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Polanyi and the Revised Taxonomy: Teaching Technology for High-Level Creative Thinking and Risk Taking

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Abstract

This paper presents a model for mastery learning. The framework for this model overlays the cognitive and knowledge dimensions from Krathwohl's revision of Bloom's Taxonomy, the Revised Taxonomy, with Polanyi's theory of personal knowledge. A simplified framework integrates Polanyi's concepts of subsidiary and focal awareness with the Revised Taxonomy levels of knowledge acquisition to form a new model consisting of two dynamic parts: base thought and elevated thought. The base/elevated thought framework serves as a model for mastery learning with regards to the usefulness, application, and integration of technology into the creative problem-solving process. Allocating base knowledge to other means of instruction (for example, online tutorials or flipped classroom techniques) frees up the instructor's time and allows the expert (teacher) to engage novices (students) in more direct student-instructor contextual learning requiring higher levels of cognitive thinking. While this paper proposes the use of the framework within the context of a technology-focused model, its application has potential for other learning scenarios.

Introduction

Teaching technology as a tool for creative thinking is complicated by the nature of skills necessary to visualize and to conceptualize "what doesn't yet exist." The student who relies upon computer software to visualize a creative solution draws upon previous physical interaction with technology intuitively rather than by rote performance. Creative thinking and new, innovative solutions emerge only when the relationship of the student to the technology becomes intuitive. Merely presenting a new software program with its specific capabilities and options does not enhance the student's ability to create solutions. Instruction by rote memorization can limit a novice by connecting the action to one specific software that has its own limitations. The ability to explore, improvise and take risks is an important aspect of breaking through those limitations.

Teaching technology has practical difficulties. One common approach is by rote memorization. An instructor shows each tool of the software, the student memorizes how it works and then moves on. Creative, higher-level thinking may never be achieved by the student who simply applies the basic knowledge to each new problem. A second approach to teaching technology is by exploration. The instructor directs the student to the software for a specific use, and the student uses tutorials (via text or video) to learn the basics and advances through trial and error. However, only when the relationship of the student to the technology becomes intuitive will creation of innovative solutions emerge, and this does not occur without direct instruction of the right measure at the right time. To illustrate this idea, the instructor can use methodology to lay a foundation of basic skills for creativity as a music teacher might use in the process of teaching the student a skillset to play music that has already been composed. Furthermore, to interpret existing music uniquely, or to create new music, the musician must have the ability to imagine something, a skill Reimers (1970) equated to a combination of kinesthesia with high-order, creative thinking. Similarly, while learning technology a student must gain a level of confidence in basic knowledge to engage in the willingness to take risks required to employ creative thinking.

An essential component to creative thinking is the willingness to take risks. Dewett (2007) explored the link between creativity and an individual's willingness to take risks. He concluded that intrinsic motivation, which is the individual's positive feelings toward their work, manifests through an increased willingness to take risks. It is important to take risks when using technology as a tool because the ability to experiment in the learning process without being overly concerned about failure increases the possibility of innovation and discovery. Educational psychologists have reported that an individual's willingness to take risks diminishes with time due to the cumulative impact of ridicule and negative feedback (Humphreys, et al., 2015). Fully understanding the learning process enhances an instructor's ability to teach and provide positive feedback and encourage risk taking in the instructional process in order for a creative student to feel confident using technology to find innovative solutions.

In contexts requiring creative thinking essential to technology master learning, Polanyi's theory of personal knowledge is a promising framework for heightened understanding of the unique instructional processes that facilitate development of technological skills and knowledge. This paper proposes a model for mastery learning based on the overlay of Polanyi's theory of personal knowledge and Krathwohl's revision of Blooms original Taxonomy, the Revised Taxonomy, as a foundation for the use of direct student-instructor methods. Following is first an overview of the foundational theories supporting the model, then an explanation of the new framework.

Foundational Theory: Piaget, Vygotsky, Polanyi

Piaget and Vygotsky

Mastery learning allows students to move forward at their individual paces with mastery of knowledge, skills, and dispositions (Ellis, 2019). Teaching technology in post-secondary settings can be aligned with the seminal works of Piaget and Vygotsky to deliver the knowledge and skills that support technology mastery learning. These two theorists created a foundation useful for understanding the creative process of problem solving. Piaget focused on how knowledge the learner construct knowledge (Wadsworth, 2004.) The student creates new knowledge by building on existing knowledge. Certain concepts within Piaget's work explain creative work at all ages. Schemata, assimilation, accommodation, body schema, and decentering are five of those concepts. *Schemata* is both the transmitted knowledge and the process of how one acquires that knowledge. *Assimilation* is a more obvious concept within computer-assisted design. A learner seeks familiarity and imagines how a new object or program feature can replace or enhance an existing feature then seeks to find what is familiar within the new to quickly embed it into the existing set of skills. Piaget believed that *accommodation* was central to adaptation. The learner moves from broad application to targeted application by adjusting a bit with each new experience. *Body Schema,* or kinetic awareness is most obvious in the mastery of the keyboard and accessing individual features from a program's menu presented by icons and drop-down box features. And *decentering* is the ability of the learner to consider multiple aspects of any situation (Sanghvi, 2020; Supratman, 2019). Piaget argues that learning formal operations is a cumulative process for the learner, which occurs over the lifespan, but can serve as broad guides to cognitive development (Feldman, 2004). Incorporating Piaget's concepts through proper pedagogy encourages students towards exploration and invention for creative problem solving as *active learners*.

Vygotsky theorized that authentic learning (as opposed to rote learning) occurs in an experiential zone of development with assistance of prompts in a social context. As such, scaffolding supports a range of student learning styles and levels of proximal development, as well as constructivist and instructionist teaching approaches (Margolis, 2020). Vygotsky's contribution to our understanding of the learning process is best visualized by his Zone of Proximal Development, which is the space between what a student is already capable of doing independently and what that student could be capable of with help. Instructors provide the *scaffolding*, or support structures, which help the learner's development between those two spaces (Cole et al., 1978; Varadarajan & Ladage, 2022). The role of the instructor is to help the learner gain knowledge that will lead them through the Zone of Proximal Development to the next level of development (Smagorinsky, 2018). Per Vygotsky, students do not acquire higher-level intellectual skills through an instructor telling or demonstrating but through the novice learner's experience through participation with the advanced other (Taber & Li, 2021). Moore and Mollenkopf (2014) explored the relevancy of Piaget's and Vygotsky's paradigms within construction of online content delivered through technology. They concluded that the use of technology is only limited by the effort of the instructor to design and deliver it effectively. The authors suggest that a third perspective on student learning be added to Piaget and Vygotsky frameworks. Connecting Piaget's conceptualization of the *active learner* and Vygotsky's *scaffolding* with Polanyi's construct of *tacit knowledge* provides foundational understanding of student processes for technology mastery learning.

Polanyi

Polanyi, a chemist and philosopher, defines "skill" as the ability to perform expert actions for which the rules are unknown to the performer. Skills such as this are evident in professions such as the medical surgeon, the concert pianist, the expert craftsperson. These skills include tasks completed during the process to create the desired outcome that even the accomplished professional cannot explain. Polanyi calls this *tacit* knowledge. Tacit knowledge cannot necessarily be explained by empirical analysis. Additionally, Polanyi emphasizes that while the "articulate contents of science" can be transferred via recipes (or explicit steps), the "art of science" (expert knowledge) is translated differently (Polanyi, 1958). The transference of expert knowledge, per Polanyi, is through personal contact as opposed to book knowledge. This forms the basis for apprenticeship, a common way of transferring knowledge in many professions. The apprentice works alongside the master as the master models the actions or "rules" that are implicit skills, the tacit knowledge, necessary to perform the task (Bohlooli & Zargharmi, 2018). Tacit knowledge is learned through observation of the expert and trial and error under the expert's supervision. Polanyi explicitly argues that craft expertise cannot be reproduced through explicit (step-by-step) means or learned in the abstract. The expertise of the master craftsperson is learned by the apprentice through experience with the master.

Two Kinds of Awareness

Polanyi posits there are two kinds of awareness that comprise personal knowledge, subsidiary and focal. Subsidiary awareness is the content of those actions which become intuitive knowledge wielded to perform higher level tasks or thinking. Focal awareness is the content of initial awareness required to achieve learning or complete a task. Subsidiary awareness naturally occurs in the master without thought allowing focal awareness of a task to take precedent. Polanyi provides examples. Playing the piano is a task which exemplifies differences between subsidiary awareness and focal awareness. When learning to play the piano a student focuses on fingering and notes. Later, as mastery is gained, keys and notes are no longer the focus as those skills become subsidiary tacit knowledge and the musical dynamics of the piece becomes the focus. Another example provided by Polanyi is riding a bicycle. The rider initially concentrates on pedaling and balancing. An individual is not concerned with riding into the street or to the neighbors but simply upon the most basic of aspects of keeping the bicycle in balance and moving forward. Eventually, the rider no longer thinks of pedaling or balancing and focuses on the destination, or speed, or enjoying the surroundings. The whole of knowledge is comprised of both focal and subsidiary awareness as knowledge transfers from subsidiary awareness to tacit knowledge freeing the individual to focus on the creative aspects of a task.

Tools

As knowledge translates from focal awareness to subsidiary awareness it becomes tacit knowledge. Tacit knowledge refers to the understanding and skills that are implicit and often difficult to transfer other than through experience, and the tools wielded become an extension of the body. The keys on the typewriter are an extension of the fingers as the accomplished typist's focal attention is on creating the content of a written document. The keys of the piano, the notes, and the fingering of the concert pianist become tacit knowledge and an extension of the body as the dynamics of the music (e.g., slow to fast, soft to loud) become the focal attention of the musical expression. The hammer becomes an extension of the expert craftsperson as the focal attention becomes the creation of the form that yields the object. The procedural details, steps, or outside influencing factors of a master's "focal attention" still exist while a master presses on toward a goal; however, they fall into a state of "subsidiary awareness" not requiring direct focus of the master to reach the goal. This progression cannot be short-changed, rushed, or transferred from master to apprentice verbally or diagrammatically. For the novice, it requires assimilation through an active and direct teaching relationship with the master (Bohlooli & Zargharmi, 2018; Polanyi, 1958).

Polanyi and the Revised Taxonomy

The Revised Taxonomy (Krathwohl, 2002) carries the learner from rote memorization to synthesis and creation through increasingly complex levels of knowledge acquisition (see Figure 1). Krathwohl's Revised Taxonomy provides a two-dimensional framework that emphasizes both the knowledge and cognitive dimensions. An instructor's purpose in using the Revised Taxonomy for learning outcomes is to build knowledge from lower-level cognitive processes to higher-order thought that will encourage creative thinking.

Similarly, Polanyi's example of the master artisan's use of the hammer requires knowledge transition from lower-level cognitive processes to higher-order thought. Memorizing nail weights, joint types, wood species, and the characteristics of each are useful, but actual cabinet creation is an outcome requiring knowledge all along each axis of the Revised Taxonomy. Comparably, memorizing keyboard shortcuts or sequenced processes for learning computer software does not ensure creative outcomes. However, while transitioning through cognitive process and knowledge dimensions account for traditional classroom practices, it "does not account for the new processes and actions associated with web 2.0 technologies and increasing ubiquitous computing" (Churches, 2010, 2).
Tacit knowledge cannot be explicitly described as it is based on personal knowledge learned in relation to context and experience rather than scientific objectivity. The learning acquired by the student develops from discovery and creating in context of relationship with the instructor (Bohlooli & Zargharmi, 2018). Learning computer software requires students to transition from basic knowledge to high-order applications to empower creative outcomes, which the learner achieves best through the interjection of the instructor's expert knowledge at opportune moments.

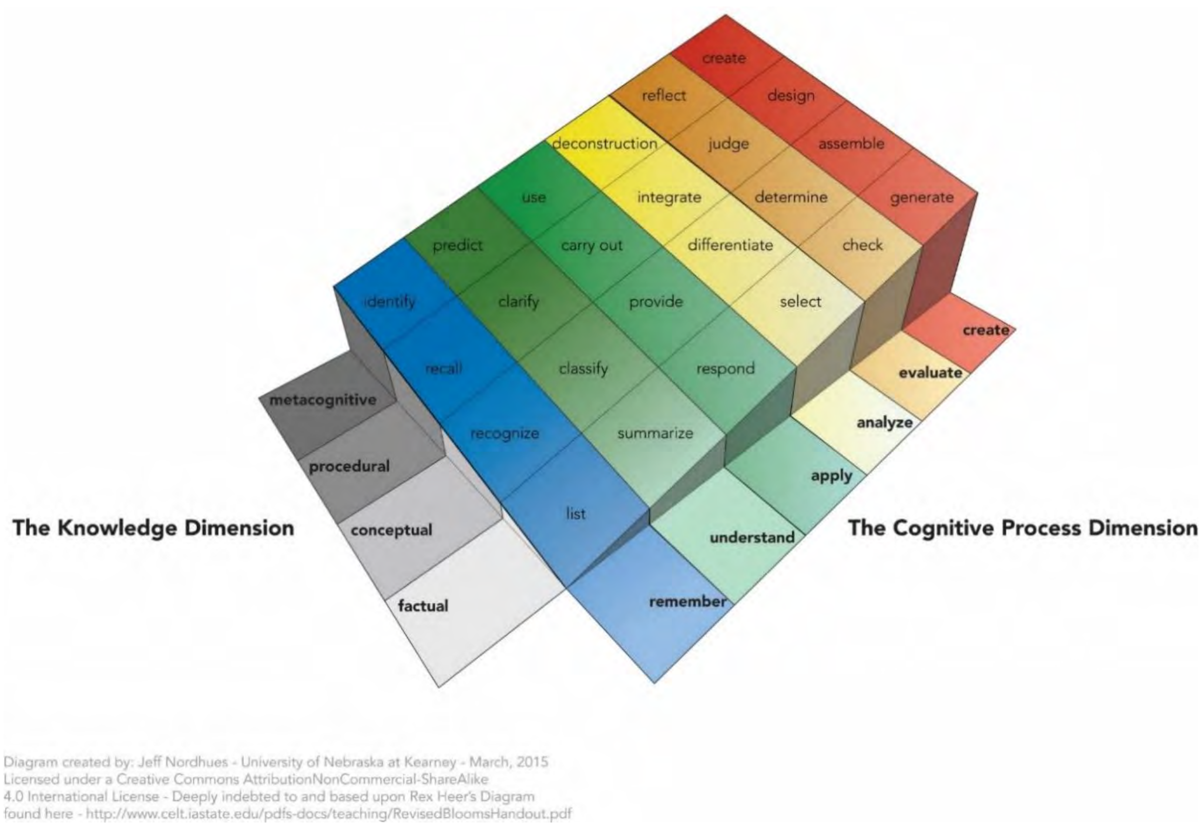

Figure 1. Revised Taxonomy Diagram: Based on Rex Heer's Diagram

By overlaying Polanyi's Theory of Personal Knowledge with levels of knowledge and cognitive thinking as defined in the Revised Taxonomy, an instructional methodology emerges that supports the use of direct student-instructor contextual learning methods requiring higher-order thinking essential to student technology mastery learning. Following is a model for technology mastery learning in education integrating Polanyi's T*heory of Personal Knowledge* and the *Revised Taxonomy.* First is an overview of the framework for the model, followed by an explanation of the model.

Model for Mastery Learning of Technology

Technology's Unique Mastery Learning Problem

Two primary trajectories appear when it comes to technology instruction: the first is to "help yourself" and the second is to teach to the lowest common denominator. In the "help yourself" approach, the instructor expects students to know X software by X point for X class. The students may work through a step-by-step tutorial or other means of self-study. However, videos date quickly and graduate student and support staff in technology labs are limited by institutional budget and staff availability. For the student, the process often results in lower competency levels, higher frustration and adapted methods that may be inefficient or ineffective.

The second approach is to teach technology in designated courses with a click here, click here, then here, hand-holding approach. While it may move all students through the basic knowledge content, those students who easily master the content quickly become bored and the struggling student may still be left behind.

Both instructional methods can be useful in helping students to acquire base-level skills, and in both cases video tutorials may supplement face-to-face lectures in addition to study groups or labs. However, both processes leave students without the guidance and transfer of subsidiary awareness from the expert (teacher) to the apprentice (student). Students often do not come away with the level of mastery learning necessary to apply technology in contexts requiring higher level cognitive thinking and risk taking resulting in creative thinking. The outcome of these instruction methods suggests the need for a model that utilizes the best of both processes with outcomes of mastery learning.

The New Model: Polanyi and the Revised Taxonomy Revisited

Base and Elevated Thought

A change in teaching process implementing the proposed learning model can result in elevated student mastery relative to more time with the "master," or in this case, the course instructor. Allocating base knowledge to other means of instruction such as online tutorials or flipped classroom techniques (Berrett, 2012; Cheng, et al., 2019; Deng, 2019) frees up the expert's time allowing direct student-instructor contextual learning necessary for higher cognitive skills (see Figure 2). Once the basic skill set required to utilize a software program as a tool becomes mastered by the student as tacit knowledge, the base knowledge allows the student to engage in higher level cognitive thinking, or per the model, elevated thought that leads to creative thinking outcomes.

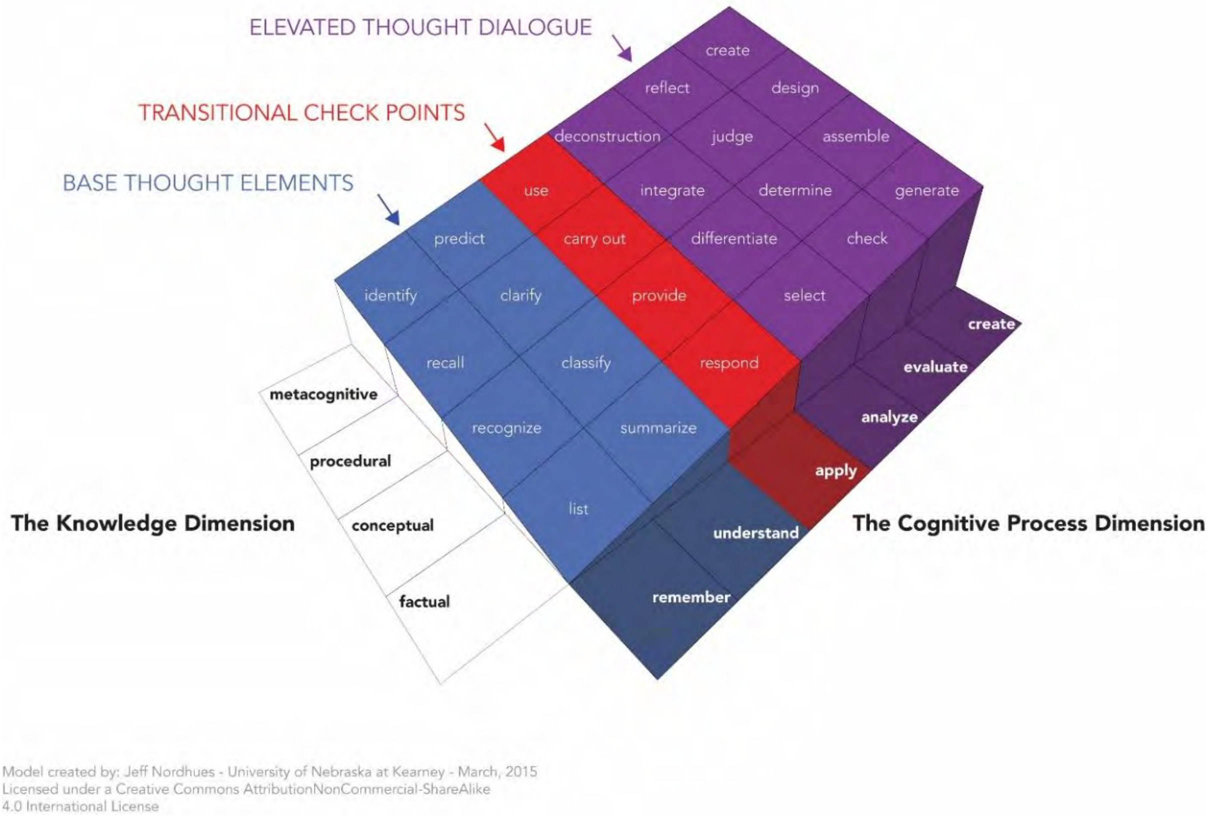

Figure 2. Learning to Learn Overlay with Transitional Check Points

Learning to Learn

Goals or projected outcomes are the focus of an expert craftsman. This represents “focal awareness” per Polanyi. The procedural details, steps, or outside influencing factors still exist while an expert presses on toward a goal. However, they fall into a state of “subsidiary awareness” not requiring direct focus of the expert to reach the goal. This progression cannot be short-changed, rushed, or transferred from expert to apprentice verbally or diagrammatically. Transference of knowledge from base to elevated thought requires assimilation through a direct teaching relationship with the master. (Polanyi, 1958) A change in teaching process implementing the base/elevated thought model results in elevated student mastery relative to more time with the "master," or in this case, the course instructor. Allocating base knowledge to other means of instruction or digital means of instruction (for example online tutorials or flipped classroom techniques) frees up the expert’s time, allowing them to engage in more direct student-instructor contextual learning that requires and encourages higher cognitive skills resulting in creative problem solving. A significant outcome is students’ learning to master the learning of technology, not simply the technology itself.

The base and elevated thought diagram provides a means of analysis for the Revised Taxonomy and Polanyi’s concepts at a simplified level as an abridged entry point for a framework of analysis. Studies on cognitive thinking reveal that students required to learn new knowledge while simultaneously being required to apply it to creative problem-solving results in cognitive overload, not mastery learning (Van Merriënboer et. al., 2006; Van

Merriënboer & Sweller, 2005). Cognitive Load Theory (CLT) is based on the cognitive information processing model that describes how information makes it into our long term memory and thus becomes useable for future problem solving. Cognitive Load Theory is primarily concerned with integrating short term memory demands with instructional models to build schema and maximize transfer. Skills requiring complex learning also simultaneously require significant cognitive resources to master.

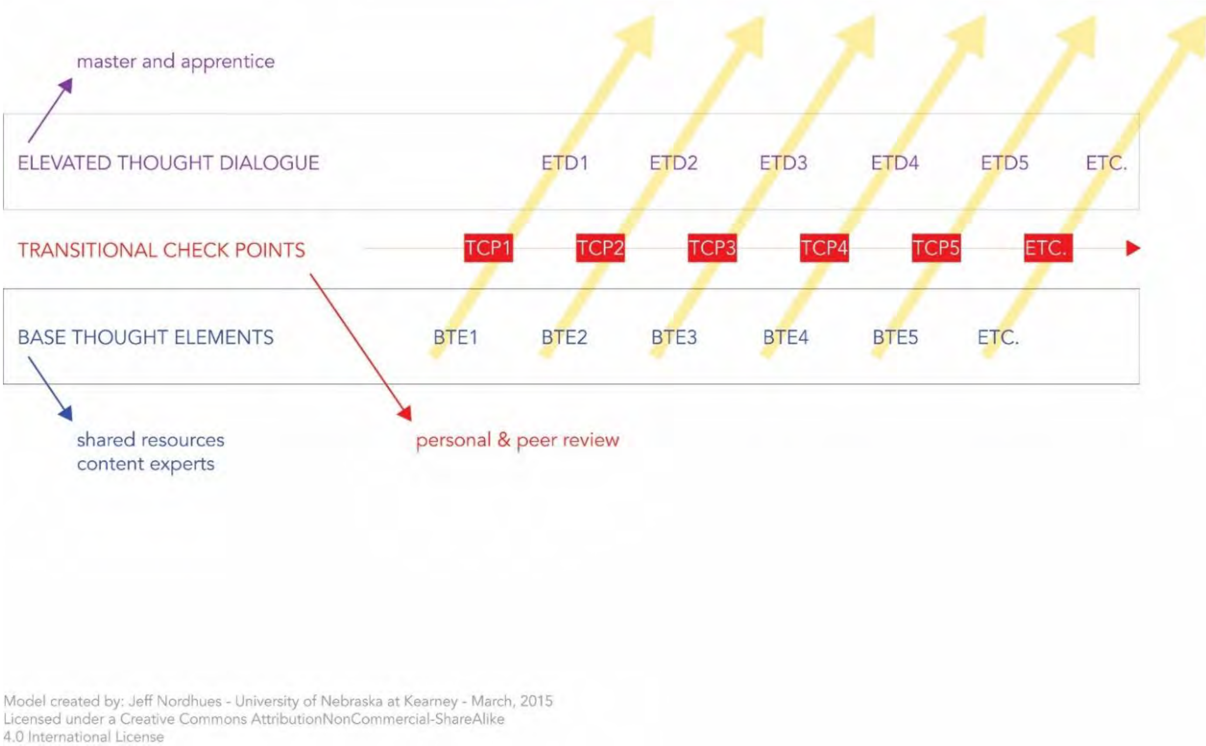

Figure 3. Learning to Learn Progression Diagram

Van Merriënboer, & Sweller (2005) argue that such models of instruction require complex learning that uses substantial cognitive resources on the part of the student. Additionally, complex learning is so resource intensive, it has the potential to overwhelm the working memory and prevent the formation of schema in long term memory (van Merriënboer, Kirschner & Kester, 2003). While the common instructional response is to find ways of lowering students' cognitive load, it is critical to examine how load reducing methods impact transfer of learning because methods that work well to reach high retention and in class performance "are precisely those that hinder transfer of learning" (van Merriënboer, Kester, & Paas, 2006, p.343). Methods such as step-by-step guidance encourage routine building which constrain the problem spaces within which learners work and make it significantly more difficult to generate creative solutions (Vaux, et al., 2016).

The model shown in Figure 2 allows students to acquire basic skills and develop them to a level of subsidiary awareness before requiring the student to apply the basic knowledge to creative outcomes. In this new model, a transitional checkpoint is added after the base thought elements are mastered by the student. The transitional checkpoints ensure input from the expert instructor to transfer tacit knowledge at key points of readiness. So, in the classroom, a professor may utilize step by step instructions provided in a text with a combination of video tutorials to help the students gain memory and understanding of basic skills. When the student has reached a level of competency through other sources, the instructor can guide and challenge the student into an elevated thought dialogue that encourages interpretation and creation of novel solutions.

The process of acquiring base level thought through transitional input from the instructor raises the confidence of the student apprentice and thus the potential to engage in the risk taking necessary for imaginative thinking. The Learning to Learn Diagram (see Figure 3) graphically shows the process of scaffolding instructional techniques and student-instructor supervision in advancing base and elevated thought.

Conclusion and Future Research

Technology mastery learning requires both base and elevated thought to generate creative solutions. This paper presents a model for mastery learning that encourages acquisition of base level knowledge with transitional checkpoints to stimulate elevated thought applications. Technology has many uses within the learning process as a tool for creative problem solving. However, a student's basic use of a software program does not validate its use as a tool. (Nordhues & Vaux, 2015). Simply learning technology at a base level does not necessarily lead to master application for creative problem solving. Technology only becomes a tool for creative thinking when its base level functions become tacit knowledge to allow for focal attention on advanced outcomes.

While this paper proposes the use of the framework within the context of a technology-focused model, its application has potential for other learning scenarios. The learning model presented in this paper developed from instructional processes in a technology course. A formal study using the framework to analyze the usefulness of the model with inputs from other academic courses would validate its veracity for mastery learning in broader contexts. Content within the study could include transferability from academia to industry as well as the effectiveness of attaining base level knowledge from other sources (e.g., video tutorials, flipped classroom techniques). In future studies, the base/elevated thought model could serve as a means of analysis for both education and professional applications with regards to the usefulness, application and integration of technology into the creative process.

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