon previous creative process theories. Though an in depth discussion of these previous theories is beyond the scope of this thesis, Table 1 and Table 2 depict nine stage and componential process theories of creativity and maps the steps of those theories to Sawyer’s eight stages.

	Sawyer	Wallas	Creative Problem Solving	IDEAL Cycle	Robert Sternberg	Possibility Thinking
	2012	1926	2000	1984	2006	2006
1	Find the Problem		Framing Problems	Identify Problems, Define Goals	Redefine Problems	Posing Questions
2	Acquire Knowledge	Preparation	Exploring Data	Learn	Know the Domain	
3	Gather Related Information			Look		Immersion
4	Incubation	Incubation	Constructing Opportunities	Explore Possible Strategies	Take Time Off	Play
5	Generate Ideas	Insight	Generating Ideas		Generate Ideas	Being Imaginative
6	Combine Ideas		Developing Solutions		Cross-Fertilize Ideas	
7	Select the Best Ideas	Verification			Judging Ideas	
8	Externalize Ideas	Elaboration	Building Acceptance	Act and Anticipate Outcomes	Sell the Idea, Persevere	Self-Determination

Table 1. Sawyer's Eight Stages of the Creative Process Model and How They Correspond to Other Process Models, Part One (after Sawyer 2012, 89)

	Sawyer	UK QCA	Synectics	Mumford's Group	IDEO
	2012	2005	1961	2004	2001
1	Find the Problem	Questioning and Challenging		Problem Finding	
2	Acquire Knowledge		Groundwork	Information Gathering	
3	Gather Related Information	Envisaging What Might Be	Immersion		Observation
4	Incubation	Keeping Options Open		Concept Search	
5	Generate Ideas	Exploring Ideas	Divergent Exploration	Idea Generation	Brainstorming
6	Combine Ideas	Making Connections and Seeing Relationships		Conceptual Combination	
7	Select the Best Ideas	Reflecting Critically on Ideas	Selection	Idea Evaluation	
8	Externalize Ideas		Articulation of Solution, Development and Transformation, Implementation	Implementation Planning and Action Monitoring	Rapid Prototyping, Refining, Implementation

Table 2. Sawyer's Eight Stages of the Creative Process Model and How They Correspond to Other Process Models, Part Two (after Sawyer 2012, 89)

Sawyer's eight stages will be discussed in detail later in this chapter.

2. Appropriateness of Stage and Componential Process Theories of Creativity for Improvement by Systems Engineering Processes

Though stage and componential process theories of creativity are varied, they contain many similar elements. Referencing Table 1, one can see that each of the contained creative process theories map to each other. Each theory emphasizes a different area of the creative process and has a different intent. A large difference between the theories is the level of detail in each of the steps of the creative process. Per Table 1, each of the sampled theories has at least one fewer step than Sawyer's eight stages. This is not to say that the theory with the most steps is necessarily the best theory for that reason, but further study, which shall follow later in this chapter, will show that each of Sawyer's eight stages are a valid part of the creative process. Omission of one or more of those steps would create gaps in the creative process, and combination of one or more of those steps would require a later decomposition into the form proposed by Sawyer.

Because many stage and componential process theories of creativity share elements, any that are deemed valid in the creativity domain could be theoretically improved by systems engineering processes. As an example, the bubble model, as previously introduced, has two steps. The bubble model is a good theoretical construct, but to turn it into a useable prescriptive process model, it would have to be decomposed. At that point, the model would look more like a model with more fidelity, such as Sawyer's eight stages. It makes sense to eliminate models from consideration that are more theoretical or have less fidelity than other models. For these reasons, Sawyer's eight-stage creativity theory is selected for further study and eventual conversion into a process model for creativity.

D. DISCUSSION OF SAWYER'S EIGHT STAGE CREATIVITY THEORY

As Sawyer's eight stages are discussed, creativity concepts will be introduced and explained. Many of those concepts will be sourced from previous creativity theories whose steps mirror or have corollaries in Sawyer's eight stages.

Sawyer's eight-stage model is a cognitive process theory (2012). As Sawyer (2012) explains, "The consensus resulting from cognitive psychology is that creativity isn't a single, unitary middle process. Instead, creativity results from many different mental processes, each associated with one of the eight stages" (90). Sawyer contends that there are identifiable stages to the creative process, and that those stages can be decomposed.

Sawyer is an *action theorist*, meaning his theories propose "…execution of the creative work is essential to the creative process" (Sawyer 2012, 87). In other words, Sawyer believes and his eight-stage process contends that ideas are refined after their conception and generally not born in their final state. He further elaborates, "Once you start executing an idea, you often realize that it isn't working out like you expected, and you have to change what you had in mind. Sometimes a final product emerges that's nothing like your beginning idea" (87–88).

The eight stages of Sawyer's (2012) creative process are:

1. Find and formulate the problem (88)
2. Acquire knowledge relevant to the problem (88)
3. Gather a broad range of potentially relevant information (88)
4. Take time off for incubation (88)
5. Generate a large variety of ideas (88)
6. Combine ideas in unexpected ways (88)
7. Select the best ideas applying relevant criteria (88)
8. Externalize the idea using materials and representations (90)

1. Find and Formulate the Problem

The first step in creativity is to "…identify a good problem and to formulate the problem in such a way that it will be more likely to lead to a creative solution" (Sawyer 2012, 88). Unfortunately, problems are normally not presented in the most suitable format for creativity (Sawyer 2012, 90). The ability to properly frame a problem is a direct contributor to innovative thought (Kaye and Kelly 2013, 113).

The normal lack of suitable problems is not a completely negative issue. According to Sawyer (2012),

> …most creativity occurs when people are working on ill-defined problems: (1) they can't be solved through rote application of past experience; (2) the problem situation isn't clearly specified; (3) the goal state isn't clearly specified; (4) there may be many different end states; (5) there are multiple potentially viable paths to the end state. (90)

The reason for this, drawing upon previous distinctions between divergent and convergent thinking, is that "Solving well-defined problems involves primarily convergent thinking; solving ill-defined problems involves a higher degree of divergent thinking" (Sawyer 2012, 90–91).

Variance in problem finding skill has large effects on the speed with which one is able to solve a problem. According to Sio and Rudowicz (2007),

> When solving domain-related tasks, experts tend to spend longer than novices at the beginning of the problem-solving process, examining the nature of the problem carefully, after which experts will execute the required problem solving steps more quickly. This problem solving style allows experts to outperform novices in terms of speed and accuracy. (317)

It may seem as though experienced creators are initially on a slower track to generate ideas, but their problem finding skills allow easier completion of the problem overall (Sio and Rudowicz 2007, 317).

There are several suggestions for problem finding in the creative literature. First, consider restrictions on feasible approaches when formulating the problem (Sawyer 2012, 93). Second, "Creativity researchers have discovered that exceptional creativity more often results when people work in areas where problems are not specified in advance, where a big part of success is being able to formulate a good question" (Sawyer 2012, 91). Third, create analogies for the problem, and think of how those analogies could be solved (Scott, Lonergan, and Mumford 2005, 79). Lastly, seeking and using a mentor for advice "…is particularly helpful in developing the ability to identify good, promising problems" (Sawyer 2012, 95).

Figure 3 is a concept map of step one of Sawyer's eight stages, find and formulate the problem. The author created this concept map by merging concepts discussed in the preceding section that were presented by Sawyer (2012).

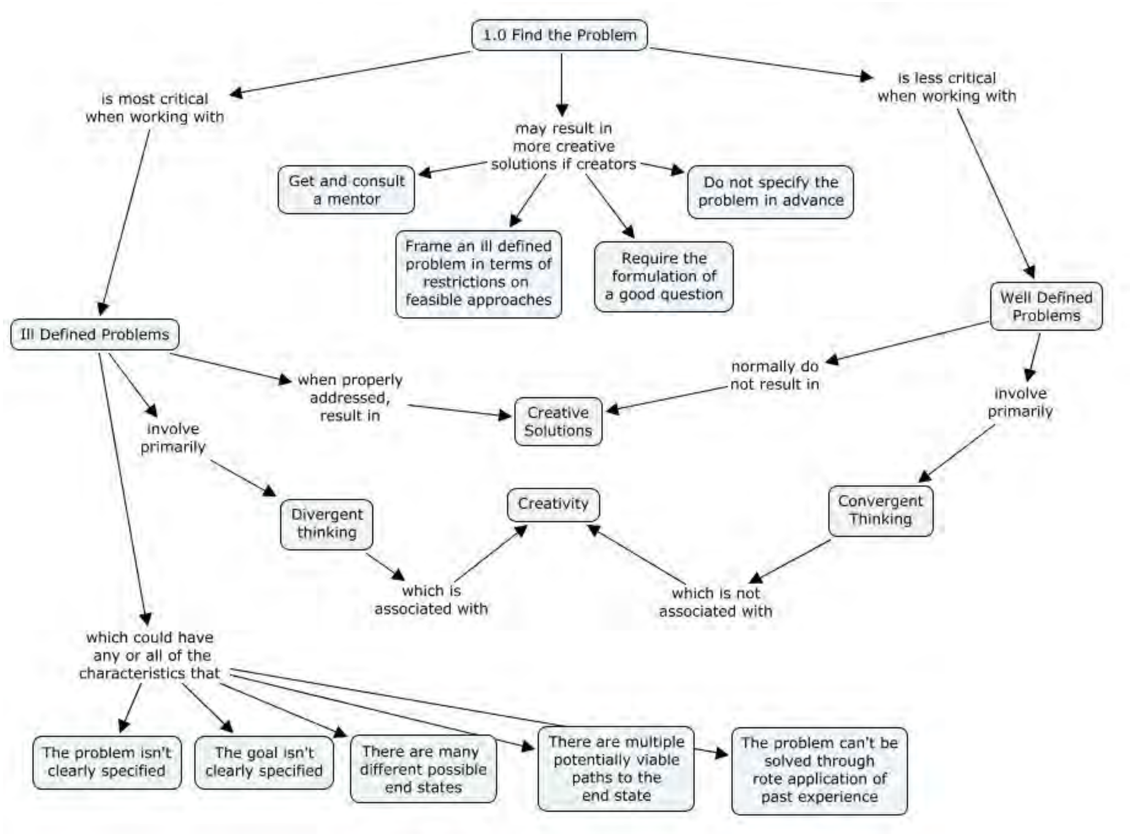

Figure 3. Concept Map of Find and Formulate the Problem (after Sawyer 2012)

2. Acquire Knowledge Relevant to the Problem

The next step is to gather as much knowledge as possible about the problem and the problem's domain (Sawyer 2012, 93). According to Sawyer, "Creativity is always based on mastery, practice, and expertise" (88).

Learning about a domain, and what has been done in that domain, provides a creator the resources necessary to create something in that domain.

Sawyer (2012) contends, "…an important part of the creative process is to first become very familiar with prior works, and internalize the symbols and conventions of the domain" (93).

a. The 10-Year Rule

Historical study of exceptional creators reveals a common thread. Creators tend to have major breakthroughs in a domain after approximately 10 years of deep involvement in that domain (Sawyer 2012, 93). This involvement may or may not occur in a formal setting, but the learning is normally achieved through *deliberate practice.* According to Sawyer (2012), deliberate practice is not just repeating known capabilities, "…it requires working on tasks that are little bit beyond what you're capable of doing, but that can be mastered with concentration and feedback" (94). The 10-year rule corresponds to 10,000 hours of deliberate practice in the domain (at four hours per day, five days per week). The 10,000 hour mark "…has been demonstrated to hold in domains as varied as chess, medicine, programming, physics, dance, and music" (94). This degree of mastery and domain knowledge leads to another assertion: "Exceptional creators tend to start learning their domain very early in life" (95).

Figure 4 is a concept map incorporating the above concepts for Sawyer's second stage of the creative process.

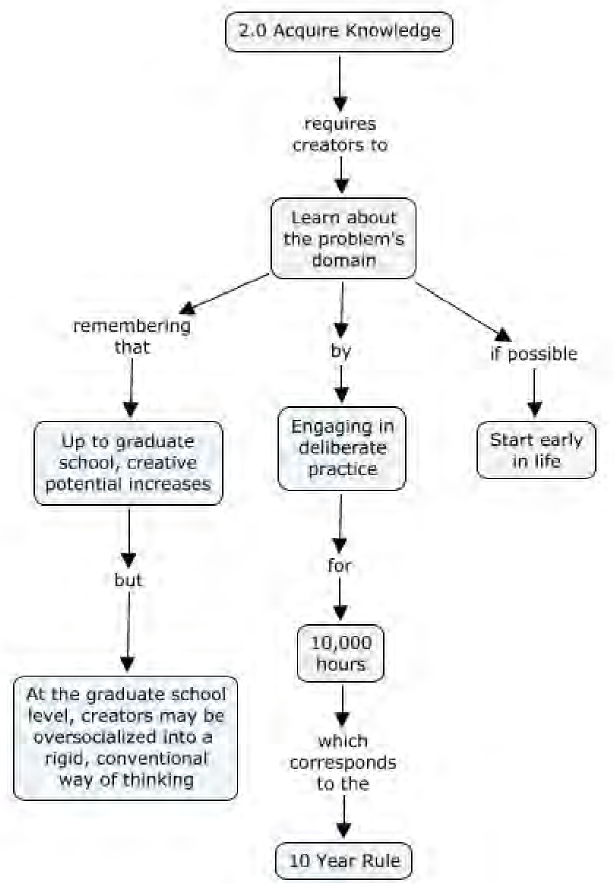

Figure 4. Concept Map of Acquire Knowledge Relevant to the Problem (after Sawyer 2012)

3. Gather a Broad Range of Potentially Related Information

According to Sawyer (2012), "After defining the problem and mastering the domain, the third stage of the creative process is to remain constantly aware of your environment, and to absorb information from a wide variety of sources" (96). In contrast to the previously discussed second step, the third step is concerned with knowledge that is not domain specific to the problem. The acquisition of this knowledge manifests in a search for key facts and anomalies (Scott, Lonergan, Mumford 2005, 79).

Creative individuals are able to spot information relevant to their problem, no matter what domain that information comes from. This results in "…a particular sort of perception: one that's active and alert to opportunities relevant to your problem" (Sawyer 2012, 96). This results in "…being able to spot opportunities to link new information with existing problems and tasks" (96).

Creative individuals are adept at searching for anomalies. They are tuned in to "…unexpected and apparently unrelated information in the environment" (Sawyer 2012, 88). One way to exploit this is through the creation of a new category. As Sawyer (2012) said, "…people create new categories every day, and that means you can learn to scan for unusual and potentially relevant information by creating a new category or set. Creative people are better at seeing gaps, at spotting difficulties, at noticing opportunities and flaws" (96). The search for key facts and anomalies can result in an overflow of information, requiring the ability to edit the information to conform it to the creative task (Sawyer 2012, 96).

Figure 5 is a concept map incorporating the above concepts for Sawyer's third stage of the creative process. The description of the search for non-domain specific knowledge as a search for key facts and anomalies comes from Scott, Lonergan, and Mumford (2005). The remaining information comes from Sawyer (2012).

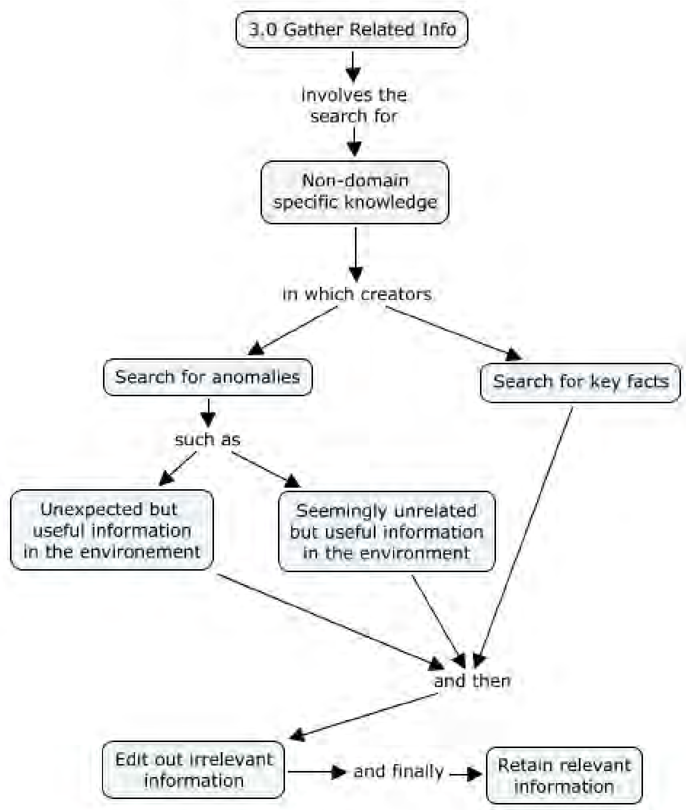

Figure 5. Concept Map of Gather a Broad Range of Potentially Related Information (after Sawyer 2012; Scott, Lonergan, and Mumford 2005)

4. Take Time Off for Incubation

Sawyer's fourth step is incubation. Incubation is a common element to many creative theories, and exceptional creators normally attribute their idea generation capabilities to incubation (Sawyer 2012, 97). According to Finke, Ward, and Smith (1992), "*Incubation* refers to cases in which a problem is set aside temporarily after an initial impasse is reached. The problem can then be solved more easily when attention is returned to it, or a solution may suddenly burst into the problem solver's awareness even without intentionally returning to the problem" (149). Stopping work on a problem, at first glance, appears to be a counterintuitive way of solving that problem. However, according to Sawyer (2012), "To provide time for incubation, many creative people force themselves to stop working periodically" (97).

Incubation does not require stopping work on *all* problems. It simply requires stopping work on the problem in question. For this reason, as Sawyer (2012) explains, "…creative people multitask in networks of enterprise; they make sure that they're working on more than one project at the same time. While they're consciously attending to one project, the others are incubating" (97).

Incubation is a fairly difficult phenomenon to study. As Orlet (2008) explains, "The difficulties of studying incubation appeared to arise from the application of traditional experimental methodologies to investigate processes of the human mind that defy direct observation and measurement" (303). Though there is a near universal acknowledgement of the phenomenon of incubation, there is still some disagreement as to what actually occurs during incubation (303). Luckily, in depth knowledge of the mechanisms of incubation is not required for a prescriptive creative process model. For background purposes, this thesis will provide information about several theorized mechanisms of incubation.

Incubation begins when one "…consciously withdraws from the theoretical solving of a problem" (Orlet 2008, 298). This withdrawal occurs when an impasse in the solution of the problem has been reached (Ellwood et al. 2009, 6). Orlet (2008) explains the reasons for this withdrawal thusly:

> During the initial stages of problem conceptualization and problem solving, the determination is made that the process of inquiry requires moving beyond existing knowledge and specific memory representations. After the preparatory work takes the person to the boundaries of existing knowledge in his or her area of expertise, the researcher ''steps beyond'' and enters the incubation phase. The sole determination for this step is the apprehension that one has reached one's intellectual limits with regard to the investigation of the problem at hand and that there is nothing else to do but to consciously abandon the theoretical work. (298)

An impasse in thought typically comes from some sort of mental block.

a. Mental Blocks

Mental blocks "…prevent successful problem solving in cases where it ought to occur" (Finke, Ward, and Smith 1992, 179). Mental blocks do not cover a lack of reasoning ability (which relates to the threshold theory as previously discussed) or insufficient knowledge of the problem or its domain (which relates to the first three steps of the creative process) (179).

Though mental blocks are discussed within the context of incubation, there exists the possibility of overcoming mental blocks without incubation. Potential methods for overcoming various mental blocks will be discussed as each type of mental block is introduced in the following sections. Perhaps the single best way to overcome mental blocks consciously (that is, without incubation) is to be aware of the varying types of mental blocks. One can then realize they are being stymied by one or more of the mental blocks, and attempt to overcome them (Finke, Ward, and Smith 1992, 180).

(1) Mental Set

People have a tendency to solve problems in ways that have worked for them in the past. This results in the "…tendency to approach a problem or situation in some habitual way" (Finke, Ward, and Smith 1992, 179). The use of mental sets is "…useful in many situations because they can make it easier to organize and understand new information" (179). However, when an example or a biasing problem statement is provided, those inputs can lead to "…temporary mental sets that resulted in various types of fixation in problem solving, creative generation, and design" (179). A shift in context, either as a result of incubation or conscious thought, is necessary to overcome improper mental sets (179).

(2) Functional Fixedness

Functional fixedness occurs when one cannot think of something in terms of anything other than its normally used functions. For example, "*…*most people would suggest using a gasoline cap or an oil cap for temporarily plugging an automobile radiator rather than using a potato, an unusual but more effective solution" (Finke, Ward and Smith 1992, 179). Functional fixedness usually does not decay or fade on its own. In order to overcome functional fixedness, it may be necessary to suspend one's expertise, or apply "categorical reduction" (179). Categorical reduction, in systems engineering terms, equates to functional analysis (specifically functional decomposition).

(3) Emotional Blocks

Emotional blocks are "…fear of thinking in unusual ways, fear of making mistakes, being excessively judgmental about creative ideas, and lacking motivation" (Finke, Ward and Smith 1992, 180). To consciously overcome emotional blocks, one must attempt to generate ideas without judging them at too early of a phase in the idea generation process (Adams 2001, 49). A lack of motivation will most likely not occur when one is working on something that he or she truly finds interesting or enjoys (Adams 2001, 55).

(4) Cultural Blocks

Cultural blocks result from "…the notions that fantasy, playfulness, and humor have no place in serious problem solving, that traditions are important to uphold, and that taboos are not to be considered" (Finke, Ward and Smith 1992, 180). Being aware that these cultural blocks exist as well as possessing a willingness to break the rules in order to solve a problem can help to overcome this type of block (Adams 2001, 70–71).

(5) Environmental Blocks

Environmental blocks result from "…the lack of operation in support of colleagues and superiors, job distractions, and lack of resources" (Finke, Ward and Smith 1992, 180).

(6) Incorrect Organizing Assumptions

Segal outlines the concept of organizing assumptions, which "…connects all the elements of the problem to each other and thus enables the solver to understand the problem and to act upon it" (2004, 142). Organizing assumptions, in systems engineering terms, can be more concisely relabeled as context. To quote Segal (2004):

> Without an organizing assumption, the problem would not be formed in the mind of the solver in the first place, and changing it

> would change the way one represents the problem. The organizing assumption has another critical function: It directs the attentive activity of the solver into closed borders, or in other words, into a bounded problem space. When the organizing assumption is false, it is impossible to reach the solution within the limits of a false problem space. (142)

In order to recover from an incorrect organizing assumption, a shift in context is required, which may be best facilitated by an incubation period (Finke, Ward and Smith 1992, 179).

(7) Fixation

Fixation occurs when one gets stuck or “fixates” on an incorrect solution. As Finke, Ward, and Smith (1992) state, “When fixation occurs during problem solving, the interfering agent is often an inappropriate approach or solution” (151). Finke, Ward and Smith (1992) further explain:

> Thinking may be ‘stuck’ when information searches continue to produce the same incorrect or inappropriate material, thus preventing retrieval of correct or appropriate material. The inappropriate information is then more likely to be retrieved with each successive attempt, making the situation worse. When one stops thinking about a problem, fixation decreases, resulting in a greater likelihood of retrieving the appropriate information. (149–150)

An example of fixation is the “tip-of-the-tongue” (TOT) phenomenon. In this case, one is trying to remember something but cannot quite recall the desired fact. As Sawyer (2012) explains, “One study found that 53% of reported TOTs were the result of the incorrect word or name coming to mind first, thus blocking retrieval of the correct word or name” (111).

Incubation helps to dissipate fixation (Finke, Ward, and Smith 1992, 150). Another method that may assist in alleviating or preventing fixation is to deliberately divorce oneself from the problem domain immediately prior to engaging in the creative process (166). One can also try to *reinstate a creative context*. An example of reinstating a creative context would be to “…try working on a problem in the same place where one had had previous creative insights in the past. Another technique is to pick a particular place that is isolated from everyday routines and to go there for the express purpose of generating creative ideas" (166). *Changing context* can also help. This approach is almost the opposite of reinstating a creative context. If one were stuck on a problem, one would change one's environment (go somewhere else, or do something else) in order to try to relieve the fixation (166).

b. Incubation Theory

Two of the theories used to explain what occurs during incubation are *selective forgetting* and *spreading activation* (Finke, Ward, and Smith 1992, 160).

(1) Selective Forgetting

The selective forgetting hypothesis states that irrelevant material (which causes fixation) dissipates in the mind during incubation periods, "…while the long-term memory accumulates more substantial information" (Segal 2004, 142). Finke, Ward, and Smith (1992) state:

> In cases where recalling information leads to fixation, however, there will be decrements in performance as memory impedes thinking. The solution is to allow the information to be forgotten, by displacement, interference, decay, repression, or other related processes. This enables more useful information to become accessible. This increase in accessibility can serve as a memory mechanism for recovery, reminiscence in episodic recall, and, most important for our discussion, incubation. (159)

(2) Spreading Activation

The spreading activation hypothesis states, "…activation spreads to the nodes representing the relevant concepts. Thus, problem solvers become more sensitive to them, and the problem solving process is facilitated" (Sio and Rudowicz 2007, 307). In other words, recently used knowledge spreads to other forms of knowledge that are linked in the brain by context (Finke, Ward, and Smith 1992, 160). In this way, during incubation, "…new ideas can be assembled unconsciously and then represented in working memory in their finished form" (Dietrich 2004a, 1017).

c. Transient Hypofrontality

Selective forgetting and spreading activation provide insights into what may be happening during incubation. Another phenomenon, known as *transient hypofrontality,* may be the cognitive mechanism that allows incubation to happen (Jung 2012). During transient hypofrontality, lower levels of activity in the prefrontal cortex allow a defocusing of the thought process (Kaye and Kelly 2013, 10-11), which in turn allows for "…thoughts that are comparatively more random, unfiltered, and bizarre to be represented in working memory" (Dietrich 2004a, 1016). As explained by Finke, Ward, and Smith (1992),

> This may help to explain why concentrating attention on the common uses of an object, as when one is under pressure to perform, might lead to increased functional fixedness and a reduced amount of divergent thinking. It may therefore be important to deliberately defocus one's attention when attempting to discover creative solutions to a problem. (185)

EEG studies confirmed, "…creative individuals exhibit lower levels of mental activity when engaged in the solution of creative problems (i.e., transient hypofrontality)" (Jung et al. 2009, 5319).

The phenomenon of transient hypofrontality is not the only brain process in play during creative thought. Transient hypofrontality is crucial to divergent thinking, though (Finke, Ward, and Smith 1992, 185). However, once an unusual idea or idea component has been generated via transient hypofrontality, the prefrontal cortex is reengaged to refine and express the idea (Dietrich 2004b, 758; Finke, Ward, and Smith 1992, 185; Jung et al. 2013, 9–10).

d. Evidence of Incubation

Multiple experiments designed to test the existence of incubation have determined that providing an incubation period results in better problem solving and more creative solutions than working on a single task continuously (Ellwood et al. 2009, 6, 7, 12; Finke, Ward, and Smith 1992, 160; Segal 2004, 147; Sio and Rudowicz 2007, 308).

Results of an incubation period are dependent upon what type of activity (or lack thereof) is conducted during that incubation period (Ellwood et al. 2009, 12). As previously established, any type of break is better than working continuously on a problem. Working on another project is better than simply resting during the incubation break (Sio and Rudowicz 2007, 308). In fact, according to Segal (2004), it is best to engage in activities that have higher cognitive demands while another problem is incubating (147). Additionally, when working on another project, it is best if that project does not make similar cognitive demands as the problem that is incubating (it is best to work on a different type of problem) (Ellwood et al. 2009, 12).

This information leads to a method proposed by Wallas, which was echoed by Sawyer 86 years later. Creators should work on multiple projects at the same time so that they can work on one project while another incubates. This allows the creator to remain productive during various incubation processes (Sawyer 2012, 97; Wallas 1926, 86).

Figure 6 is a concept map incorporating the above concepts for Sawyer's fourth stage of the creative process. The overall organization and integration of the concept map is the work of the author. Incubation as a concept was taken from Sawyer (2012) and Wallas (1926). Incubation's placement as stage four of Sawyer's eight-stage creativity theory was taken from Sawyer (2012). The concept of "when idea generation has stopped," "allow time for incubation," and the arrangement of those two concepts comes from Elwood et al. (2009) and Orlet (2008).

The concept of "work on another problem that requires different cognitive resources" comes from Elwood et al. (2009). The concept of "work on another problem that requires similar cognitive resources" comes from Sio and Rudowicz (2007). The concept of "take a break from the initial problem" comes from Ellwood et al. (2009), Finke, Ward, and Smith (1992), Segal (2004), and Sio and

Rudowicz (2007). The hierarchy of the concepts in this paragraph was built by the author, but derived from Ellwood et al. (2009), Sio and Rudowicz (2007), and Segal (2004).

The concept “mental blocks” as well as the concept of being aware of mental blocks as a remedy to mental blocks comes from Finke, Ward, and Smith (1992). The concept of “incorrect mental sets,” “functional fixedness,” and “cultural blocks” comes from Finke, Ward, and Smith (1992). The concepts of “emotional blocks,” “environmental blocks,” and “cultural blocks” come from both Adams (2001) and Finke, Ward, and Smith (1992). The concept of “fixation” comes from Finke, Ward, and Smith (1992) and Sawyer (2012). The concept of “incorrect organizing assumptions” comes from Segal (2004).

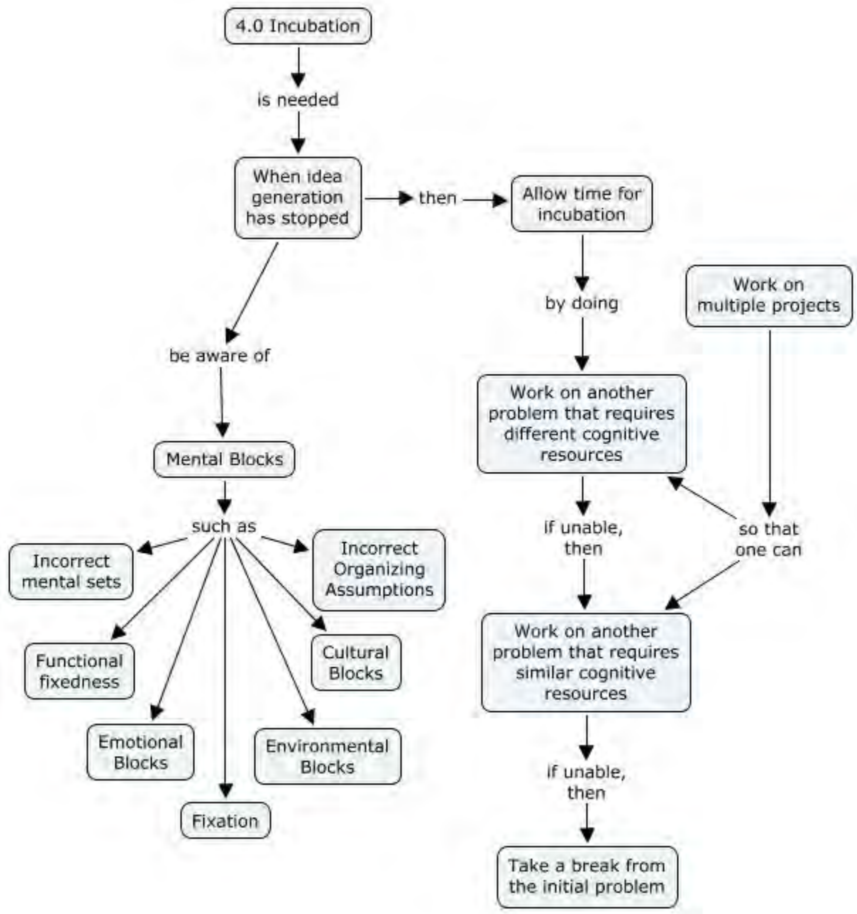

Figure 6. Take Time Off for Incubation[1]

5. Generate a Large Variety of Ideas

In stage five of the Sawyer's eight stages, the creator attempts to leverage connections of remote ideas in the brain to produce innovative ideas. The four previous steps have led the creator to the point where ideas can be generated (Sawyer 2012, 114). At this point, idea generation proceeds from the unconscious realm (incubation) to the conscious realm (insight), as explained by Dietrich (2004a):

> First, to evaluate the appropriateness of a novel thought, one has to become conscious of it. Given the view that the working memory

[1] Figure 6 was built from information from Elwood et al. (2009); Finke, Ward, and Smith (1992); Orlet (2008); Sawyer (2012); Segal (2004); Sio and Rudowicz (2007); and Wallas (1926).

> buffer of the prefrontal cortex holds the content of consciousness, a novel thought becomes an insight when it is represented in working memory. Information that is not represented in working memory is unconscious to the extent that we cannot reflect or report on it. (1015)

Dietrich (2004a) more succinctly explains, "…sophisticated creative behavior is based on the prefrontal integration that follows once unconscious novel thoughts become manifested in consciousness" (1015).

While step five leverages off of incubation, there is still significant work for the conscious mind to do. Sawyer (2012) explains, "…conscious attention to the problem can also result in potential solutions" (88). There is experimental support for the role of the conscious mind beyond simple convergent thought. Sawyer (2012) states, "many studies show that when people are instructed to 'be creative,' they generate more creative ideas" (103).

a. Insights

Insights are bursts of inspiration as to how to solve a problem. According to Finke, Ward, and Smith (1992), Creative insights rely

> …on both the retrieval of prior knowledge related to the problem and a sudden, unanticipated restructuring of the problem. This restructuring indicates that memory mechanisms that are triggered in insight problems interact with those that are involved in exploring deeper structural relations and implications. (164)

Sawyer (2012) points out

> A creative insight that generates good questions is more valuable than one that conclusively answers every known question but doesn't suggest any further research. The task of solving a good question leads to the reformulation of difficult problems and the generation of completely new questions. (138)

Thus, insights feed back into problem finding, allowing for eventual refinement of the creative product.

(1) Mini-Insights

Many times creators believe that they achieved inspiration in one grand insight. In actuality, each large insight is made possible by a procession of *mini-insights* (Sawyer 2012, 138). Wallas (1926) stated that “Sometimes the successful train seems to consist of a single leap of association, or of successive leaps which are so rapid as to be almost instantaneous” (93–94).

Sawyer (2012) contends, “Rather than coming in a single moment of insight, creativity involves a lot of hard work over an extended period of time. While doing the work, the creator experiences frequent but small mini-insights” (138). Sawyer further contends that mini-insights normally are a result of the hard conscious work that was conducted immediately prior to them (138).

b. Idea Generation Concepts

Analogy and morphological synthesis techniques can be used to generate ideas.

(1) Analogy

According to Finke, Ward, and Smith (1992), “Analogical reasoning involves the transfer or mapping of knowledge from one domain, called the source, to another domain, call the target. Analogies provide another means for creatively exploring solutions to problems, especially those that are ill defined” (177). Using analogies in the creative process involves the transfer of properties from one mental model to another (Sawyer 2012, 116).

One analogical idea generation technique is *synectics*. According to Finke, Ward, and Smith (1992), synectics is “… the general process of connecting different and apparently unrelated elements in the search for creative solutions to problems, mostly in the form of analogies that call attention to the unusual aspects of a problem or to alternative ways of thinking about a task” (178). Synectics involves the use of four different analogies. The four analogies, as shown in Sawyer (2012), are as follows:

- *Pers*onal analogy: Personal identification with the elements of the problem. If you're designing a new banking system, imagine yourself as the bill, being mailed to the customer and eventually returned with payment. (119)
- Direct analogy: Compare parallel concepts or technologies (sound to water waves). Synectics later renamed this technique Example. (119)
- Symbolic analogy: Use poetic phrases, objective and impersonal images to describe the problem—aesthetic, holistic, immediate. Synectics later renamed this technique Book Title—the task is to develop a two-word, poetic title for your book about X. (119–120)
- Fantasy analog*y*: How do we in our wildest fantasies hope this will work?" (120)

(2) Morphological Synthesis

Morphological synthesis involves listing attributes and interactions of an object and then generating a number of variations to those attributes and interactions. The variations can then be recombined to generate new concepts (Finke, Ward, and Smith 1992, 110). Morphological synthesis can generate a lot of potential solutions. In order to narrow the solution set to something manageable, the problem needs to be correctly decomposed. For this reason, morphological synthesis works best on well-structured problems (Sawyer 2012, 411).

c. Group Creativity Concepts

Several techniques are designed for and best suited to group idea generation. In some cases, these techniques can also be tailored for individual use.

Brainstorming involves a group generating as many ideas as possible, and is centered on the idea that "group thinking is always superior to individual thinking" (Sawyer 2012, 235). Brainstorming requires a deferment of judgment about generated ideas, meaning that "…idea generation should be strictly separated from idea evaluation" (235). Brainstorming is also based on the principle of "quantity breeds quality" (235).

Studies have shown that traditional brainstorming, on average, generates about half as many ideas as the brainstorming group would have as individuals. This is primarily because of the *groupthink* phenomenon, "…a state of lazy, shared consensus where no one wants to rock the boat" (Sawyer 2012, 232).

Several methods can be used to make brainstorming more effective. Ideas can be generated by individuals and then reviewed by the group. This technique should "…avoid the inhibiting effects of the presence of others as ideas are being conceived, while benefiting from the diversity of interpretive possibilities that would be afforded by a group. It would also avoid the dangers of groupthink" (Finke, Ward, and Smith 1992, 186). This also leverages on the skills of groups, which studies have shown are better at selecting ideas than individuals (Sawyer 2012, 242). Brainwriting, in which ideas are first written down on paper before group evaluation, and electronic brainstorming, in which individuals enter ideas into a computer before group evaluation occurs, are variations of the individual generation/group evaluation concept (Sawyer 2012, 241).

In addition to idea evaluation, groups are more effective than individuals at solving spatial problems and complex problems. Cognitively diverse groups are also more effective at problem finding than individuals (Sawyer 2012, 246–247).

Figure 8 is a concept map incorporating the above concepts for Sawyer's fifth stage of the creative process. The overall organization and integration of the concept map is the work of the author. "Generate ideas" as a concept and its placement as stage five of Sawyer's eight-stage creativity theory was taken from Sawyer (2012). The concept of "morphological synthesis" was taken from Finke, Ward, and Smith (1992) and Sawyer (2012). The concept of "analogies" comes from Finke, Ward, and Smith (1992) and Sawyer (2012). The concept of "synectics" was outlined in Finke, Ward, and Smith (1992). The components of synectics were taken from Sawyer (2012). The concept of "working in groups" when one is working on "spatial problems," "complex problems," and "problem finding" comes from Sawyer (2012). The concept of "modified brainstorming" comes from both Finke, Ward, and Smith (1992) and Sawyer (2012). The concepts of “brainwriting” and “electronic brainstorming” come from Sawyer (2012). The concept of “group idea selection” comes from Finke, Ward, and Smith (1992).

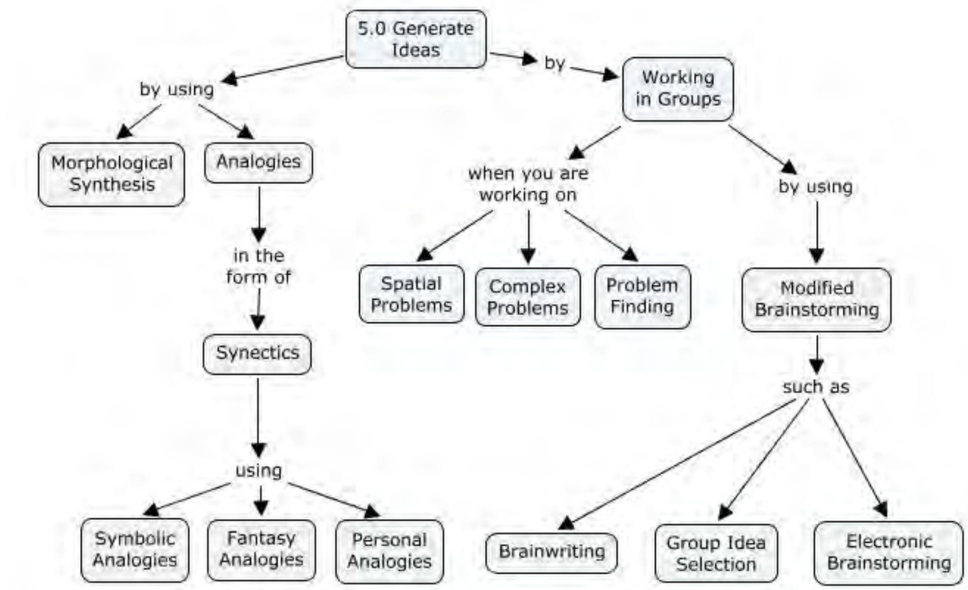

Figure 7. Concept Map of Generate a Large Variety of Ideas (after Finke, Ward, and Smith 1992; Sawyer 2012)

6. Combine Ideas in Unexpected Ways

Ideas can also be generated by combining existing ideas or concepts to generate new insights and ideas (Sawyer 2012, 88).

a. Emergence

The end product of conceptual combination is *emergence*. Sawyer defines emergent attributes as “Properties that that aren’t true of either base concept” (2012, 116). This definition of emergence is very similar to that used in systems engineering.

Two generalities relate to emergence and creativity. First, “Incongruity among the components of mental blends seems to result in a greater number of emergent features” (Finke, Ward, and Smith 1992, 108). The combination of unusual concepts is difficult, but it results in more creative end products. According to Sawyer (2012), "When concepts are very different, you have to use the more complex strategies of property mapping or structure mapping, and these strategies result in the most novel and innovative combinations" (118). However, Finke, Ward, and Smith (1992) warn, "At the same time, there must be some limits to incongruity. If items in a metaphor are too discrepant, for example, the result may simply be an anomalous statement, with no inherited or emergent properties" (108).

The second generality about emergence and creativity is that "…artists produced works of higher rated quality when they did not start with a definite plan in mind but were concerned instead with exploring and discovering emergent structures and forms" (Finke, Ward, and Smith 1992, 27). A focus on the interrelationship of combination elements results in more creative products than a focus on the elements themselves.

b. Conceptual Combination

Conceptual combination is the combining of different concept to achieve new ideas (Sawyer 2012, 115–116). Scott, Lonergan, and Mumford (2005) describe conceptual combination as referring to "…the creation of new knowledge structures through the integration of previously distinct concepts or, alternatively, the rearrangement of elements within an existing concept" (80). They elaborate that "With the generation of new knowledge through combination and reorganization, new features, new relationships, or new connections may emerge. With elaboration and extrapolation of these emergent elements, it becomes possible for people to generate new ideas" (Scott, Lonergan, and Mumford 2005, 80).

Conceptual combination occurs in several ways. Six different types of conceptual combination are explained in this section.

(1) Selective Modification Model

In the selective modification model, an adjective modifies a single property of a noun, but all other properties remain the same (Sawyer 2012, 117). The adjective modifier can have a positive, neutral, or negative connotation to the resultant structure. For instance, a red apple might have a positive connotation, a brown apple might have a negative connotation, and an unsliced apple might have a neutral connotation (Smith and Osherson 1984, 340–341). This connotation is based on point of view, or the context that the resultant structure is observed in.

(2) Attribute Inheritance Model

In the attribute inheritance model, attributes of high enough importance across the two concepts are inherited in the resultant structure with the caveat that the "necessity and impossibility of attributes is always inherited" (Hampton 1987, 55). As an example, "…a "car boat" is the union of the properties of both car and boat: has four wheels, has four seats, has a propeller coming out of the bottom, and floats" (Sawyer 2012, 117). No new properties typically emerge when using this model, as properties that do not fit both component concepts are discarded (Sawyer 2012, 117).

(3) Property Mapping

In property mapping, a single value from one concept is merged with the second concept (Wisniewski and Gentner 1991, 272–273). For example, if one were to imagine a "pony chair" and picture a brown and white chair, what is being done is "…taking the 'color: brown and white' value of pony, and setting the color property of chair to the same value" (Sawyer 2012, 117).

(4) Concept Specialization Model

The concept specialization model "…proposes that general knowledge drives a combination of categories" (Sawyer 2012, 117). For instance, "…in the *pet fish* prototype, the role-values SCALES and SLIMY will have greater weight than the role-values FURRY and CUDDLY inherited from *pet*" (Cohen and Murphy 1984, 53). Without knowing the properties of *pet* and *fish*, one could not assign accurate values to *pet fish*.

(5) Structure Mapping

In structure mapping, the complex structure of one concept is used to restructure the second concept. Structure mapping can be divided into *internal structure* and *external structure*. Revising the "pony chair" example, internal structure mapping may result in a chair that is shaped like a pony. An example of external structure mapping would be a small chair. What is conceived "…isn't a chair that's smaller than a pony, but a chair that's smaller than other chairs—in the same way that a pony is smaller than other horses" (Sawyer 2012, 118).

(6) Cross-Fertilization

Cross-fertilization is the deliberate combination of concepts from different domains (Sawyer 2012, 115). When one attempts a cross fertilization, one hopes that "…the resulting ambiguity and incongruity would facilitate creative discovery" (Finke, Ward, and Smith 1992, 111).

Figure 8 is a concept map incorporating the above concepts for Sawyer's sixth stage of the creative process. The overall organization and integration of the concept map is the work of the author. "Combine ideas" as a concept and its placement as stage six of Sawyer's eight-stage creativity theory was taken from Sawyer (2012). The "selective modification" conceptual combination model comes from Sawyer (2012) and Smith and Osherson (1984). The "attribute inheritance" conceptual combination model comes from Hampton (1987) and Sawyer (2012). The "property mapping" conceptual combination model comes from Sawyer (2012) and Wisniewski and Gentner (1991). The "concept specialization" conceptual combination model comes from Cohen and Murphy (1984) and Sawyer (2012). The "structure mapping" conceptual combination model comes from Sawyer (2012). The concept of "cross fertilization" comes from Finke, Ward, and Smith (1992) and Sawyer (2012).

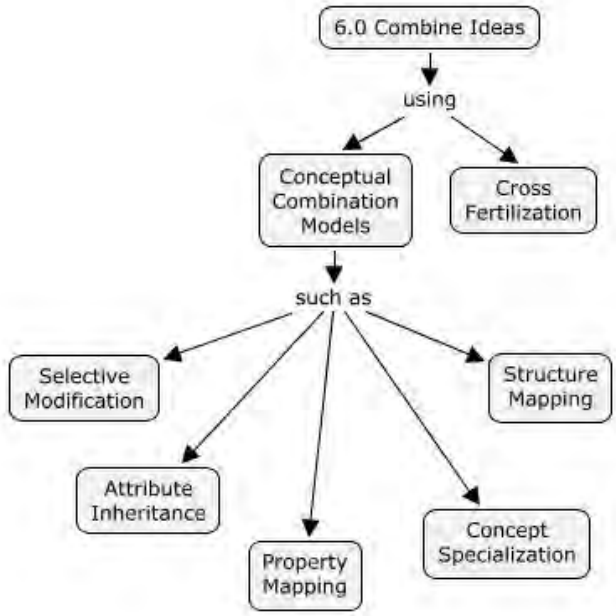

Figure 8. Concept Map of Combine Ideas in Unexpected Ways[2]

7. Select the Best Ideas Applying Relevant Criteria

After ideas are generated, the creator must then select and refine those ideas. When examining historical creators, "…creators who had the highest overall lifetime output were the people most likely to have generated a significant work" (Sawyer 2012, 131). Furthermore, "A 1998 study of patented inventions found that in a group of 408 full-time inventors, those with the most patents were those whose patents were judged the most significant" (131). This indicates that creators can expect to have many unsuccessful ideas along with those that are successful (88).

According to Dietrich (2004a), "Innumerous insights turn out to be incorrect, incomplete, or trivial, so judging which insights to pursue and which to discard requires prefrontal cortex integration" (1015). The selection of valuable ideas is primarily a convergent thought process (Sawyer 2012, 129). Creativity

[2] Figure 8 was built from information from Cohen and Murphy (1984); Finke, Ward, and Smith (1992); Hampton (1987); Sawyer (2012); Smith and Osherson (1984); and Wisniewski and Gentner (1991).

studies have shown that "…creative people are good at critically evaluating their many ideas and selecting the best one" (Sawyer 2012, 131).

A technique to revise elements in a concept is to eliminate unnecessary attributes from that concept. Finke, Ward, and Smith (1992) explain:

> …one might be able to be more creative by examining as many properties of a generated form as possible and asking whether each is necessary and, if so, why. More generally, one could systematically explore the consequences of removing or altering each of the attributes to reveal the nature of any interfering, implicit assumptions. (142)

Figure 9 is a concept map incorporating the above concepts for Sawyer's seventh stage of the creative process. The concept of "eliminating unnecessary attributes" comes from Finke, Ward, and Smith (1992). Remaining elements in the concept map come from Dietrich (2004a) and Sawyer (2012).

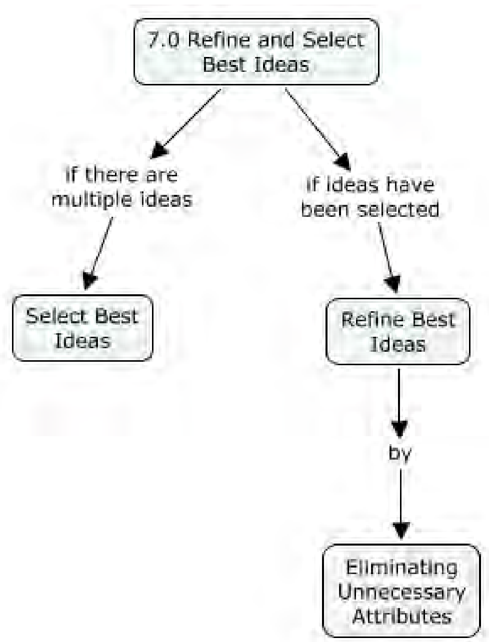

Figure 9. Concept Map of Select the Best Ideas Applying Relevant Criteria (after Dietrich 2004a; Finke, Ward, and Smith 1992; Sawyer 2012)

8. Externalize the Idea Using Materials and Representations

The final stage in Sawyer's eight-stage model is to externalize the idea. This step can be executed in two ways. One is a preliminary step for idea and problem refinement, and the other is to "sell" the idea to the world (Sawyer 2012, 134, 136).

The first way of externalizing the idea is with the intent of advancing the refinement of the idea or the problem (which in turn develops the idea). As Sawyer (2012) explains, "…the most creative people don't wait until their idea is fully formed before they start externalizing it; in the early stages of the process, when the idea may be just an intuition or a bare outline, they start putting it out in the world" (134). This early and iterative externalization helps with revising the initially perceived problem as well as contributing to the creative process (134, 137). Per Sawyer (2012), "Creativity isn't just having ideas; creative ideas emerge, develop, and transform as they are expressed in the world" (90). Additionally, "Externalizing an idea often results in other ideas and follow-on ideas" (134).

The final iteration of externalizing the idea involves getting the idea out into the world and selling it. As Sawyer (2012) explains,

> This Final stage is mostly conscious and directed; it's where the creator takes the raw insight and molds it into a complete product. Most creative insights aren't fully formed; the creator has to use his or her immense domain knowledge– in particular, how to work using the materials and techniques of the domain– to convert the idea into a finished work. (134)

Sawyer (2012) further elaborates,

> Successful creators are skilled at executing their ideas, predicting how others might react to them and being prepared to respond, identifying the necessary resources to make them successful, forming plans for implementing the ideas, and improvising to adjust their plans as new information arrives. These activities are important in all creativity, but are likely to be even more important in practical domains such as technological invention and entrepreneurship. (134)

Patience and skill are required in this convergent phase of creativity. Dietrich (2004a) explains that "Great works of art or science such as Picasso's *Guernica* or Einstein's theory of relativity are the result of goal-directed behaviors that took months or years to mature" (1015).

Figure 10 is a concept map incorporating the above concepts for Sawyer's eighth stage of the creative process. The overall organization and integration of the concept map is the work of the author. "Externalize ideas" as a concept and its placement as stage eight of Sawyer's eight-stage creativity theory was taken from Sawyer (2012). Dividing "externalize ideas" into an iterative and a final externalization is the work of the author, but was based on the information in Dietrich (2004a) and Sawyer (2012). The concept of "build representations to refine the problem or idea" comes from Sawyer (2012). The concept of "refine and finalize the idea" also comes from Sawyer (2012).

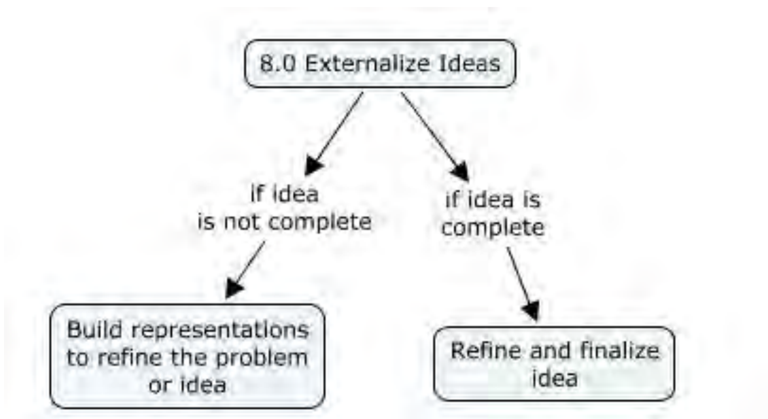

Figure 10. Concept Map of Externalize the Idea Using Materials and Representations (after Dietrich 2004a; Sawyer 2012)

9. Elaboration on the Creative Process

The creative process, as described by Sawyer (2012) and elaborated in this section, has several caveats. First, Sawyer's eight stages are domain-general, meaning that the creative process applies to all domains (138). Second, the creative process is iterative. Finally, the creative process is nonlinear.

a. Iterative and Recursive Nature of Creativity

According to Sawyer (2012),

> The eight stages lead up to the generation of a creative work: A product that can be shared, discussed, and communicated. What typically happens next is that trusted colleagues or mentors provide editorial suggestions, and the creator takes those to heart and returns back to the work. Revising and improving isn't always a straightforward task; it often involves creativity as well, so the creator has to revisit the eight stages. Very little creativity research has focused on this process of revision, the dialog that occurs with the work itself after a first draft has been generated. (141)

In an iterative externalization of the problem (step eight), data is gathered to further refine the problem, beginning the creative process again for another iteration. As Csikszentmihalyi (1996) explains, the creative process is full of stops and starts where creators

> …look at the situation from various angles first and leave the formulation undetermined for a long time. They consider different causes and reasons. They test their hunches about what really is going on, first in their own mind and then in reality. They try tentative solutions and check their success—and they are open to reformulating the problem if the evidence suggests they started out on the wrong path." (365)

Creativity requires iteration where ideas are proposed and then fine-tuned over successive iterations until an acceptable variant is achieved (Finke, Ward, and Smith 1992, 164). Ideas can then lead to wholly new problems, which recursively start the creative process again (Sawyer 2012, 134).

b. Nonlinear Nature of Creativity

The creative process rarely happens in a linear fashion, starting at finding the problem and finishing with externalizing the idea. The stages of creativity tend to overlap with each other as various aspects of a problem are explored (Wallas 1926, 81–82). Sawyer (2012) states,

> …creativity rarely unfolds in a linear fashion. The mental processes associated with the eight stages can overlap, or cycle repeatedly,

> or sometimes appear in reverse order. This is why some creativity researchers prefer describe them as the eight 'disciplines' or 'habits of mind' that are associated with highly creative individuals. (138)

Sawyer provides further hints about the nonlinear nature of creativity and how that nonlinearity could be quantified in a deliberate process. Sawyer (2012) states that "Although we generally think that the critical thinking of evaluative thought follows a more creative stage, evaluation is likely to be a constant presence in the creator's work" (133). This indicates that step seven, *select the best ideas applying relevant criteria*, would appear repeatedly throughout the creative process. If step seven is modified to become *refine and select the best ideas applying relevant criteria*, the repeated returning to that step is accounted for in the process. In a similar fashion, step one, *find and formulate the problem,* can be changed to *find and formulate/revise the problem*.

Sawyer (2012) further states, "Incubation doesn't occur in a particular stage but operates to varying degrees throughout the creative process" (139). This indicates that the creative process repeatedly proceeds through incubation. Finally, Sawyer (2012) states, "Although I've placed *externalizing* as the final and eighth stage, in creative lives it happens throughout the process" (136). Again, this indicates that ideas are repeatedly externalized throughout the creative process.

c. Walkthrough of the Creative Process

Taking the above stated information about the nonlinear and iterative nature of creativity, one can propose a creative process based on the available creativity literature. The proposed process is depicted as a concept map in Figure 11. The overall organization and integration of the concept map is the work of the author. The eight steps, including "find the problem," "acquire knowledge," "gather related info," "incubation," "generate ideas," "combine ideas," "select best ideas," and "externalize ideas" as concepts and their placement as stages of Sawyer's eight-stage creativity theory were taken from Sawyer (2012). The changes from "find the problem" to "find/refine the problem" and from "select best ideas" to "refine and select best ideas" are the work of the author, based on information compiled from Csikszentmihalyi (1996), Finke, Ward, and Smith (1992), Sawyer (2012), and Wallas (1926). The arrows connecting the steps as well as their organization are based on information compiled from Csikszentmihalyi (1996), Finke, Ward, and Smith (1992), Sawyer (2012), and Wallas (1926).

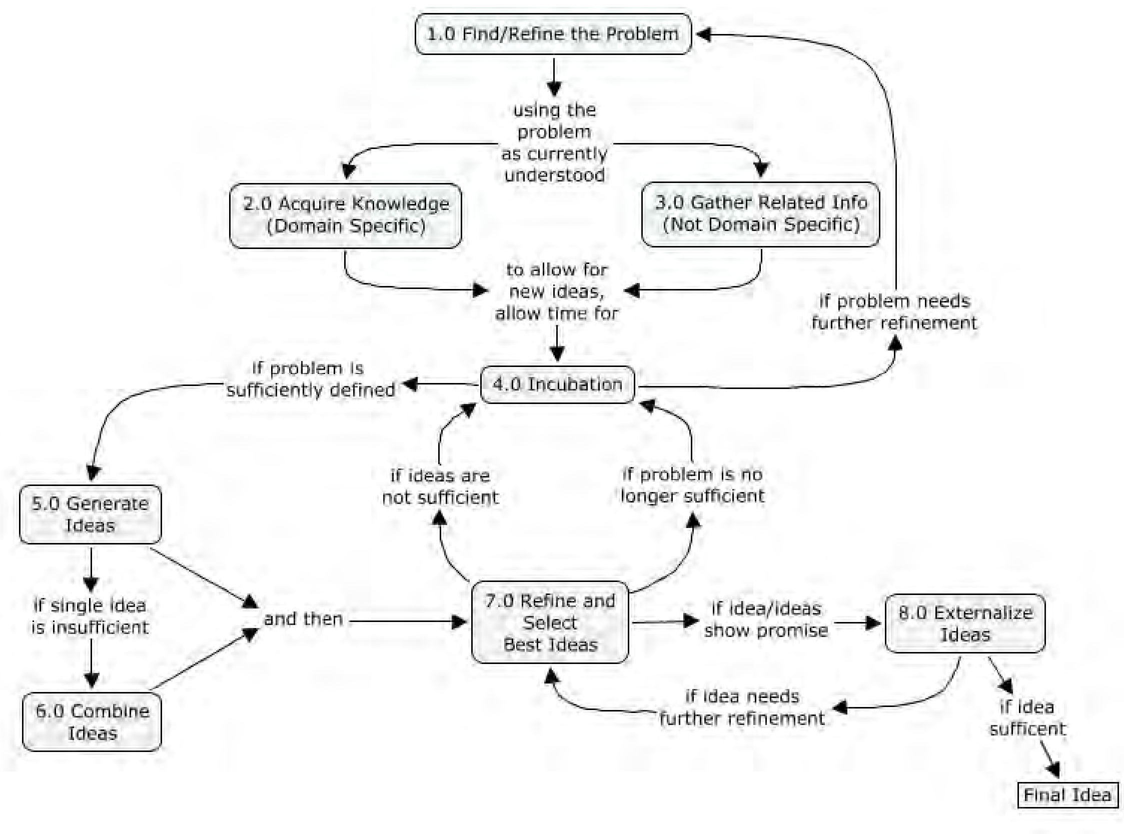

Figure 11. Proposed Concept Map for the Creative Process[3]

The proposed creative process works in conjunction with the previously proposed concept of mini-insights. Each iteration before the final idea can result in a mini-insight. Each mini-insight builds upon previous insights, eventually culminating in a finished idea.

[3] Figure 11 was built from information from Csikszentmihalyi (1996); Finke, Ward, and Smith (1992); Sawyer (2012); and Wallas (1926).

The problem is first formulated in stage one of the process. With knowledge of the problem, one looks to acquire domain related knowledge (stage two), while at the same time gathering non-domain specific but relevant information (stage three). If the additional knowledge gained provides information indicating that the originally conceived problem is insufficient, the creator returns to stage one to refine the problem further. Once the problem is revised, more information is gathered based upon the reformulation of the problem (repeating stages two and three) before proceeding to incubation once again. Even if the creator does not consciously attempt to acquire more information, his or her mind seeks and retains additional information.

After incubation, if the problem is sufficiently defined, the creator proceeds to stage five, generate ideas. Those ideas, or elements of ideas, then may be combined to produce more ideas (stage six). Stages five and six may be a conscious, directed process, or, more likely, an undirected process resulting in insight. The best idea or ideas are then selected in stage seven. Stage seven, like stages five and six, might be conscious and directed, but will most likely be an unconscious, undirected process. In fact, stages five, six, and seven may or may not (depending on the individual and circumstance) occur at an unconscious level, simply resulting in an idea. It is important to note that the process is occurring, though, whether the creator realizes it or not.

If the idea is judged insufficient, incubation is reentered before moving back to the generate and combine ideas stages again. If the problem is no longer adequate based on new insights, the creator moves back to stage one and reformulates the problem. Ideas on subsequent iterations through the process are revised at step seven.

If the idea is sufficiently promising after selection, it is externalized in some fashion. On iterations through the process, this could be simply sketching out a concept, a discussion of the idea with peers, or a modeling of the system. After an iterative externalization, the creator further refines the idea in stage seven, after which either incubation or externalization will be entered again. At some point, the idea will be, as judged by the creator, sufficiently formed for final externalization. At this point, the idea is refined into its final form for presentation to its intended audience.

E. CREATIVITY AS A SYSTEM

Creativity can be viewed as a system. A discussion of a way to classify the creative system follows, as does a discussion of how systems concepts can be translated to a creative system.

1. Classification of the Creative System

The creative system generates ideas. In other words, the idea is the product of the creative system. The creative system can be classified as a human made, conceptual, dynamic, open system.

The creative system is a human made system, though some could argue that the creative system straddles the line between human made and natural systems. According to Blanchard and Fabrycky (2011), "*Human-made systems* are those in which human beings have intervened through components, attributes, and relationships" (20). The creative process, and therefore the creative system, naturally occurs in human beings. However, the creator is able to monitor and change the creative process through his or her actions. This ability to modify the creative system makes it a human made system.

The creative system is a conceptual system, "…where symbols represent the attributes of components. Ideas, plans, concepts, and hypotheses are examples of conceptual systems" (Blanchard and Fabrycky 2011, 20). This is in contrast to physical systems, which "…manifest themselves in physical form" (20). While the creative system may produce an idea that eventually leads to a physical system, the creative system itself is a conceptual system.

The creative system is a dynamic system. This is in contrast to a static system, which has "…no operating or flow components" (Blanchard and

Fabrycky 2011, 21). Knowledge is an example of a dynamic system, and the creative system deals in the manipulation of knowledge and ideas.

The creative system is an open system. An open system allows "…information, energy, and matter to cross boundaries" (Blanchard and Fabrycky 2011, 22). This is in contrast to a closed system, which does not "…interact significantly with its environment" (22). As shown in the literature review of this thesis, the creative process is greatly dependent upon the interaction of the creator with the environment.

2. Creativity Models in a Systems Context

Each stage and componential process model in the creative literature can be translated to a systems engineering process model. In order to illustrate this, the bubble model is applied to a generic systems engineering Vee process model. The generic systems engineering Vee, was previously depicted in Figure 2.

The generic SE V starts with a decomposition and definition sequence on the left side of the model before proceeding to an integration and verification sequence on the right side of the model. The decomposition and definition sequence is a fundamental breakdown of the elements of the system based on defined requirements (Blanchard and Fabrycky 2011, 51).

The decomposition sequence is used to generate a system that meets all stated requirements. This process has strong parallels to divergent thinking. The integration and verification side of the SE Vee has strong parallels to convergent thinking.

If the idea generation process is viewed as a system, as previously proposed, the creator first uses divergent thinking when decomposing and combining elements of the idea, later followed by convergent thinking as those idea elements are integrated into the final idea.

Figure 12 is a depiction of the bubble model of the creative process integrated with the generic SE Vee. The diagram of the SE Vee comes directly from Blanchard and Fabrycky (2011). The concepts of convergent and divergent thought were taken from Sawyer (2012).

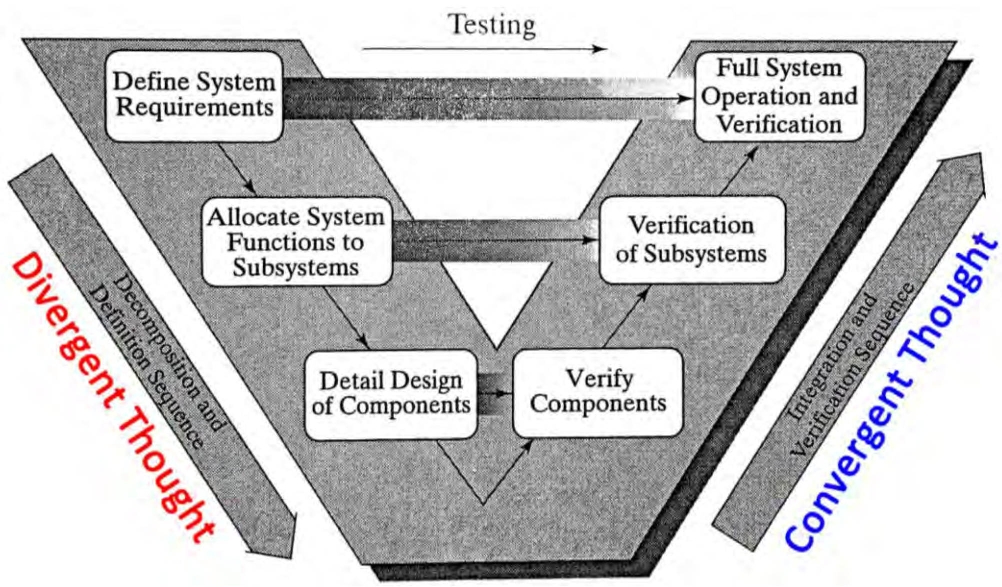

Figure 12. Bubble Creative Process Model Integrated with Generic Systems Engineering Vee (after Blanchard and Fabrycky 2011, 51; Sawyer 2012)

3. Systems Engineering and Creativity

As previously stated, stage and componential process theories of creativity can be mapped to systems engineering process models. There is a good reason for this. The systems engineering process is the creative process (Gary Langford, personal communication). The creative process, as previously outlined, involves finding the problem, acquiring knowledge, decomposing that knowledge, recombining that knowledge into new ideas, and then refining the ideas before eventually externalizing them (Sawyer 2012). Each of these elements of creativity has parallels in the systems engineering process. The two domains (creativity and systems engineering) simply use different terminology to describe them. The systems engineering process involves a sequence of stakeholder analysis (finding the problem and acquiring knowledge), formulating functions (decomposing knowledge), determining requirements (finding the problem), designing a set of possible solutions (recombining knowledge into new ideas), architecting for efficiency (refining the ideas), integrating for effectiveness (refining the idea) and delivering the solution to the stakeholders that have the need (externalizing the idea) (Langford 2012; Sawyer 2012).

The following chapter will translate systems engineering process elements to the creative process for use in the domain of creativity.

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III. HOW CAN SYSTEMS ENGINEERING BE APPLIED TO CREATIVITY?

In this chapter, systems engineering process elements that can potentially be applied to a creativity process model are selected and defined. Those elements are then incorporated into the previously proposed stage and componential process creativity theory. In this way, a creative process model is generated based on the foundational research of previous chapters.

A. WHICH SYSTEMS ENGINEERING PROCESS ELEMENTS ARE MOST APPLICABLE TO CREATIVITY?

A discussion of systems engineering process elements that are potentially applicable is warranted so that these elements can later be translated to the creativity domain. As each element is discussed, its applicability and translation to the domain of creativity will be discussed.

1. Systems Engineering Process Elements

Stakeholder analysis, problem definition, requirements generation, performance measures definition, functional analysis, concept development, system modeling, system design, system integration, system test, configuration management, and risk management were selected from a list of systems engineering process elements from a winter 2013 lecture for the SI4021 Systems Engineering for Product Development class, prepared and presented by Gary Langford on 18 January 2013. The elements were selected for their potential applicability to the creative process model, based on knowledge gleaned from the creativity research in this thesis.

a. Stakeholder Analysis

According to Langford (2012), "Stakeholder analysis is the systematic gathering and analyzing of qualitative information to determine whose interests should be taken into account when developing and/or implementing a policy or program" (260). A stakeholder analysis is the first step in identifying the problem to be solved.

(1) Stakeholder Identification

A stakeholder is "An enterprise, organization, or individual having an interest or a stake in the outcome of the engineering of a system" (U.S. Department of the Navy 2004, 170). Stakeholders can be thought of as a pool in which customers are contained. In other words, all customers are stakeholders, but not all stakeholders are customers. Stakeholders need to be determined so that customers can be determined.

(2) Customer Identification

Customers are defined as "The person or organizational entity (object or process) that buys products or services (objects or processes)" (Langford 2012, 356). Customers need to be identified so that their needs can be addressed.

(3) Customer Needs

Customer needs need to be distinguished from wants. According to Langford (2012), "The systems engineer differentiates needs from wants by reflecting the needs in the design and architecture baselines, weighing whether needs or wants are disguised and miscategorized. A need has measurable requirements" (259). Langford further states, "The systems engineer's role is to assure that all objects are appropriately specified, that is, the need(s) are met" (259).

Stakeholder analysis, or some form of it, is of concern to the creative process. Determining who the stakeholders are, who the customers are, and what their respective needs are in the potential idea is an important part of the problem finding process, as well as the gathering of knowledge, both domain specific and non-domain specific. Though the creative process is nonlinear, a stakeholder analysis would fit in near the beginning of the process, after a potential problem is initially identified.

b. Problem Definition

Gary Langford provided a four-step process for defining the problem in a lecture entitled "Defining the Problem" during the winter 2013 SI4021 Systems Engineering for Product Development class at the Naval Postgraduate School on 25 January 2013. The steps outlined were to develop situational competence, explore boundaries and boundary conditions, determine consequences of limitations and constraints, and develop context competence. The four steps and enabling definitions are outlined below. All information contained in the below four steps, unless otherwise cited, comes from the previously referenced lecture by Gary Langford.

(1) Developing Situational Competence

Research needs to be conducted in the subject area so that stakeholder and customer needs can be translated from deficiencies as those deficiencies are described.

(2) Explore Boundaries and Boundary Conditions

As problem formulation proceeds, abstractions of the problem should be considered to determine where boundaries exist. The concept of boundaries can be applied at many levels, but for this purpose, the boundaries of the problem should be considered. What affects the problem, and what can the problem effect? Where does the problem end?

(3) Determine Consequences of Limitations and Constraints

With boundaries and limitations to the solution in mind, hypothesize potential emergence that results from formulated problems.

(4) Develop Context Competence

Langford (2012) states, "Context is the situation or framework in which the interaction between two objects takes place" (356). Because context changes with varying circumstances, slight modifications to the proposed problem can bring about additional required changes to the problem. Awareness of context when formulating problems requires answers to the three previous steps, and results in an iterative process to refine the problem.

Problem definition, as outlined in systems engineering literature, is of concern to the creative process. A systematic method of defining the problem could be used to advantage in the idea generation process.

c. Requirements Generation

According to Whalen, Wray, and McKinney (2004), requirements are "Characteristics that identify the accomplishment levels needed to achieve specific objectives for a given set of conditions" (289). Stakeholder and user needs drive the definition of requirements (Blanchard and Fabrycky 2011, 53). The validation of requirements determines that those requirements "…are sufficiently correct and complete" (Whalen, Wray, and McKinney 2004, 299).

A formalized process of requirements generation similar to that used in systems engineering could be of use in a creative process model. The generation of requirements would allow a creator to measure the progress of his or her idea towards solving the problem.

d. Performance Measures Definition

Performance measures for the system need to be defined. These performance measures need to be observable and measurable "…according to a reference scale or standard of measurement" (Langford 2012, 365) so that system performance can be compared to performance of alternate designs, other competing systems, or itself after changes to the system. Performance measures are not peculiar to systems engineering. Most other domains use measurable and recordable performance measures (Vanek, Jackson, and Gryzbowski 2008, 113).

Performance measures are not peculiar to systems engineering. Formalizing performance measures during the creative process would enhance the creator's ability to determine progress in the creative process.

e. *Metric*

According to Vanek, Jackson, and Gryzbowski (2008), “The purpose of SE metrics in the product development process is to identify or create a quantitative measure based on SE theory or practice that indicates that the process is moving toward a successful outcome” (110). Langford (2012) further clarifies the definition of metrics as “the shared value of what the common goal needs to be” (363). More colloquially, Langford (2012) states, “Metrics are used to represent that state of being, the determinant of ‘how is it going?’” (363)

One possible approach to choosing metrics is the Goal/Question/Metric (GQM) approach (INCOSE 1998, 11). Four steps are performed iteratively to identify “appropriate and useful measures from identified project goals” (11). The four steps are as follows, taken from INCOSE (1998):

1. State the information goal (organizational and project goals as appropriate) (11)
2. Ask questions to determine whether the goal is being met (11)
3. Determine the measure (what must be measured to answer the questions posed in step 2?) (11)
4. Do and evaluate (Apply the measures and evaluate them) (11)

The flow chart in Figure 13 shows the GQM process and its iterative nature.

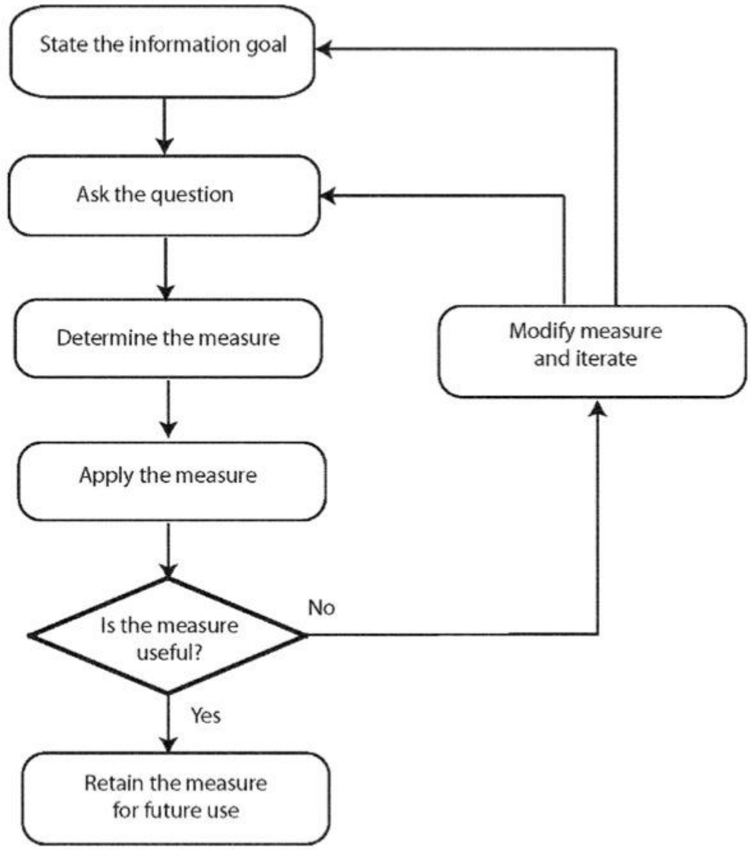

Figure 13. Flow Chart for the Goal/Question/Metric Approach (from Vanek, Jackson, and Gryzbowski 2008, 116)

Metrics are not formally used in the creative process, but could be incorporated formally. They could be used to determine the goal of the idea, as a way to both evaluate the idea (using MOEs) and determining when the idea needs revision, refinement, or a complete rework.

f. Functional Analysis

Systems can be designed effectively through the study of functions and their interactions. This concept is the basis of functional analysis. The functional analysis is a crucial element of the systems engineering process. According to Blanchard and Fabrycky (2011):

> The *functional analysis* is an iterative process of translating system requirements into detailed design criteria and subsequent identification of the resources required for system operation and

> support. It includes breaking requirements at the system level down to the subsystem, as far down the hierarchical structure as necessary to identify input design criteria and/or constraints for the various elements of the system. The purpose is to develop the top-level *system architecture*, which deals with both 'requirements' and 'structure.' (100)

According to Haskins (2011):

> Identified functional requirements are analyzed to determine the lower-level functions required to accomplish the parent requirement. Every function that must be performed by the system to meet the operational requirements is identified and defined in terms of allocated functional, performance, and other limiting requirements. Each function is then decomposed into sub-functions, and the requirements allocated to the function are each decomposed with it. This process is iterated until the system has been completely decomposed into basic sub-functions and each sub-function at the lowest level is completely, simply, and uniquely defined by its requirements. (157)

(1) Functional Flow Block Diagram

The decomposition of functional requirements into iteratively smaller and smaller subfunctions feeds into the construction of *functional flow block diagrams* (FFBDs). According to Blanchard and Fabrycky (2011), "Accomplishment of the functional analysis is facilitated through the use of *functional flow block diagrams*" (100). FFBDs "…are developed to describe the system and its elements and functional terms" (713).

A functional analysis would be of great use in a formalized process model for creativity. Decompositions and functional flow block diagrams can aid in the problem definition, idea generation, and idea combination phases of the creative process.

g. Concept Development

According to Haskins (2011), "During the Concept Stage, the team begins in-depth studies that evaluate multiple candidate concepts and eventually provide a substantiated justification for the system concept that is selected" (29). The intention is to refine concepts and models hypothesized in initial research. Concepts are further developed using mockups and prototypes (29).

Concept development is similar to the idea generation/idea combination/idea selection stages of the creative process. Concept development also has parallels to iterative externalizations of the idea during the creative process.

h. System Modeling

Modeling and simulation can be used to refine concepts as well as communicate those concepts to others (Haskins 2011, 149). This allows the gathering of information about a design prior to the commitment of significant time and resources to that design, allowing changes to be made earlier, with less cost (150). The following steps, described in the 2011 INCOSE *Systems Engineering Handbook*, should be used in modeling and simulation:

1. Select the appropriate type of model. (154)
2. Design the model. Determine what system characteristics need to be evaluated, and how best to evaluate them. (154)
3. Validate the model. Prove that the model suitably represents reality. (155)
4. Document the model. Document the background, development, and description of the model. (155)
5. Obtain needed input data and operate the model. Run the model to see what results. (155)
6. Evaluate the data. Examine data from the model operation to make decisions about the modeled system. (155)
7. Review the process and revise the model. Iteratively run the model to make improvements to the model or revise the concept. (155)
8. Evolve the model. If large-scale changes in the system require it, evolve the model so that it maintains relevance. (156)

System modeling has parallels to the idea externalization stage of the creative process. The formalized modeling and simulation process outlined above could potentially be used to advantage in the creative process in order to evaluate the efficacy of generated ideas.

i. System Design

According to Langford (2012), "…system design poses alternatives that could be considered as solving the stated problem to some varying degrees" (272). System design is an iterative process, resulting "…in the allocation of requirements first to subsystems, then to assemblies, then to subassemblies, and then to components" (272). The system design alternative that results in the most effective solution to the problem is determined through analysis and evaluation (272).

System design has parallels in the second half of the previously proposed modified Sawyer eight-stage creative theory. Idea generation, combination, refinement, selection, and iterative externalization, taken together, are very similar to system design.

j. System Integration

Systems integration is the unification of system elements in order to provide "system-level functionalities and performances" (Langford 2012, 371). System integration is similar to the refinement of ideas stage of the creative process.

k. System Test

According to Langford (2012), "Testing is a process to determine the difference(s) between an object's properties, traits, and attributes under certain conditions in a given set of circumstances with that of a representation (or test model) of what is desired" (371). Testing the system has parallels to externalizing the idea, particularly during iterative externalizations of the idea.

l. Configuration Management

Per ISO/IEC 15288:2008, as quoted in Haskins (2011), "The purpose of the Configuration Management Process is to establish and maintain the integrity of all identified outputs of a project or process and make them available to concerned parties" (228).

As the idea proceeds through iterations of the creative process, it is continually modified. Furthermore, the problem itself may be modified, starting the process over again. As these iterations and recursions happen, the creator exercises a form of configuration management to keep the idea or ideas moving forward in the creative process.

m. Risk Management

Per ISO/IEC 15288:2008, as quoted in Haskins (2011), "The purpose of the Risk Management Process is to identify, analyze, treat and monitor the risks continuously" (215). Technical risk can occur when a system is on the cutting edge of technology. Schedule risk can occur when allotted time for system development may not be sufficient. Cost risk may occur if funding is not sufficient due to limited funding cost overruns (216).

Ambient risk is of critical concern to the creative domain. According to Haskins (2011),

> The ambient risk is defined as the risk caused by and created by the surrounding environment (i.e., ambience) of the project. Project participants have no control over ambient risk factors, but they can learn to observe the external environment and eventually take proactive or reactive actions to minimize the impact of the environment on the project. The typical issues are time dependent processes, rigid sequence of activities, one dominant path for success, and little slack. (216)

Risk management, while not specifically applicable to a creative process model, could be applicable to creativity, particularly in minimizing ambient risk.

B. HOW CAN THE SELECTED SYSTEMS ENGINEERING PROCESS ELEMENTS BE APPLIED TO THE SELECTED CREATIVITY THEORY TO BUILD A PROCESS MODEL FOR CREATIVITY?

Based on the information gathered and presented in this thesis, a process model for a system of creativity is proposed. The process model incorporates systems engineering methodologies throughout the creative process. Specific techniques for idea generation derived from creative literature and previously depicted in concept maps are not incorporated into the creativity process model.

For ease of viewing and use, the process model is divided into two parts. The first part of the creativity system process model depicts the problem finding process. The second part depicts the idea generation process.

1. Problem Finding Process Model Walkthrough

The problem finding process model is depicted in Figure 14. The systems engineering concepts in the process model, including “stakeholder analysis,” “problem definition,” and “functional analysis,” were taken from an SI4021 Systems Engineering for Product Development lecture given by Gary Langford at the Naval Postgraduate School on 18 January 2013.

The creativity concepts in the process model come from several sources. “Acquire domain specific knowledge” and “acquire non-domain specific knowledge” come from Sawyer (2012). The concept of “incubation” comes from Sawyer (2012) and Wallas (1926).

The components of “stakeholder analysis,” including “stakeholder identification” and “needs identification,” come from Langford (2012) and U.S. Department of the Navy (2004). “Develop situational competence,” “explore boundaries and boundary conditions,” “determine consequences and limitations of constraints,” and “develop context competence,” as well as their subordinate relationship to problem definition, come from a “Defining the Problem” lecture given by Gary Langford at the Naval Postgraduate School on 25 January 2013. The components of “functional analysis,” including “functional decomposition,” and “FFBDs,” come from research taken from Blanchard and Fabrycky (2011), Haskins (2011), and Langford (2012).

Organization of creativity elements is the work of the author, and was based on information taken from Csikszentmihalyi (1996), Finke, Ward, and Smith (1992), Sawyer (2012), Scott, Lonergan, and Mumford (2005), Sio and Rudowicz (2007), and Wallas (1926). The integration of systems engineering elements and creativity elements and their placement in relation to one another is the work of the author, as was the separation of the creative process model into the “problem finding process” and the “idea generation process.”

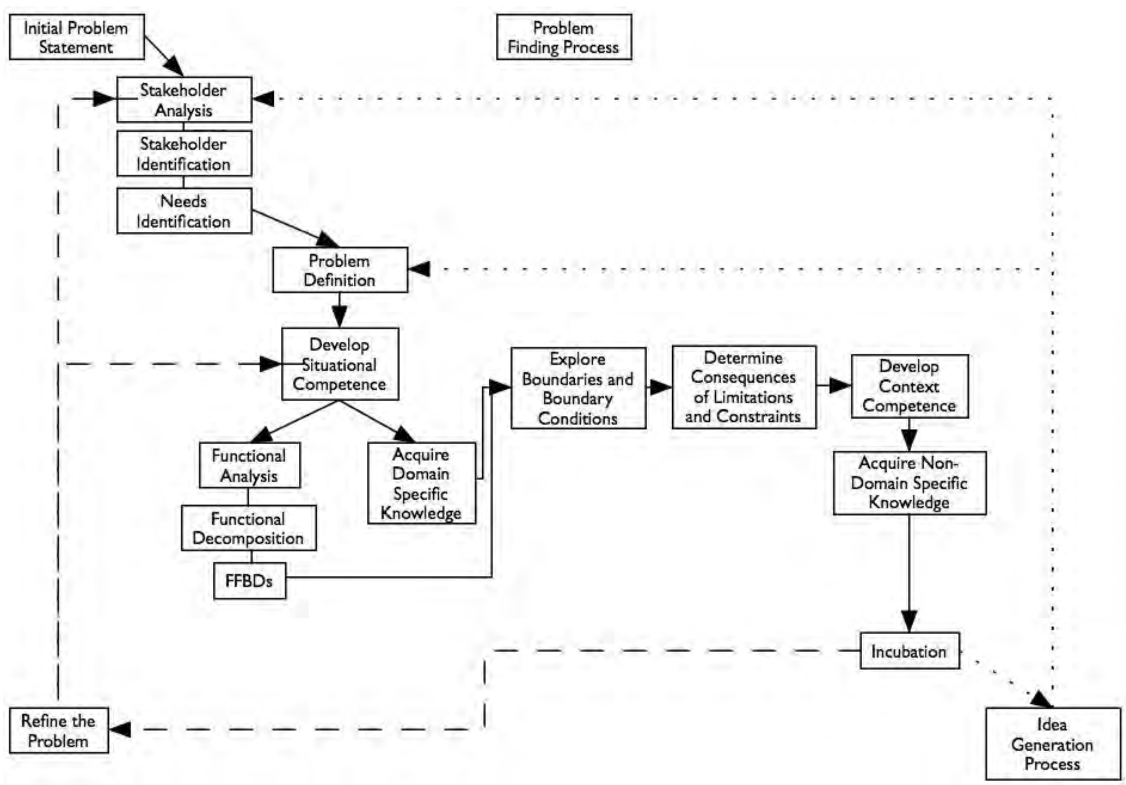

Figure 14. Proposed Creativity Problem Finding Process Model[4]

[4] Figure 14 was built from information from an SI4021 Systems Engineering for Product Development lecture given by Gary Langford at the Naval Postgraduate School on 18 January 2013; a “Defining the Problem” lecture given by Gary Langford at the Naval Postgraduate School on 25 January 2013; Blanchard and Fabrycky (2011); Csikszentmihalyi (1996); Finke, Ward, and Smith (1992); Haskins (2011); Langford (2012); Sawyer (2012); Scott, Lonergan, and Mumford (2005); Sio and Rudowicz (2007); U.S. Department of the Navy (2004); and Wallas (1926).

The problem finding process begins in the upper left of the model with an initial problem statement. This initial problem statement may not be very well defined or accurate. It is merely something that generates a need in the creator to begin the creative process. Once the process has begun, a stakeholder analysis is conducted. The creator determines who the stakeholders are in his or her initial problem, and then determines their needs.

The model then progresses to problem definition. To define the problem, Langford's problem definition process is adapted. The creator first attempts to develop situational competence. This is done through functional analysis and the acquisition of domain specific knowledge. Once a sufficient level of situational competence is attained, boundaries and boundary conditions are explored. Then Consequences of limitations and constraints are determined. Finally, context competence is developed, specifically through the acquisition of non-domain specific knowledge, anomalies, and key facts.

Upon completion of this initial problem definition, a period of incubation is entered. From there, the creator decides whether the problem is sufficiently defined or not. If it is not sufficiently defined, the creator can refine the problem and begin the problem finding process again, either beginning with another iteration of stakeholder analysis or another iteration of developing situational competence. This process repeats as many times as necessary until the problem is sufficiently identified. At this point, the creator proceeds to the idea generation process.

2. Idea Generation Process Model Walkthrough

The idea generation process model is depicted in Figure 15. The systems engineering concepts in the process model, including "determine MOEs," "determine metrics," and "refine requirements," were taken from an SI4021 Systems Engineering for Product Development lecture given by Gary Langford at the Naval Postgraduate School on 18 January 2013.

The creativity concepts in the process model, illustrated in Figure 15, come from several sources. The concept of “incubation” comes from Sawyer (2012) and Wallas (1926). “Generate ideas,” “combine ideas,” “select ideas,” and the concept of externalizing the idea come from Sawyer (2012). Using “refine ideas” as a separate concept is the work of the author, but is based on research from Csikszentmihalyi (1996), Finke, Ward, and Smith (1992), Sawyer (2012), and Wallas (1926). Splitting the concept of externalize the idea into “iterative idea externalization” and “final idea externalization” is the work of the author, but is based on research from Csikszentmihalyi (1996), Finke, Ward, and Smith (1992), Sawyer (2012), and Wallas (1926).

Organization of creativity elements is the work of the author, and was based on information taken from Csikszentmihalyi (1996), Finke, Ward, and Smith (1992), Sawyer (2012), Scott, Lonergan, Mumford (2005), Sio and Rudowicz (2007), and Wallas (1926). The integration of systems engineering elements and creativity elements and their placement in relation to one another is the work of the author, as was the separation of the creative process model into the “problem finding process” and the “idea generation process.”

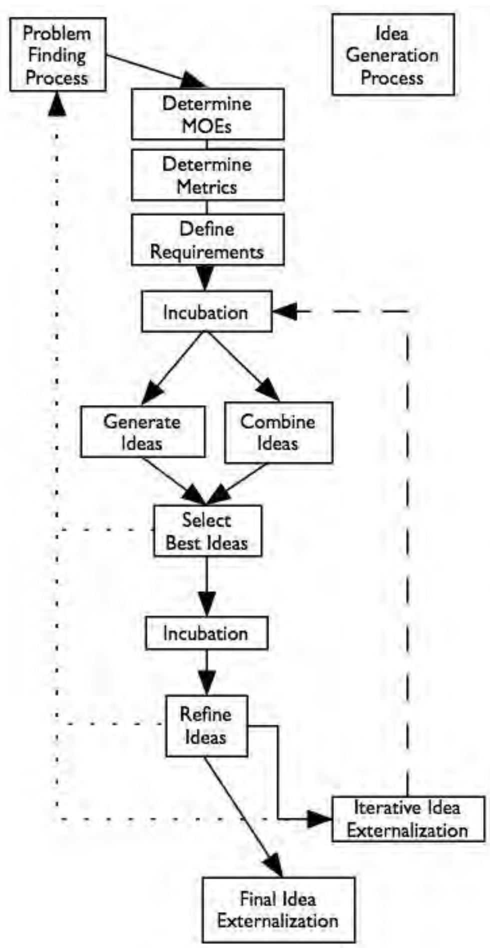

Figure 15. Proposed Creativity Idea Generation Process Model[5]

The idea generation process begins in the upper left corner of the model, when a sufficiently defined problem passes from the problem finding process model to the idea generation process model. The creator then determines performance measures. Measures of effectiveness and metrics are determined. This enables the definition of requirements that are mapped to stakeholder needs.

After requirements are defined, the creator enters an incubation phase. Following incubation, the creator generates ideas and combines ideas to come

[5] Figure 15 was built from information from an SI4021 Systems Engineering for Product Development lecture given by Gary Langford at the Naval Postgraduate School on 18 January 2013; Csikszentmihalyi (1996); Finke, Ward, and Smith (1992); Sawyer (2012); Scott, Lonergan, and Mumford (2005); Sio and Rudowicz (2007); and Wallas (1926).

up with a pool of new ideas. The creator then selects the most promising of the ideas. If the work to this point requires a revision to the problem, the creator returns to the problem finding process, either at stakeholder analysis or at problem definition as necessary.

Following another incubation period, the creator refines the generated ideas. If the work to this point requires a revision to the problem, the creator returns to the problem finding process, either at stakeholder analysis or at problem definition as necessary. If the idea is not judged to be sufficient or complete after refinement, the creator executes an iterative idea externalization. The creator then returns to incubation, followed by idea generation and combination.

After multiple iterations, if the creator deems the idea to be sufficient, a final idea externalization is executed. During the final externalization, the idea is put out to the world in some form.

C. WHAT EXPECTATIONS SHOULD ONE HAVE IF SUCCESSFUL IN APPLYING THE SYSTEMS ENGINEERING PROCESS TO THE CREATIVE PROCESS?

The intent of applying systems engineering to the creative process is to improve the creative abilities of a person or organization. Improvement could be judged in several ways. Significant increases in creative output, judged either by across the board improvements in quality of end product (measurable), volume of products created (measurable), speed of production (measurable), or ease of production (subjective) would be considered an improvement. This would indicate the success of the process model. Conversely, failure could be defined as across the board significant reduction of the above four criteria. Anything in between those two poles will require a tradeoff analysis to determine whether the process has been a success or a failure.

The actual determination of success or failure of the proposed model could be done through the use of a loss function. Product quality, volume, production speed, and production effort could be characterized as smaller-the-better cases in a quality loss function (Langford 2012, 339–340). Trial and evaluation of the proposed model is beyond the scope of this thesis, and would make a good topic for future research.

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IV. CONCLUSIONS AND RECOMMENDATIONS

This chapter briefly summarizes key learning points from previous chapters and then makes recommendations for future research related to this thesis.

A. KEY TAKEAWAYS

Creativity is a relatively young field of study. Acknowledgement that creativity is a system provides vast potential for study and improvement of the creative process. That acknowledgement allows the introduction of systems engineering and general systems thinking into the domain of creativity.

Systems engineering provides a means to study creativity and improve understanding of the creative process. Systems engineering allows the construction of a process model for creativity, which can be continually refined as further research becomes available regarding various research aspects of creativity.

The process model for creativity proposed in this thesis provides a first step in providing an accurate process model for creativity. As creativity study matures, the potential for greater fidelity is nearly unlimited.

B. RECOMMENDATIONS FOR FUTURE RESEARCH

There are several areas that are ripe for future research. First, the proposed creative process model could be improved by enhancing the detail of incorporated elements. Specific guidance as to the method and execution of incorporation of systems engineering elements could provide a more consistently successful process model. Second environmental factors such could be incorporated into the model. Third, motivational factors could be incorporated into the model.

As outlined in the previous section, creativity research is ongoing. As advances are made in the domain of creativity, the model should be updated to reflect the latest and most accurate representation of creativity.

Lastly, evaluation of success or failure of this model was addressed theoretically, at a high level. Trials of the proposed process model should be conducted while using a loss function to evaluate the results of those trials. In this way, determination of the success or failure of the model could be evaluated.

APPENDIXSYSTEMS ENGINEERING DEFINITIONS

Systems engineering concepts and definitions follow to provide background on systems engineering and general systems thinking.

A. SYSTEM

Haskins (2011) proposed that a system is "a combination of interacting elements organized to achieve one or more stated purposes" (5). *The Naval Systems Engineering Guidebook* closely mirrors INCOSE's basic definition (U.S. Department of the Navy 2004, 171). A quick decomposition of this definition reveals several key terms: combination, interacting, elements, organized, and purpose. Different organizations and individuals have varying definitions of what a system is, but those key elements persist in some form in accepted definitions of system.

Blanchard and Fabrycky (2011) defined a system as "…an assemblage or combination of functionally related elements or parts forming a unitary whole, such as a river system or a transportation system." This definition introduces the term *unitary whole,* a description of the result of the previously described organization of interacting elements (17).

Haskins (2011) built upon its initial definition by describing the e*lements* of a system in greater detail. Haskins (2011) explained that elements of a system can be "…products (hardware, software, firmware), processes, people, information, techniques, facilities, services, and other support elements." These elements may themselves also be subsystems or assemblies which are composed of other elements (5). Whalen, Wray, and McKinney (2004) also advised of the existence and use of differing definitions of system in different engineering disciplines (10).

The INCOSE Fellows definition of system echoes the previously discussed definitions, and also added a concept of "value added" to the system: "The value added by the system as a whole, beyond that contributed independently by the parts, is primarily created by the relationship among the parts; that is, how they are interconnected" (INCOSE 2006).

Langford's (2012) definition is similar to previously discussed definitions, but several additional concepts are introduced (370). The elements in systems are described as being bounded and stable. Interaction between the elements of a system is also described as being necessary to call something a system (370).

For the purpose of relating systems to creativity, the following statements regarding systems are compiled from the above definitions:

1. Systems are composed of a combination of elements.
2. System elements can themselves be systems.
3. System elements interact.
4. System element interaction generates value beyond what is contributed by its elements.
5. System element combination forms a unitary whole.
6. Systems are organized, and can thus be described.
7. Systems are bounded.
8. Systems are stable.
9. Systems serve a purpose.

B. SYSTEMS ENGINEERING

Blanchard and Fabrycky (2011) state, "…there is no commonly accepted definition of systems engineering in the literature" (31). To define systems engineering, a sampling of definitions from various resources follows.

In the Federal Aviation Administration *Systems Engineering Manual,* Simon Ramo describes systems engineering as "…a discipline that concentrates on the design and application of the whole (system) as distinct from the parts. It involves looking at a problem in its entirety, taking into account all the facets and all the variables and relating the social to the technical aspect" (quoted in Haskins 2011, 7). This broad definition focuses on the overall mindset of systems engineering, which is a primary concentration on the system and its properties as opposed to a primary concentration on individual elements of the system.

Howard Eisner, in Essentials of Project and Systems Engineering Management, defines systems engineering as "…an iterative process of top-down synthesis, development, and operation of a real-world system that satisfies, in a near optimal manner, the full range of requirements for the system" (quoted in Haskins 2011, 7). This definition eschews elaboration on the components and construction of the system in systems engineering, instead focusing on the method of system design, development, and operation, and the need to satisfy system requirements. This definition also describes systems engineering as a top-down process, meaning that the system is viewed as a whole. This top-down construct is in contrast to a bottom-up approach, where design begins with system components and then progresses up to system level design (Blanchard and Fabrycky 2011, 32). Eisner also states that systems engineering is *iterative*. As defined by Langford (2012), iterative is "To do again or to do something similar to that which was done before with the aim of improving on what was done before" (360).

Haskins (2011) provides a description of engineering:

> Systems Engineering (SE) is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing, and disposal. SE considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs. (6)

INCOSE's description possesses more detail than the previously discussed definitions, delving into actual elements of the systems engineering process. It and the definition proposed by the INCOSE Fellows also state that systems engineering is *interdisciplinary,* pulling knowledge and expertise from multiple disciplines (INCOSE 2006).

Many systems engineering definitions tend to service technical objectives. However, systems engineering has applicability outside of the technical realm. Vanek, Jackson, and Gryzbowski (2008) state, "…the application of SE need not be limited to technical objectives, as social objectives play an important role in overall project success, and technical excellence cannot save a socially unacceptable project" (110).

A common element in the above definitions is their focus on product development. Each definition states that systems engineering is concerned with some aspect of the design, development, operation, and disposal systems. Honour, Axelband, and Rhodes (2004) state that systems engineering practices "…promise to provide better systems in less time and cost with less risk" (3). Vanek, Jackson, and Gryzbowski (2008) similarly state, "The underlying purpose of the application of SE to product development is, simply stated, to improve the outcome" (110). Though these two definitions lack the fidelity of earlier described definitions, they hint at an ability to use systems engineering processes to improve extant systems.

This broader applicability is more explicitly expressed by Langford (2012):

> The essence of systems engineering is to unbound the seemingly bounded, broaden the concepts to beyond recognition, open the solution domain to include the ridiculous, and consider the issues and problems in an abstract space rather than as they are posed or presumed to be real. No other discipline or field carries with it that worldview. (370–371)

C. GENERAL SYSTEMS THINKING

According to Langford (2012), general systems thinking is "Thinking in terms of systems to bring partial patterns into full view by changing perspective, granularity, and the abstraction of cognitive structures to a generality that is applicable across all observations, fields, disciplines, and frameworks" (358). Blanchard and Fabrycky (2011), in describing *general systems theory,* say much the same thing, with less fidelity, by saying, "General systems theory is concerned with developing a systematic framework for describing general relationships in the natural and the human-made world" (23).

By realizing that the universe is composed of systems of varying size, complexity, and interrelatedness, one can begin to describe fundamental relationships between and inside of those systems, and thus may be better able to influence the actions of those systems.

As stated in multiple definitions of systems engineering, systems engineering is concerned with creating systems. Systems thinking takes a broader perspective and encompasses systems engineering. Haskins (2011) states:

> The SE perspective is based on systems thinking. Systems thinking occurs through discovery, learning, diagnosis, and dialog that lead to sensing, modeling, and talking about the real-world to better understand, define, and work with systems. Systems thinking is a unique perspective on reality—a perspective that sharpens our awareness of wholes and how the parts within those wholes interrelate. A systems thinker knows how systems fit into the larger context of day-to-day life, how they behave, and how to manage them." (7)

Haskins (2011) further discusses the thought processes necessary to engage in systems thinking when stating,

> Systems thinking recognizes circular causation, where a variable is both the cause and the effect of another and recognizes the primacy of interrelationships and non-linear and organic thinking—a way of thinking where the primacy of the whole is acknowledged. (8)

The broad nature of systems thinking makes it more accessible than systems engineering to those working outside of engineering fields. Bahill and Gissing (1998) illustrated this breadth when they stated, "Systems engineering is a grand unified theory for making things work better. Systems engineering has been in the domain of the technical community. But now we see nontechnical practitioners using systems thinking" (516).

D. EMERGENCE

Emergence is any unexpected effect that results from interactions between objects (Langford 2012, 356). Emergence was alluded to in INCOSE's definition of a system, and will be echoed in conceptual combination discussions under the domain of creativity.

Emergence is used similarly in the systems engineering field and in creativity research. The concept of emergence is an important component (indeed, the goal) of both conceptual combination (in creativity literature) and integration (in systems engineering) (Langford 2012, 2; Sawyer 2012, 116).

E. ATTRIBUTE

According to Langford (2012), an attribute "…is a measure and measurement, configuration and structure, and constraint (e.g., time, cost, and scope), performance, and loss due to achieving the performances of a function" (353). Therefore, a measure can be defined as "…the quantified value of an attribute" (Vanek, Jackson, and Gryzbowski 2008, 113). Blanchard and Fabrycky (2011) define attributes as "…the properties (characteristics, configuration, qualities, powers, constraints, and state) of the components and of the system as a whole" (17). Both definitions are similar to the conception of attribute in the creativity domain.

Attributes are used similarly in both systems engineering and creativity. In creativity, the use of attributes revolves around conceptual combination.

F. FUNCTION

Functions are fundamental building blocks of the system and the systems engineering process. Langford (2012) states that a function is the result of the relation between two objects that interact with the property that at least one object provides input(s) and another object receives input(s). Functions are different from processes (116).

Functions are of great import to the systems engineering process. In creativity research, functions are discussed and used, but not sufficiently defined. Adoption of a standardized systems engineering definition of function would aid the creative process, particularly in conducting a proper functional analysis as part of a creativity system process model.

G. MEASURES OF EFFECTIVENESS

Sproles (1999) defines *measures of effectiveness* (MOE) as

> …standards against which the capability of a solution to meet the needs of a problem may be judged. The standards are specific properties which any potential solution must exhibit to some extent. MOEs are independent of any solution and specify neither performance nor criteria. (54)

Measures of effectiveness are intended to determine to what extent objectives are accomplished and how well the results compare with the desired results (Langford 2014).

MOEs are independent of quantities. An example of an MOE is “the probability of being hit by hostile fire” (Sproles 1999, 54). Adding target values to MOEs ties those MOEs to a particular solution, resulting in *criteria* (Sproles, 56).

MOEs are not formally used in the creative process, but could be adopted in order to standardize success in the creative realm. What is the creator attempting to accomplish with his or her idea? How would one determine that that idea is effective?

H. INTEGRATION

According to Langford (2012), “Integration is the unification of the objects through their interactions of energy, matter, material wealth, and information to provide system-level functionalities and performances” (359). In systems, integration results in emergence, which

> …facilitates outcomes that are beyond what an individual object can do either individually or by a number of objects acting

> independently, that is, makes things happen that would otherwise not happen. The whole is crucially greater than the sum of its parts. (2)

In contrast to decomposition, integration is performed from the bottom up. Components of the system are built into subsystems, and those subsystems are then built into systems (Haskins 2011, 120). Integration, as described in SE literature, is similar to conceptual combination in creativity. Both result in emergence (Langford 2012, 2; Sawyer 2012, 116).

I. PROCESS

According to Haskins (2011), a process is a "set of interrelated or interacting activities which transforms inputs into outputs" (5). Langford (2012) describes process as "…the amalgamation of activities and tools that combine ideas" (366). Process is enabled and driven by input as well as received EMMI through an object's procedures (Langford 2012, 70). Processes, in other words, "guide the work" (Langford 2012, 366) of systems engineering.

Processes can be nested, meaning that processes may be composed of subprocesses (Blanchard and Fabrycky 2011, 21). Processes can be mapped out and documented, and as such, they can be compared to other processes (Langford 2012, 366). This final property lends the capability to improve one process by incorporating tools, techniques, and methods from another process.

Processes are applicable to creativity as well as SE. The idea generation mechanism is itself a process. Each of the eight steps of the creative process is also a process, as are various substeps. Processes generate output, the end product (or a product that is a step toward that end product).

Similarly, systems engineering is composed of processes. Because creativity is a system, as previously asserted, systems engineering processes can be translated to the production of a creativity process model.

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