The seven transdisciplinary habits of mind of creative teachers: An exploratory study of award winning teachers

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ARTICLE INFO

ABSTRACT

Although discussions of thinking skills often revolve around students and learners, it is equally important to consider habits of mind and thinking skills for successful and creative teachers. Teachers are primary mediators of thinking and learning for their students, and understanding how excellent teachers function and use thinking skills is an important, albeit often underserved, area of research. Amid the expansion of research and discussion around thinking skills in general, one approach that has garnered interest in recent years is the idea of "transdisciplinary" thinking—which entails effective approaches to thinking and working, that cut across disciplinary boundaries. Existing research has shown that the most successful creative thinkers in the sciences tend to use a set of meta-level cognitive "transdisciplinary" skills. While others have suggested this transdisciplinary skill set as a framework for teaching, it has not yet been formally studied with regard to teachers, particularly those deemed as "effective" or "creative". This article discusses a qualitative study that investigated the use of seven transdisciplinary thinking skills among highly accomplished and nationally award winning teachers. National teacher of the year award winners and finalists were interviewed with regard to their use of transdisciplinary thinking skills in their teaching beliefs and practices. Results exemplify how such skills are used by such effective, creative teachers in a diverse range of ways, with broader implications for future study and practice.

1. Introduction

Through the history of educational psychology, there has been discussion, debate, and analysis about cognitive skills people need to be effective thinkers (Baron & Sternberg, 1987). Critical thinking skills, defined as "deliberate use of skills and strategies that increase the probability of a desirable outcome" (Halpern, 1998, p. 449), have dominated the discourse, particularly as skills for learners (Ennis, 1985). Recently, this discussion has expanded into other aspects of cognition (Baumfield, 2015; Zohar & Dori, 2003) extending into areas of creativity, abstract thought, verbal or mathematical thinking, among others—to offer a wide range of skills that describe thinking (Baron & Sternberg, 1987; Connell, Remington, & Armstrong, 2012; Costello, 2013; King & Kitchener, 1994; Kuhn et al., 1988; Loes, Pascarella, & Umbach, 2012; Segal, Chipman, & Glaser, 2014).

Although such discussions often revolve around students, it is equally important to consider habits of mind for teachers (Anderson, Greene, & Loewen, 1988). Teachers are primary mediators of thinking and learning for their students (Amabile,

1996). Understanding how excellent creative teachers use thinking skills is an important, albeit underserved, area of research (Calderhead, 2012).

Amid the general discussion around thinking skills, one growing approach is the idea of "transdisciplinary" thinking—or approaches to thinking and working that cross disciplinary boundaries (Ramadier, 2004; Palmer, Smith, Willetts, & Mitchell, 2007; Root-Bernstein & Root-Bernstein, 1999). This suggests that, while discipline-specific knowledge is important, there are also overarching approaches to thinking that successful, creative people use across disciplines.

However, there have not been many descriptions of specific skills or habits of mind used by transdisciplinary thinkers. Literature has noted a relationship between transdisciplinary thinking and creativity, but with only a few examples of skills frameworks, for instance that of Root-Bernstein and Root-Bernstein (1999). This article describes a study that explores transdisciplinary thinking in the practice of exceptional teachers. It uses a framework of transdisciplinary thinking skills that several scholars have pointed to (Mishra, Koehler, & Henriksen, 2011; Root-Bernstein & Root-Bernstein, 1999; Root-Bernstein, 1996, 2003). Research suggests that these transdisciplinary skills are effective among successful, creative thinkers across disciplines.

A few scholars have discussed the value and potential for transdisciplinary approaches to pedagogy (Root-Bernstein & Pathak, 2016). This brings a framework of transdisciplinary cognitive tools into the classroom (Root-Bernstein & Root-Bernstein, 2005; Root-Bernstein, 1987, 1991; Root-Bernstein, Root-Bernstein, & Root-Bernstein, 2004). Root-Bernstein and Pathak (2016) review scholarship in this area and note significantly impactful outcomes for the explicit teaching of such thinking tools. Yet there has been little research to investigate a complete framework of transdisciplinary skills, or to consider approaches to employing them by successful teachers in K12 contexts. This study is an initial step—to explore if and how transdisciplinary thinking tools are utilized by excellent creative teachers, and their personal approaches to employing them.

The impact of creativity in teachers has been championed by many researchers (Anderson, 2002; Sternberg, 2006; Tan & Law, 2004). The complexity of teaching makes it difficult to define "creative" teaching, and educational research has often designated "creative teaching" as "effective teaching" (Anderson, 2002; Bain, 2004; Davidovitch & Milgram, 2006; Esquivel, 1995). There is a strong body of thinking in educational research that either equates or tightly links effective teaching with creative teaching (Anderson, 2002; Bain, 2004; Bleedron, 2003, 2005; Chambers, 1973; Cropley, 2003, 1967; Davidovitch & Milgram, 2006; Esquivel, 1995; Fasko, 2000–01; Milgram, 1979; Newcomb, McCracken & Warmbrod, 1993; Renzulli, 1992; Torrance, 1981, 1995). Anderson (2002) noted, "…the most fundamental risk these teachers accept is found in their willingness to confront both success and failure in the interest of teaching better. They risk themselves in being responsible for their work. In this way, they are not so different from creative artists in other arenas." (p. 35). Torrance (1995) suggested that creative teachers are also effective teachers, because they are willing to try new approaches and ideas varying from some traditional educational beliefs to improve practice. Many such assertions highlight the fact that teachers who are noted as successful and effective are also *creative* teachers (Bleedron, 2005).

This study is part of a larger qualitative inquiry on creativity among exceptional classroom teachers (Author 1 & Coauthor, 2015). This article focuses on one specific aspect of that inquiry, focused on transdisciplinary thinking (drawn from the work of Root-Bernstein & Root-Bernstein, 2005, and Mishra et al., 2011). I conducted in-depth interviews with individuals recognized as exceptional, creative teachers—about their transdisciplinary thinking skills and practices. Interviewees were teachers who have received, or been a national finalist for, the National Teacher of the Year award (full discussion of the rationale for this group as exceptional, creative teachers is given in Methodology). Studying individuals noted at the top of their field offers an opportunity to learn from the best. In a complex and difficult profession like teaching, these are individuals recognized for performing well. Such inquiry fits with a tradition in creativity research of studying outstanding creative practitioners (Gruber & Barrett, 1974; Schön, 1983; Simonton, 1999). In the next section, the transdisciplinary nature of creative thinking is explored.

2. Across the disciplines: creativity and transdisciplinarity

Creativity in the sciences is often depicted as if it were entirely separate from the arts (Catterall, 2002). Hudson (1967) described how scientists are often classified as "convergent thinkers," and artists as "divergent thinkers". Weisberg (2006) and Freedman (2003) suggested that creativity is a thinking approach that cuts across disciplines.

Transdisciplinary thinking suggests that learning to think creatively in one discipline opens the door to creativity in other disciplines. So that there may be a structure of thought processes (habits of thinking) for this. Yet there are relatively few frameworks that offer a set of cognitive skills for this.

2.1. Transdisciplinary thinking: an overview

Ramadier (2004) and Palmer et al. (2007) give a broad definition of transdisciplinary thinking, as a type of thinking and approach to problem solving that "calls in a general way for collaborative, creative, higher order thinking which transcends discipline boundaries", which "involves a combination of different types of knowledge such that the whole is more than the sum of its parts" (Palmer et al., 2007, p. 2).

Scholars frequently note transdisciplinary thinking as approaches that cross disciplines, or use approaches in one discipline to enhance another (Root-Bernstein, 2003). Rosenfield (1992) suggests that a "transdisciplinary approach can provide a systematic, comprehensive theoretical framework for the definition and analysis of the social, economic, political, environ-

mental, and institutional factors influencing human health and well-being." (p. 1343) She does not provide specific thinking skills for transdisciplinary problems, but suggests including knowledge and experts from different fields to solve problems in creative, effective ways. Other scholars (Hall, Feng, Moser, Stokols, & Taylor, 2008) have also argued that an approach representing diverse disciplines is one of the best ways of resolving real-world scientific problems. However, these approaches to transdisciplinary thinking are usually predicated on a team model of working, rather than an individual's process of thinking.

All of this suggests that thinking across disciplines is beneficial for creative problem solving. Yet there is a gap in which little work exists around transdisciplinary skills frameworks for individuals' thinking. The work of Root-Bernstein and Root-Bernstein (1996, 1999, 2003), and Mishra et al., 2011 provide a transdisciplinary framework for individual creativity. This framework, described below, is the basis for this study.

2.2. Transdisciplinarity for award winning teachers

Root-Bernstein (1987, 1991, 1996, 2003) proposes a transdisciplinary framework, with a specific set of creative-cognitive skills to explain how successful and innovative thinkers solve problems. They identify thirteen cognitive skills that have been used by highly creative thinkers across disciplines. These skills include: *Observing, Imaging, Abstracting, Recognizing Patterns, Forming Patterns, Analogizing, Body Thinking, Empathizing, Dimensional Thinking, Modeling, Playing, Play, Transforming, and Synthesizing.*

Mishra et al. (2011) collapse the Root-Bernsteins' thirteen transdisciplinary thinking skills into a condensed set of seven. These skills (discussed more fully in the next section), include: *1) observing; 2) patterning; 3) abstracting; 4) embodied thinking; 5) modeling; 6) play; 7) synthesis.* The framing for this study uses this shortened skill-set from Mishra et al. (2011) primarily because this shortened version condenses the original list of thirteen skills into a more representative but compressed framework for study, which they also suggest as a valuable creative skill set for teaching (Author anonymous for blind review, 2014, 2015).

Root-Bernstein and Pathak (2016) conducted a meta-analysis of pedagogical literature from STEMM (science, technology, engineering, mathematics, and medicine) that, while not explicitly grounded in the tools for thinking approach, examines whether teaching specific transdisciplinary skills in education settings improves learning outcomes. They discuss enhanced learning outcomes from pedagogical approaches to STEMM that connect different disciplines (i.e. bringing arts, crafts, design and more into STEMM disciplines) via specific thinking skills. However, there remains a gap in the creativity and educational literature for K12 teachers across contexts. No current work has examined the range of thinking tools utilized by different classroom teachers within their own personal approaches to employing them. In particular, there is the need for a first step that considers whether and how these skills are employed by effective teachers in K12 public education.

2.3. The seven transdisciplinary skills

A definition and description of these seven skills (Root-Bernstein & Root-Bernstein, 1999; Mishra et al., 2011) with appropriate citations for further reading, follows:

2.3.1. Observing

Observing is the first step to understanding anything. It involves close attention to information gathered through the five senses, with intent focus and curiosity. For example, bacteriologists use their sense of smell to observe bacteria, and an ornithologist might identify bird species by sound. Inventors and mechanics cultivate hands-on experience with tools and machines, relying on a sense of "feel" to understand their craft. Observation requires going beyond registering information to notice details and meanings. It can be honed with practice and attention to detail. [For more on this skill, see: (Author anonymous for blind review, 2014).]

2.3.2. Patterning

The *Patterning* tool includes both the act of recognizing patterns and forming them. *Recognizing patterns,* a fairly familiar mental act, involves identifying a repeating form or a plan in a seemingly arbitrary arrangement of things or processes. *Recognizing* is the analytical part of Patterning, while *forming* is basically a creative act. *Pattern forming* starts when one combines components in a regular way to create a pattern. For example, poets rely on their knowledge of linguistic patterns and structures in order to create new poetic structures, while mathematicians rely on patterns and relationships in numbers (Gardner, 1983; Root-Bernstein, 2003). [For more on this skill, see: (Author anonymous for blind review, 2014).]

2.3.3. Abstracting

Abstracting involves capturing the essential nature of a thing—concentrating on one feature of a thing or process in order to boil it down to grasp its essence. For example, scientists use abstractions when they eliminate all superfluous traits from a physical situation (i.e. shape, size, color, texture, etc.) to key in on features of interest such as boiling point/mass/etc. This can also happen through creating analogies, by noticing the key similarities in seemingly dissimilar things. Isaac Newton compared the moon to a ball thrown so hard that its descent misses the earth and passes into orbit; leading to the idea of universal gravitation. [For more on this skill, see: (Author anonymous for blind review, 2014).]

2.3.4. Embodied thinking

The skill of *embodied thinking* involves both kinesthetic thinking and empathizing. *Kinesthetic thinking* is bodily thinking exemplified by sensations and feelings in the body, of movement, balance, tensions and so forth. Einstein, for instance, used physical imagination to view himself riding a beam of light, to understand relativity (Root-Bernstein & Root-Bernstein, 1999). *Empathizing*, is another element of this requiring a person to understand someone else's point of view—imagining walking in their shoes, feeling what they feel. Actors, poets, or novelists empathize to portray characters in authentic ways; even scientists apply empathetic thinking to understand other organisms and processes. This is the notion of understanding concepts via a "feeling for the organism" (Keller, 1983). [For more on this skill, see: (Author anonymous for blind review, 2015).]

2.3.5. Modeling

Modeling involves creating a representation of something in real or theoretical terms in order to study its nature, composition, or purpose, and can be used in both scientific and artistic modes of working. Artists and designers create models by sketching or preparing smaller views of a piece in advance of creating it. Scientists employ basic models of things or processes. Architects do this when they take two-dimensional information (blueprints, maps etc.) and construct them in three dimensions, or vice-versa. [For more on this skill, see: (Author anonymous for blind review, 2015).]

2.3.6. Play

*Play*ing is something that we do just "for the fun of it". It may involve creating new rules or breaking the existing ones of established procedures. Simply put, "play" is using knowledge, body, mind, and abilities for the pure enjoyment of using them. When imaginative or innovative people play with things or concepts or processes, they open doors to new ways of thinking and new insights. Creative people across disciplines speak to the value of play. It can involve playing with ideas, distinctions, boundaries, unassailable truths, and the limits of utility. [For more on this skill, see: (Author anonymous for blind review, 2015).]

2.3.7. Synthesizing

Synthesizing is the cognitive tool that ties together the previous ones, putting different ways-of-knowing together into a synthesized whole. When a person fully understands something, feelings, senses, knowledge, and experiences come together in a multi-faceted, cohesive way. A person feels what they know and knows what they feel. Experts across disciplines describe the creative process as the joining of the five senses and the emotions into a holistic, aesthetic, and intellectual experience. [For more on this skill, see: (Author anonymous for blind review, 2015).]

This study is an initial, exploratory line of inquiry, examining the use of these seven transdisciplinary thinking skills in the pedagogical approaches, practices and beliefs of excellent, creative teachers. This offers a new paradigm for creative teaching, leading to the research question guiding this study: *Do accomplished, creative teachers use transdisciplinary thinking skills in their practice, and if so, in what ways?*

3. Methodology

This study used a qualitative research design through semi-structured in-depth interviews with accomplished, successful teachers (National Teacher of the Year award winners and/or finalists), to better understand transdisciplinary thinking in their practice.

3.1. Instrumentation

Thinking skills are frequently noted as a complex subject matter to investigate (Klein, 1982; Plucker, Beghetto, & Dow, 2004). Hocevar (1981) suggested, "A useful way to measure…is to simply ask the subject. This is not a profound position, but yet the procedure is rarely used" (p.459). A semi-structured interview protocol (see Appendix A) guided each interview, covering teaching beliefs, classroom practices, and personal examples relating to transdisciplinary thinking. Before the formal interviews three in-depth pilot interviews were done to test the protocol/guide. These pilot interviews helped establish the interview protocol for examining the research questions.

3.2. Sample

This study used a purposeful sampling approach with selected individuals in keeping with Patton (2002) and Creswell (1998, 2005) who suggest this approach ensures that all participants actually have experienced the phenomena and can speak to it. This study required participants who were "effective", "accomplished," and "creative" teachers. The participants selected were teachers who received or were finalists for the U.S. Teacher of the Year award. These awards are generally given to classroom teachers who have been noted on multiple levels for excellence and innovation in teaching.

3.2.1. Rationale for "Teachers of the year" as research group

In the United States, one teacher per state, every year, is selected based on specific, rigorous, and consistent criteria (though there is some variation from state to state). Applicants must show: 1) a clear record of substantial positive classroom outcomes and student learning (i.e. a verifiable track record of teaching results), 2) examples of original, effective teaching, and 3) high recommendations (in written form) from peers, principals, students/parents. Four of these state winners are further selected to be finalists with one selected as the National Teacher of the Year.

These are highly effective teachers. A significant body of research argues that effective teachers are also highly creative (Anderson, 2002; Bain, 2004; Bleedron, 2003, 2005; Chambers, 1973; Cropley, 2003; Davidovitch & Milgram, 2006; Esquivel, 1995; Fasko, 2000–01; Milgram, 1979; Renzulli, 1992; Torrance, 1981, 1995).

To support this argument for creativity within this sample group of exceptional teachers, I reviewed the applications and/or online data for 15 recent Teacher of the Year finalists to ensure that there was discussion and evidence of creativity in their practices. This review of application data was done prior to data collection, in looking through the work of a range of recent National Teacher winners/finalists, to see that this sample would be able to speak to the topic of creative teaching. The data and information (retrieved from the National Teacher of the Year website) included teaching philosophy statements, lesson examples, and more. The review of this information demonstrated clear evidence of creativity, both implicitly (examples of creative teaching) and explicitly (direct mentions of "creativity" in teaching philosophy). Appendix B is a general overview of this data. For instance, 14 out of the 15 teachers in this overall group made specific references to "creativity" in their comments about teaching and all 15 provided examples of classroom teaching or lessons which can be construed as "creative," in that they were original, innovative and valuable. Given all of this, it can be argued with some confidence that National Teacher of the Year finalists/winners can be considered representative of teachers who are both effective and creative, and thus a good sample for this study.

Beyond that it is important to address, why study the best? The short answer is that they are doing something right. Expert practitioners (be they scientists, artists or teachers) have a deep knowledge of what works and how to do it well. They may not or may not know the psychological or theoretical underpinnings of why they do what they do. But at some level (either instinctually or in learned practice) they have figured things out, and there is much to learn from them. Schön's work (1983) suggests that such practitioner's often have more knowledge than they immediately articulate. The opportunity for research to explore is significant.

3.3. Data collection and analysis

The teacher award winners/finalists were recruited for the study via email, resulting in-depth interviews with eight teachers (consistent with Creswell's (1998) suggestion of using "long interviews, with up to 10 people" for descriptive study of a phenomena (p.65)). The interviews were audiotaped with the expressed-informed consent of each interviewee, then transcribed prior to analysis. Each transcript was read and reread for familiarity with the text/ideas prior to coding.

To make sense of the data, I reviewed all text/statements, considering them equally, then grouping them into "meaning units", or codes of significant statements (Moustakas, 1994). HyperResearch©, a qualitative data coding software, was used to facilitate the management and organization of interview text data and the resulting themes or coding schemas. I conducted three separate iterations of coding on transdisciplinary skills and creativity.

Reliability and validity, or "standards" and "verification" were established by creating a cross-referencing table of the research questions and the instrumentation, to ensure the data could appropriately answer the research questions (Anfara, Brown, & Mangione, 2002). Additionally, several of Creswell's (1998) verification techniques were used, including peer-review or debriefing (via conversations with several faculty/peers in the field, overviewing the research), member checks (sending copies of the transcripts to each interviewee for their approval or input), and rich, thick description (direct quoting interviewees in the findings, for description of ideas in their own words) (Lincoln & Guba, 1985; Anfara et al., 2002).

4. Findings and results

This section begins with some teaching and background information for each interviewee in Table 1 below. Following that is more discussion and exemplification of the transdisciplinary creativity skills that this study focused on.

4.1. Note on coding the data

The seven skills were coded as transdisciplinary themes using HyperResearch©. The seventh skill of synthesizing was not specifically or directly asked about in the protocol because the broad nature of synthesizing made it difficult to ask concrete, definitive interview questions. However, synthesizing was part of the analysis (and findings) as an emergent theme.

The findings below help establish a basis for seeing that the seven skills do play out in the experiences and practices of these accomplished teachers. Analysis shows (a) that these skills do emerge; and (b) they manifest themselves in a range of ways—ways that included some themes, but that were most often variable and divergent. This suggests not just that transdisciplinary thinking plays a role in the thinking of excellent creative teachers but also that the unique and varied nature of classrooms, teachers, and educational contexts means that these skills are instantiated in a variety of ways.

Table 1
Teaching context/background for participants.

Teacher	Grade Level/Subject	School or District Context
Mark	Middle school (grades 7); science teacher	Rural community, high poverty and high unemployment.
Sandra.	High school (grades 9–12); language arts teacher	Large suburban community with a mix of socio-economic backgrounds; many ESL students.
Carrie	Middle school (grades 6–8); language arts and reading teacher	Large urban community. And serving as "teacher on loan" to the state Department of Public Instruction.
Jack	Elementary teacher (grade 3); and currently working as a teacher recruiter and mentor	Rural district; Title 1 school with many at-risk students.
Julia	Middle school (grades 7–8); science teacher	Micro-district adjacent to a very large urban district with many free/reduced lunch students.
Adam	Middle school (grades 7–8); math teacher	Large urban district with fast growing poverty rate (approximately 90% Latino-Hispanic); Title 1 school with mostly free/reduced lunch students.
Mia	Elementary teacher (grade 4 primarily; but has taught grades 1–3 in the past)	Large urban district with high poverty rates; Title 1 school with mostly free/reduced lunch students.
Marie	Elementary teacher (grade 4 primarily, but has taught grades 1–5 in the past)	Suburban setting; now retired running a multi-district inter-disciplinary learning program.

In the section below we look at each of these seven skills in turn providing key examples, in so far as possible, in the words of the teachers themselves, to show the manner in which these skills play out in their thinking and practice.

4.2. Observation

The interviews demonstrated the value of finely-tuned or well-honed observational skills for teaching. This skill was frequently discussed by the teachers in how it helps build awareness of multiple elements within a classroom.

Julia discussed the value of observational skills, or always "having your feelers out", noting that it does more than just provide a good overall sense of a classroom, but helps in identifying opportunities for "teachable moments", as she stated:

> It helps to be finely tuned in looking for those teachable moments, the times when you see that the discussion is taking a turn; or a question that was asked that you can turn into a teachable moment. Observing when there's an opening, or a chink in the armor of boredom, or in the armor of a kid who pretends they aren't interested. You can find a hook to pull them towards the ideas.

In this way, Julia highlights observation as a skill that provides awareness about subtle learning opportunities. It provides a chance to refine teaching skills, and pursue opportune moments for creating excitement and engagement; or at times, to turn things around when students are experiencing boredom or confusion. In this way observation becomes a fundamental skill for identifying teachable moments, or interesting situations that lend themselves to discussion or learning opportunity (Lozo, 2005).

Adam also remarked on the fact that he felt that good observation is a skill he focuses on and that this has helped him deal with a variety of teaching situations. He commented on this, saying:

> The key to observation is being able to separate yourself from the situation. That's one thing I try to do. . .observing a situation *as is* and not just as it relates to me.

This ability to make careful objective observations or, as Adam noted, to "enjoy the process of observation without taking it personally" is not depersonalization—but rather an objective awareness of teaching situations and a more open-minded approach to assessing a situation accurately.

Similarly, Carrie describes the significance of observation in teaching as a skill that gives information on what is happening in multiple ways, in her classroom. In addition, she believes that these skills have been honed directly in practice, noting:

> I have been trained to see all kinds of things in a classroom. I've got to notice body language and attitude right when they come in the door. If there is one coming in to class who has gotten upset during the day, or about something at home, and I'm trying to get him to answer a question, there can be an outburst that is unrelated to me, and I didn't see coming· · ·Teachers have to be keen observers.

Carrie's comments emphasize the value of attention to fine detail in teaching, and the way this permits her a more in-depth awareness of her students and issues that might not be initially obvious. As importantly, she noted that not only is observation a critical pedagogical skill, it is one that can be learned and practiced. This ability to expand observation skills is in line with Root-Bernstein's (2003) framework—where thinking skills can be learned, taught, and developed in practice.

Mark broadened this discussion of observation to describe the fact that it is essential in teaching because it is a necessary thinking skill for self-awareness and creativity:

It becomes about the first step in terms of self expression. You've must be aware to be self-aware, to be creative. You've got to be aware not only of the world around you but also of yourself. . .and then actually do something with that knowledge.

This is critical because it links observational skills and the awareness they bring directly to creative ability. Mark described observation as the "first step" to understanding oneself and ones' surroundings, and described how this permits him to use that knowledge to make effective, creative decisions.

Another teacher, Sandra commented on how in language arts, she teaches her students critical thinking skills, saying "the first step is always observation. If we are not careful observers, we have no chance of doing anything else well." This essentially summarizes what these teachers focused on in describing and exemplifying observation in their practices—it allows them a deeper awareness of themselves, their students, and aspects of their classroom and context, to make better teaching moves as they go.

4.3. Patterning

The teachers in this study recognized Patterning as a skill that helped them to understand and assess classroom and school situations and events. These understandings applied broadly to teaching situations—including designing lessons, solutions and practices, and understanding their students' needs and learning trajectory.

Carrie discussed how teachers must see patterns at multiple levels, including patterns in dealing with individual students and parents, patterns in the school day, or even patterns in the school or community:

I can see patterns in student behavior, patterns in work that they turn in, or in the school day. There are patterns between different schools where I've taught in different types of communities. . .and how those kids act in different situations.

As Carrie went on to discuss, finding patterns in students is a useful skill for teachers because whether behavior or work follows a path or suddenly changes, it says something about what is happening. In this way it builds on observation, in taking what teachers observe about students or context and giving meaning to it.

Jack also described the need for patterns in understanding his students and their learning needs. He commented that looking for patterns in teaching is a learned and practiced skill, as he stated:

We need to look for patterns when we analyze our students' work – in their learning and in our instruction. What's the lesson as you analyze the data? What areas were most challenging for your students? In my first year of teaching· · ·I didn't understand how to take a lot of the information and apply it to what was going on in your class.

In this way Jack also uses this skill to better understand the dynamics and subtleties of his students and their learning needs. He describes it as a skill of analysis—there is always data or observations in classrooms, but patterns give a sense of what this information means and how to proceed.

Patterning is a broad skill and does not merely apply to the students, but to curriculum as well. Mia remarked on the importance of patterns in dealing with subject matter, saying:

This is an important skill both personally and professionally. You have to have an understanding of patterns in order to teach students to develop that same understanding in a subject idea—such as when you're looking at numbers on a chart in math. Or looking at patterns within multiples, or at patterns that you might find in different literature pieces.

Here Mia notes that as a teacher, she needs to be able to emphasize the patterns in learning a topic or idea to her students. Her comments reflect the fact that Patterning is inherent across a range of subjects, and understanding how this plays out is useful for helping students see patterns in subject areas.

Julia also emphasized Patterning as a skill that helps her better understand how students interact with ideas and lessons. She stressed how understanding patterns is a skill she had gotten more fluent with over time as a teacher. Like Jack, she identifies patterns via a series of questions she asks herself, as she described it:

As you become more expert you see patterns. When I approach a topic, I start to chunk it out into what would I see as a flow from the viewpoint of an 11 and 12-year old mind. What is it that they know and what's the foundation? What can I find out what they know about it? Where do I go from there? What's the way to make it relevant to their lives? That is a pattern of teaching, and in the structure of the day I find I have to have a pattern to help accommodate attention spans.

Julia's comment points out several interesting things. Most importantly that this is
a developed skill for teachers. Patterning is a skill fine-tuned and learned—not something set or given. Beyond this Patterning helps her work with content as a teacher, and find ways to make it more meaningful for her students in ways that fit their learning trajectory.

Sandra highly identified with the concept of patterns, as she includes the skill of identifying patterns into her teaching of language arts. She considers Patterning to be a critical part of a creative thinking paradigm:

I pretty overtly ask my students to look for patterns. What critical thinking is, marginally it's the acquisition of patterns. So, there's this incredible relationship between critical thinking and how it sparks creative thinking.

Her comments on Patterning speak to its value for critical thinkers and creative people. At the core of all of these comments is the way that Patterning helps teachers see how information relates and what it means—and then work forward based on that. If Observation helps us gather information from the world around us, then Patterning takes that information and connects it in meaningful ways. It emerged in a range of ways in the experiences of these teachers, with a general theme being how noticing patterns—in students, classrooms, schools, subject matter and across contexts—helped them to make more informed, meaningful teaching moves, across a diverse range of teaching practices.

4.4. Abstracting

The teachers in this study found Abstracting to be a significant cognitive skill in their teaching, that frequently helped them to clarify and explain complex ideas and topics to their students. Almost every Abstracting example discussed in the interviews had to do with making subject matter more relatable and coherent for students. Since Abstracting deals with identifying the fundamental essence of a thing, it was valuable to these teachers as a way to clarify ideas and help students find the essential points in a lesson.

Adam described Abstracting in his teaching practice, as an approach to simplifying content yet keeping it accurate and complete, and making it relatable to students:

I try to get rid of anything that's not useful in a lesson···The other day we were talking about how to change a decimal into a fraction. There are many different steps you can take and approaches. But I had to stop and think about how I wanted to explain it in a way that really boiled it down to just three fundamental steps that students can remember to do. So you abstract the bigger idea that you want them to understand – getting rid of anything that might be confusing.

In this way, Abstraction becomes a part of making mathematical concepts clear and honing in to the key concepts and most straightforward approach.

Similarly, Julia remarked that she found Abstracting to be a crucial thinking skill for creating lessons that are both clear and meaningful to students. To do this, she considers the essentials that she needs students to comprehend are, and brings up the important role of analogies as well:

I ask, what are the bare bones that I want these kids to walk away with? What's the essential kernel of truth that's going to best serve them when they leave here? For example, germination is important for them to know, but I'm going to talk about it as sprouting. I might frame it as a seed itself is like a baby, and it's got its lunch and the mother plant wrapped it up and sent it off···to travel through the air, or on the water, or on animal fur. Those kinds of abstractions, they help you file away the rust and get down to the gold···and everybody loves a story.

This idea of making a story out of the content came up in the way that these teachers talked about "Abstracting" the subject matter. This approach helps them find the fundamental concepts and express it in the meaning of a story. Analogies often serve the same purpose, in boiling down to the essentials by connecting a fundamental similarity between seemingly different things. The use of Abstracting actually helps pull out the key idea and make it more clear and concrete. Marie described this in one of her teaching techniques, also through use of stories:

I'm fascinated by the technique of using an object with a story to help make that abstract leap to a more complex idea···I did some teacher education work in South Africa. I wanted to help my own students to understand what happened in Cape Town during apartheid. To drive this idea home, I brought in a piece of sea glass I had found there. That simple piece of glass was what I used to tell the children the story about this neighborhood in Cape Town called District Nine and how this neighborhood got displaced because of what occurred. How one day the bulldozers came in and literally bulldozed these informal houses right into the ocean. That piece of sea glass became an abstract representation of this. One tiny object made the leap to the large concept of the historical perspective of what happened in South Africa. Really effective teachers will use simple objects or stories in order to drive home bigger concepts, to get the curiosity going.

This use of Abstracting was a common teaching technique for Marie, and she described how she was able to tackle complex concepts with her elementary students by using Abstracting to clarify and explain things. She described another such example,

I want students to think about how ideas and information connect. So immediately after a lesson, I'll grab a ball of string and say, "Let's remember what it is we just learned. Okay, we just learned a lesson about the wetlands. We learned is that wetlands help to filter water and my example of that is etc···Who else has an idea that they want to say?" And someone will say, "I know there are migrations going on with the Canadian geese." The string will go to that child and somebody else will say, "Oh what you said there reminds me of this." The string will go on with each connection··· what you see is this circle of people, this web of connection that goes every which way, and ideas are

connected. It demonstrates how a web of knowledge can form just in this group. It's a little piece of string, representing a larger conceptual idea.

Both of Marie's examples reveal, in different ways, just how Abstracting can work to help excellent teachers pick out the core idea they want students to take away, and then make it clear and relatable. This means giving some thought to the essential foundations of an idea or a lesson, and then thinking about actions, approaches or stories that students can grasp.

Mark also underscored abstract thinking as a way to distill and explain information in relevant ways. He noted that this is how he naturally thinks about teaching because it is how he learns and creatively engages for himself, stating, "Abstraction makes life much more interesting. Oftentimes the basis of most art is abstraction, of deciding which details are important, or which details we're going to focus on."

In Mark's teaching practice, as with all of the teachers in this study, abstract thinking is critical for clarifying and explaining the important aspects of an idea. It can actually be a rather difficult task to identify the simplest and clearest point of entry for students. As most of these teachers mentioned, they take time first to try to identify or "abstract out" the core ideas from content or lessons, and then think about ways to connect them to stories, analogies or other relevant approaches that students can grasp. Complex ideas often require a sense of clarity about what is important—and this is where Abstracting played out in how these teachers work with content and make it compelling.

4.5. Embodied thinking

The teachers in this study used embodied thinking to help to make learning active and engaging for students—to connect it with their "felt" knowledge and experiences. Like Abstracting, Embodied Thinking emerged as an approach to dealing with subject matter, and making it more relatable and compelling for students. With this skill however, the focus is on bodily or empathetic thinking, so it often was used to make content "feel" more real in the student experience.

Mark commented on the importance of physical movement to give a physical sense of science ideas to his 7th graders. For example, this might mean acting out the role of a molecule or understanding the path of the sun in the sky through seasonal movements. Embodied thinking helps his students use their bodies for active learning:

> I get kids up and moving and acting things out. When we're learning about the seasons and what causes the seasons – the path of the sun through the sky – we get up and actually trace the path of the sun through the sky with our arms. In the wintertime, it just comes up in the southeast. We trace that arc out, or make it into a little dance move, like "Oh, yeah! It's wintertime!" Whenever possible I'll go through a lot of different exercises where they're actually using their bodies to understand a science idea.

Mark also incorporates the empathetic aspect of this skill by having his students feel what it is like to be another object or organism, through an active, hands-on approach that gives students a physical or "felt" experience of learning:

> I encourage students to interact not only by taking on the persona of an object or an organism, but also in more traditional lab settings to actually get their hands right in there. What does that substance feel like? I want them to be engaged and using their physical senses to grasp knowledge.

Jack emphasizes a kinesthetic approach to the teaching of subject matter, and he reiterated the transdisciplinary notion of empathy as described by Root-Bernstein (2003) as gaining knowledge through bodily experience:

> There are some things that we just know in our body. Incorporating physical movement is a key teaching practice for me. In math, moving on the number line—physically having the kids move up the line. Or in learning the order of the planets from the sun, I'd have the kids get up and form a human solar system···But movement has to be with intention, so again, there is that whole sense of a learning purpose behind it.

Here Jack identifies how he applies embodied thinking to the teaching of content, figuring out what the learning purpose is, and then finding ways that can emerge through physical/bodily experiences in lessons. This was a core theme of embodied thinking for all of the teachers.

In teaching mathematical concepts to middle school students, Adam has found different ways to integrate movement into his lessons. He described how he has his students learn about the number line in a physical sense:

> There's the number line dance that we do. The negative to the left. To remind the students that when you move to the left of the line, you're going to the negative. "Negative to the left, positive to the right, it's the number line dance, I could dance all night." Actually when these students take a test, I'll see them doing hand signals or moving their feet to see where they're going on the number line.

The commonality between Adam's example and the previous ones shows that
subject matter ideas often can be understood in a physical sense. We may see a number line as an abstract idea on a piece of paper. But when we consider what it could look like to a student trying to experience it physically, the number line dance becomes a new way to learn, know and embody content ideas.

Like other teachers, Julia also incorporates embodied thinking methods to make the learning more active and engaging. She tries to keep students active and engaged in the process of "doing science" through the use of physical activity:

> Doing science involves movement, if we're going to talk about momentum, we're going to get a bunch of balls, and we're going to the gym to take data on bouncing balls. Instead of reading a text about momentum we're going to actually do it ourselves. I think when they are doing it more of their thought processes are engaged as opposed to just seeing it or hearing.

Julia also discussed how she wants her kids to "see themselves as scientists." She
sees embodied thinking as a way to get them actively engaged in doing science, as opposed to just receiving science information. Her example also shows the importance of putting yourself in another's shoes to gain knowledge from a real world perspective.

This empathetic side of embodied thinking is just another facet of making knowledge felt. As a language arts teacher, Sandra emphasized empathy as a way to teach ideas and help students feel them. She uses this to engage her students more deeply in a piece of writing and what it conveys:

> One thing that will draw a student into a piece of literature is the character. When we think of it that way, in order to understand a character, we have to empathize with them. Empathy is very akin to holding two conflicting ideas in your mind without judgment. When students empathize with characters, it opens them up to the author's ideas.

As a multi-faceted skill, there are many approaches to embodied thinking in teaching and learning settings. The different ways these teachers employed it across disciplinary content speaks to its utility for getting a "felt" sense of ideas. While the embodied thinking examples from these teachers varied in context, the core idea remained in having students get a tangible or real-world feel or sense of an idea. They started by considering the possible ways to have them empathize or experience ideas from a physical perspective, and progressed from there to make learning more active.

4.6. Modeling

The teachers in this study discussed modeling as a useful creative-teaching skill for making complex ideas relatable. Large or unfamiliar ideas are not always easy to grasp in real-world terms, but models provide cognitively manageable real-world representations that help students work directly with ideas. Across content areas, each of the teachers talked about models as a useful way to represent difficult ideas to learners.

The sciences present natural opportunities to use the skill of modeling in teaching. Mark commented on its importance in his classroom, giving several examples from earth science, such as the following:

> I'll use a roll of toilet paper to model geologic time where each square on the toilet paper represents 10 million years – all the major events in the earth's history. I have students estimate where they'll be on this roll of toilet paper we stretch across the gym. Then we do the math to see where the first mammals come onto the scene, and we find it was only a few sheets of toilet paper ago. They see how all of human history is only the thickness of a piece of toilet paper. Then students have this image in their mind for the rest of the year as we talk about rates of erosion or how mountains develop.

Modeling provides a way for teachers to give students a sense of reality and scale, especially in big ideas. Mark noted this as a reason modeling is important in classrooms, as an approach to help students creatively rethink and understand concepts that are challenging because of size and scale. Modeling helps teachers make big concepts appear more real to students in powerful ways. He gave another example using the solar system:

> It's remarkable how much nothing is out in space – so we make a scale model. Students use an exercise ball as the sun, and estimate how big the planets will be based on this. Based on their initial ideas, they sketch or draw a small model, and show us their first idea of where planets would be. We go outside, I put the sun in the middle, and they lay down their planets where they think they'll go. After we do the math, students are shocked to see that only the first couple of planets would fit in the courtyard, and that Pluto is on the other side of town, actually on the cliffs above town and smaller than a pebble. Getting ideas like that across with modeling is invaluable.

Modeling allows highly skilled teachers like Mark to explain difficult concepts in more tactile or real ways. This happens across contexts and content. In elementary class terms, Mia discussed how she finds ways to do simple yet effective modeling with her students—creatively demonstrating an idea in tactile ways:

> When we're studying polyhedrons, making them with toothpicks and gumdrops. . .we're making little models to demonstrate how they work or look.

In teaching mathematics, Adam also uses modeling. He noted that models are naturally prevalent in mathematics, and so they must be a part of math teaching:

> In solving equations, we draw a scale underneath with the middle of the scale below it, directly underneath the equal sign. It helps students realize it's something that they need to keep balanced. We also talk about real life models of number lines, such as thermometers or in terms of profit, loss and debt. Or when we're calculating perimeter and area,

I actually have students build models. We have a math project where the students build and design their own dream house, and calculate square footage and things like that. Models happen all over math.

Adam's examples (like others) show why modeling is so valuable to teachers. Models happen all the time in the real world, because ideas must be represented in different ways. So they naturally fit into how teachers communicate and have students work with ideas.

Carrie talked about how, in language arts teaching, she used modeling to create a graphic organizer to help relate concepts in writing to her students:

When we do writing, I draw a house. The house has a roof, and then the body of the house is divided into three parts. The kids write the thesis or opening sentence of their paper in the roof and then three details, three reasons, three anything that they are going to write about, in each of the columns. The little details go under them. Graphic organizers are models in language arts, and we use those a lot to help kids represent and make sense of their ideas.

In looking across these examples (a few of many given by these teachers) there is a range of diverse ways and contexts that modeling emerges in teaching. In trying to take something conceptual and relate it in a clear way, models can be physical or conceptual, as drawings, sketches, objects, or mental approaches that take an idea and make it concrete for someone else to understand.

4.7. Play

The teachers in this study all spoke to the value of Play for making learning fun, and developing an attitude toward playing creatively with ideas. Play was seen as something valuable for learning and to life—essential for students to experience in schools. While Play emerges in diverse ways across content, it commonly reflects an attitude toward learning and a way to teach and learn with creative experimental play.

Many of the teachers highlighted the increased importance of Play in an era of high stakes testing, where students need reminders that learning can be fun and informal. Mia noted the importance of play for developing a lighter, creative approach to learning—to give kids a mental break from the current educational climate of testing:

With this pendulum swing towards standardized assessment, we focus so much on curriculum, and I think our students need a chance to have that time to give their brains a break and play. That can lead to a lot of interesting thinking. That's creativity, when you're experimenting, trying new things and discovering.

Her notion of Play is aimed at playing with ideas to ultimately lead to creative thinking. This falls in line with the concept of play as Root-Bernstein (2003) and Mishra et al. (2011) talk about it. As a way to engage with content in playful ways that ultimately brings new understandings.

Jack also spoke to the value of Play in making learning fun for his students. He described how Play in learning had made a tremendous difference in his students' enjoyment of school and learning overall:

Play is one of the most essential pieces of learning. Learning is playing around with ideas, but we are purposeful in that play. In one of the pieces one of my students wrote, his favorite thing about third grade was making up songs for learning. "I had so much fun, my teacher makes learning fun." And my students met their learning goals that way. That speaks volumes — that you can learn new and exciting things and have a great time. It's an attitude. I can read countless examples from students that say "I was having so much fun that I didn't even realize we were learning."

This speaks to the fact that across examples, play manifested as an attitude and approach to learning connected with fun. Julia remarked that play is essential to childhood and that young people naturally seek out play. This makes the connection to learning fun and organic, and she commented, "Kids, they are at that stage where they want to get up, to move and Play, so I try to make sure they get time for that." Her recognition of Play as a natural stage of childhood creativity is similar to Vygotsky's (1978) notion of imaginative play as a developmental phase for creative development.

Mark also reflected on the fact that Play is an essential component of childhood and of learning and thinking in ways that are fun and creative. Like other teachers here, he lamented that the structure of schools separates Play from learning, and he sees it as his responsibility to share that sense of playful learning with his students:

This is an area I feel pretty passionately about, the loss of play from many kids' lives. As a teacher, I feel like it is partly my responsibility to let kids play···Oftentimes it leads to a state of mind where creativity can happen more readily, and also can be a breeding ground for ideas.

Mark emphasizes how school structure can make this playful attitude difficult for students and teachers. This need for Play, contrasted with the difficulty of having it in traditional school environments, arose in several teachers' comments, as Mark put it:

I feel like education, unfortunately throughout the years, hasn't been all that fun. Kids get all excited about going to kindergarten and they're just stoked to get there. By the time they get to me in seventh grade, the kids are generally disillusioned with education and it's just not fun anymore. I think it should be. I think it has to be. Because we're all

kids. The whole idea of using kindergarten to bait kids in and then slam the door behind and stick it to them for 12 more years, I think is morally reprehensible.

While Mark is an advocate of Play in learning, he emphasized that it requires some classroom structure. Within this structure, however, there is freedom to try out new things and ideas and to learn in ways that are fun and creative. Most of the teachers also spoke of building the conditions for Play in the classroom as a way set the stage for creativity because as Mark stated, it is important "see what happens when you play with ideas." Throughout the teachers' comments in interviews, it was clear that the skill of Play was significant—reflected in an attitude for teaching where learning should be fun and playful, and that students should get to experience informal creative play with ideas.

4.8. Synthesizing

As noted, synthesizing was not directly investigated as an interview question, but it was still looked at as an emergent theme in analysis. As a broad skill, it involves putting together the previous skills or subject matter into a fluid synthesis of knowledge and creative ideas, something that emerged in the entirety of what was said in the interview rather than in response to a specific question. It was clear that synthesis happens in the way that these teachers operate, in putting together their ideas and practices. Synthesis involves the totality of who these teachers are. It showed up in ways that they described the connectedness between their own selves, their teaching practices, and their creativity.

This is best reflected in lessons that connect ideas across domains and promote awareness of the wider world, bringing their own selves into what occurs in the classroom. This form of synthesis is eloquently expressed by Julia. She views teaching as a diverse and multi-disciplinary domain–one that allows creativity to come through from the personality into the classroom:

> I have to be in a job where I can exercise some creativity. I knew when I got my degree in biology that I didn't want to be sitting under fluorescent lights, filling Petri dishes and analyzing them··· I must have the ability to grab multiple colors and multiple palettes and multiple media and weave together what I see as a vital, vibrant day and lessons for my students, for myself.

This form of synthesis can also be seen in a comment by Marie, who described her own creative interests and her love for teaching saying, "I think my whole approach to teaching is in an integrated way, so that even if I'm designing lesson or something for my students, I have all of my own creative inspirations going."

This synthesized approach is instantiated in their teaching practices. Such teachers are connected and dedicated to their students and to understanding their emotional, psychological, and learning-oriented needs. They are committed in their teaching practices to developing excitement for specific subject matter. Another teacher in this study, Jack, also described this in saying, "you can take whatever gifts or interests or expertise that you bring to the class, because each person has some unique or creative things about them that they can potentially bring."

This extends to an overall passion for learning and making connections between different topics across contexts and through thinking skills. It respects the fact that "we are all whole-brain thinkers··· We sense and make sense of the world in multiple, concurrent, and inter-sensory or 'cross-modal' ways··· This is synthetic knowing" (Root-Bernstein & Root-Bernstein, 1999; p. 306). Such "synthetic knowing" helps great teachers and transdisciplinary thinkers cross-pollinate ideas and think across domains and contexts, combining them into a rich, creative teaching practice.

5. Conclusions and implications

This study was an exploratory, descriptive investigation of transdisciplinary skills in the thinking and teaching practices of highly accomplished and creative teachers. As in any research, this study has limitations. Particularly in a relatively new area of research, the work is exploratory and takes a step toward basic understanding of whether and how such skills apply for these teachers. One obvious limitation is that, in being asked about these skills, the participants might innately speak to these in affirmative ways—and one might note that it would be already expected therefore to see them arise in discussion. I attempted to control for this to some extent by asking for specific or detailed examples of how such skills were used in their practice. So rather than merely replying to affirm them, teachers were prompted for specific examples, details or discussion of how the skills are actually instantiated in their practice.

Another potential limitation lies in the open-ended and exploratory nature of the study itself. I confined my interviewees to a small sample of National Teacher of the Year winners and finalists, so while they come from quite a variety of teaching contexts, they are not necessarily representative of an overall population of teachers. While this does inhibit generalizability, statistical generalizability was not a goal of this study. This framework of transdisciplinary thinking skills has already been established as important for the work of creative and successful practitioners and thinkers in other disciplines (Root-Bernstein, 1996; Root-Bernstein & Root-Bernstein, 1999). So this study builds on that by attempting to establish and explore if and how these skills apply in a group of exceptional teachers. A limitation that arises in the nature of the study is that the teachers' eclecticism in ways of using the skills, and in their contexts, made it difficult to identify a strong pattern of use.

5.1. General findings/patterns

The ability of the teachers to respond in ways that went beyond simple affirmative answers, to offer specific examples of each skill in their practice, suggests that transdisciplinary thinking does play out as a framework for excellent creative teachers. But there was much diversity and range in how each skill emerged in their different classrooms and practices. That said, within the diversity, there were some general themes or a loose pattern of connection.

Generally speaking, *Observation* was noted for developing an awareness of classroom dynamics, students, and learning progress. *Patterning* was discussed as valuable for understanding trends in classroom and school situations and events. *Abstracting* was considered important as a teaching approach to clarify and explain complex ideas in a clearer or simpler form. *Embodied thinking* was thought to be integral in making learning active and engaging. *Modeling* was noted as a useful tool to make learning more real and tangible to students. *Play* was seen as crucial for making learning fun and developing a sense of curiosity about ideas and learning. *Synthesizing* involved seeing the process of teaching through the totality of their identity and how they use the previous skills. Of course, within these broad generalities of use there was great variability in how the teachers use these skills—as must be evident in their quotes and examples.

Beyond these common approaches and diverse examples, a key finding was in the rich qualitative evidence of these transdisciplinary thinking skills as important for excellent teaching. Transdisciplinary thinking was relevant within the teachers' creative classroom practices, which suggests a basis for further research in this area. Ideally further work would explore these skills in more depth and across more teaching contexts, to see how they emerge, and identify stronger commonalities (or perhaps show even more range of uses).

5.2. Implications for practice and future research

Given these findings and with future research and work on this topic, there may be implications for policy makers and teacher preparation programs. This could open possibilities for integrating them into curriculum and subject matter, such as the exemplar teachers from this study already do. Teacher education courses might consider some focus on transdisciplinary skills by relating them to creative, effective classroom practices and critical thinking for education.

This study is an essential, but early and exploratory, step into investigating a specific framework of thinking skills within the pedagogical approaches of exemplar teachers. Teachers are at the front lines of how students develop as thinkers and learners, so understanding how excellent teachers think and work is instructive and important.

As noted previously, the exploratory nature of this study means that there are some limitations on the findings, leaving much to be studied, understood and teased apart in the questions and considerations that arise from this work. This suggests a need for more work in this area—work that more clearly delineates certain factors and variables and explores the specifics of transdisciplinary thinking in classrooms. Such additional work would allow more specificity of research questions, and more depth in answering the questions. Implications for future research from this study are extensive. Future work in this area should suggest stronger and more definitive hypotheses to be studied. For example, it may be that the best teachers use the widest range of tools in an explicit manner in their teaching, while teachers that struggle use fewer or none of the tools explicitly. Existing research has already noted the tight connection between creative and effective teaching (Anderson, 2002; Bain, 2004; Bleedron, 2003, 2005; Chambers, 1973; Cropley, 2003, 1967; Davidovitch & Milgram, 2006; Fasko, 2000–01; Newcomb et al., 1993; Renzulli, 1992; Torrance, 1981, 1995), so it may be that explicit use of transdisciplinary skills connect to what the field knows as "effective" teaching. A future iteration of research could explore such an hypothesis, by investigating the contrast between exceptional teachers and transdisciplinary thinking, and the work and practices of other teachers, or even teachers who have struggled to perform.

Additional research is also needed to explore the varied yet specific ways that the tools could be used in the classroom. There may be a call for work that distinguishes between how a teacher uses each tool to be a stronger performing teacher and whether (and how) such teachers teach the tool to students. If, as Root-Bernstein and Root-Bernstein (1999), Root-Bernstein and Pathak (2016) and Mishra et al. (2011) suggest these are essential tools for thinking and creativity, then we might expect the very best teachers to do both, but this is an area which this study stops short of, yet further exploration could illuminate. Lastly, it would be important to explore and understand how such excellent teachers function in practice by either using or not using conventional textbooks or curriculum, or perhaps how they navigate between the demands of an increasingly structured and standards-based educational policy and their application of tools-infused pedagogy. It would be important to understand why or why aren't such teachers deviating from or strongly augmenting standard, given teaching materials and methods in the textbooks?

It seems clear that the need for work that extends beyond this early exploratory study, to go beyond this initial evidence (through multiple and specific, contextual examples) of the transdisciplinary thinking skills in the practices and beliefs of excellent teachers. The implications for possible future lines of research are multi-faceted and each demand more in-depth and specific inquiry. These are skills that have been associated with accomplished creative thinkers in the sciences and other disciplines (Root-Bernstein, 1996; Root-Bernstein & Root-Bernstein, 1999). This study brings them into the realm of teaching. This suggests how the fluid use of transdisciplinary skills is significant to the practices of creative teachers, and offers insights into future research in this area.

Appendix A. Semi-structured Interview Protocol

Open-ended Warm-up Questions

1. Tell me a little about where you teach. *(Possible probe: Tell me about your classroom, setting, students)*
2. What inspired your motivation to teach? *(Possible probe: Did you start out in teaching or a different field?)*
3. Tell me what it's like to be a teacher today. *(Possible probe: What are some of the challenges and rewards of this profession today)*

Trans-disciplinary Creativity and Thinking Skills

Preface: I have some questions about specific types of thinking skills related to creative thinking or problem solving. I will briefly define and explain each skill before asking some questions about it and how it relates to your thinking, teaching, or creative activities. Separate sets of definition/examples of *trans*-disciplinary skills will summarize each skill separately before the question (Sidenote: These were drawn from the same definitions/examples provided earlier in the Seven Transdisciplinary Skills section of this article).

Perceiving/Observing

4. Do you consider keen *Observation or Perception*, as being an important mental skill in your teaching? Can you tell me about some examples? Are there any other ways, outside of teaching, that you consider observation/perception to be a useful mental skill? *(Possible probe: Do some of your creative interests or activities outside of teaching require the skill of careful observation?)*

Patterning

5. Do you ever use *Patterning* (recognizing and creating patterns) as a mental skill in your teaching? Can you tell me about some examples? Are there any other ways, outside of teaching, that you see Patterning as a useful mental skill? *(Possible probe: Do find that you recognize and create patterns in some of your creative interests or activities outside of teaching?)*

Abstracting

6. Do you ever use the skill of Abstraction (concentrating on one key aspect of something) in your teaching? Can you tell me about some examples? Are there any other ways, outside of teaching, that you consider Abstraction to be a useful mental skill? *(Possible probe: In some of your creative interests or activities outside of teaching, do you ever think or work with Abstraction?)*

Embodied Thinking

6. Do you feel that Embodied Thinking, as a skill, has been something you have used in your teaching? Can you tell me about some examples? Are there any other ways, outside of teaching, that you consider Embodied Thinking to be a useful mental skill? *(Possible probe: Do you ever find that your creative thinking in general, has physical aspects or is connected to physical senses?)*

Modeling

7. Do you ever find that Modeling is a skill that you use in your teaching practice? (This could include sketches, diagrams, drawings, structures or any formal/informal physical structures that you use.) Can you tell me about some examples? Are there any other ways, outside of teaching, that you consider Modeling to be a useful mental skill? *(Possible probe: Do you ever use models of any kind in your creative projects or interests outside of teaching?)*

Play

9. Do you see any value in the idea of "Play" in your teaching practice (not just as a playground activity, but in giving students the chance to "play around" with ideas or concepts)? Can you tell me about some examples? Are there any other ways, outside of teaching, that you have found the concept of Play to be useful? *(Possible probe: Can you tell me about any creative activities or interests outside of teaching where you've come up with something by just "playing around" with ideas?)*

Appendix B. Creativity Notes/Evidence from Finalist Applications

Evidence for Creative/Effective Teaching

> Alex Kajitani
> California 2009 Teacher of the Year
> 2009 National Teacher of the Year Finalist

- "My Making Math Cool conference workshop offers educators creative ways to make math more accessible"
- My contribution to the Hip-Hop Association of America's efforts to help teachers use music to connect with students can be seen in their *Hip-Hop Education Guidebook.*
- Created the "Rappin' Mathematician" CDs and workbook
  • "I started rapping about all of the math concepts I was teaching, letting the wacky humor flow (realizing that cool really was just being myself, as we often tell our students). Unlike the songs on the radio, I used language that was positive, and included messages not only about math, but about believing in oneself, making good decisions, and the importance of school. The songs quickly became legendary throughout the school and district, and, encouraged by my fellow teachers, I recorded them onto an album (and the next year another) so other teachers could use them in their classroom."
- Profiled by an educational author:
  • "some of the most creative work I have ever seen a teacher do."
  • "has not dumbed-down his curriculum. Instead, he has extracted the content's purest essence and repackaged it in chunks palatable, relevant, and motivational for his students."
- School superintendant: "Mr. Kajitani is best known around Mission Middle School, the school district, the city, the county, and even nationwide as *The Rappin' Mathematician*. This creative teacher connects mathematics to the students' daily lives via math songs set to hip-hop music."

> **Susan Elliot**
> **Colorado 2009 Teacher of the Year**
> **2009 National Teacher of the Year Finalist**

- "we must make cross-curricular connections, use integrated technology, and protect our instructional time."
- "Because my students are at the center of instruction and lessons are creatively designed to meet student needs, benchmarks are never taught the same way twice. I am always learning something new with my students and this generates tremendous energy and enthusiasm."
- Director of Special Education: "sincere and passionate colleague who brings an infectious level of enthusiasm and inspiration"
- From letter of recommendation: "Her creativity and energy make her absolutely one of a kind."
- "My lessons and class projects are purposely loaded to cover the essentials of a guaranteed and viable curriculum emphasizing cross-curricular connections."
- "An essential question requires students to research, make cross-curricular connections, think critically and synthesize information."
- My students . . .. "They reflected upon their skills at the end of our unit and expressed pride in their development. In sum, my students were actively engaged in learning. They understood the targets and their creativity demonstrated ownership for learning. They were supported in their interdisciplinary learning, made outside applications, and were fully aware of their skill development and demonstrated progress."

> **Anthony Mullen**
> **Connecticut 2009 Teacher of the Year**
> **2009 National Teacher of the Year Finalist**

- A teacher must project passion in the classroom because this powerful emotion sparks the learning process in children and motivates them to remember key concepts and ideas. Students can feel the energy, enthusiasm, and creativity radiating from a teacher.
- "teaching is an avocation and not a vocation. The professional teacher must transcend existing models of educational theory and philosophy and become an artist and a creator. A teacher must perform his work as though it is art because teachers, like all artists, create. Teachers are entrusted with the imperative task of creating intelligent, ethical, and productive young adults"
- "including forensics, electronics, English, carpentry and horticulture. His lessons are innovative and stimulating."

> **Cynthia Cole Rigsby**
> **North Carolina 2009 Teacher of the Year**

2009 National Teacher of the Year Finalist

- We must work to find an accountability model that nurtures teacher creativity—and lessens the stress that educators and students experience while at the same time reshaping our schools to meet the vision of the 21st century.
- Terry Sanford Award for Creativity and Innovation in Teaching/Finalist − *2005*
- "creativity and risk-taking may be ideas of the past if we don't reform our accountability programs."
- "I am so passionate about strengthening our profession that there are times I wake in the night with an idea, and go into manic mode trying to implement it"
- "she inspires something in the soul of her students which draws them out to connect with their own stories of life. I think of no more compelling reason to write. Cindi demonstrates those life connections so vibrantly that it opens the door to writing so wide that others are swept in."
- "Over the past three years, our staff has had the pleasure of taking literacy training with her. As a direct result of our first workshop with Cindi, our physical education teacher was inspired to write down some of his own stories about his love of sports. He connected so deeply to that process that he is writing poetry this year."
- "she is a reading specialist whose professional task is to remediate high needs students, her work cuts across many academic disciplines."

Yung Bui-Kincer
Alabama 2010 Teacher of the Year

- Elementary/secondary science teacher who actively implements lesson plans designed to be "creative" and "fun"
- Provides several different examples of her science lesson plans in her online portfolio, all of which incorporate creative or artistic elements, such as drawing, creating physical models, writing stories about topical science ideas, or creating other artifacts related to the science being taught.
- Teacher specifically notes words such as "creative" and "artistic" skills when describing lesson plans, and notes the importance of learning being stimulating, motivating, hands-on and fun.
- Portfolio demonstrating some lesson plan examples, all of which are "creative":
- https://college.livetext.com/doc/135095?print=1

Megan Marie Allen
2010 National Teacher of the Year Finalist
Florida 2010 Teacher of the Year

- "I am an inventor, developing creative ways to engage every learner, helping them focus on their education and providing an escape from the daily struggles of poverty."
- "I am a lover of books and words, one who creates a rich, literate environment full of cozy book nooks, stories, and fantasies that inspire students to become avid readers. I am an actor of adventures, setting sheet-sails high as we travel through 20,000 Leagues Under the Sea, creating a tissue paper and fan campfire to make campfire tales come alive, or making a living input/output machine out of a refrigerator box so my students will be able to create their own input/output table."
- "Ralph Waldo Emerson once wrote: Insist on yourself; never imitate.Ï'm far from normal—my students even call me weird! But I love to add my glitz of creativity to make learning an active and engaging experience for my learners. As a NBCT, I reflect daily to make sure I stay creative.
- I love to use costumes; I've dressed as a pirate for a writing craft lesson, I've had students work in cooperative groups to design a recycled outfit for a recycled fashion show···I am a very cheesy song writer. My repertoire includes a parody to Beyonce's Put a Ring on It written for Florida's writing assessment. My teammates and I dressed as Beyonce to perform, If you Elaborate, We're Going to Put a 6 on It,6 being the highest score one can earn. I love to engage students with song, composing songs like A Grabber Lead for writing, sung to the tune of the Jackson 5's "I Want You Back.Ďancing includes the rounding dance or comma dance for math. My class's new personal favorite is the Drop the Decimal Like It's Hot dance for adding and subtracting decimals! I add my positive energy in little ways such as these to foster You Back.Ďancing includes the rounding dance or comma dance for math. My class's new personal favorite is the "Drop the Decimal Like It's Hot" dance for adding and subtracting decimals!"
- "Collaboration and combined creativity multiplies exponentially, and we can learn so much from each other's experiences and ideas, I have worked on cross-grade projects from solar cooking to probability fairs. −− . . .providing our students with a minds-on, hilarious review of writer's craft. Across the county I have buddy classrooms composed of teachers I've worked with in the past. Our students mail writing samples, writing responses, and book recommendations to each other."

Sarah Brown Wesseling
2010 National Teacher of the Year
Iowa 2010 State Teacher of the Year

- My elective writing class composes multi-genre papers and creates podcasts to practice the research process before writing a more traditional piece. My Myths and Legends class creates a superhero for today using all the concepts we've studied throughout the course. Using a mock Facebook page and nominating the character for Hero of the Year,ëach student gives an acceptance speech as that hero to receive his reward. My AP students go beyond the traditional curriculum of literary analysis and constantly work to apply literary theory in order to become literary critics. They create storyboards for a film trailer which must convince their audience of a particular "reading of a film they've studied in seminar groups. They participate in the Grant Proposal Project and culminate their year with a standards-based final portfolio and exit interview."
- "students are more engaged when they see their own passions, questions, and motivations reflected in their work. In each of my classes, you would see learners constructing knowledge through rigorous and relevant inquiry experiences. Students in New Start English might be creating their utopian school by generating surveys, composing a learner's Bill of Rights, rewriting the course descriptions, and composing a school song to match their school's mission. Sophomores read nonfiction books in literature circles, record their discussions and create Public Service Announcements that educate about an issue from their reading."
- "Creating innovative learning experiences provides important context and motivation."
- "I often do guest lectures at Iowa State University in a Technology and Instruction course for pre-service teachers. Each time, I begin and end with a challenge to the students: You're going to be teaching in the 21 st Century, but are you going to be a 21 st Century teacher?Ṁost of them quickly look to their laptops, BlackBerries or Pods, certainly all indicators of being a 21 st Century teacher. I then demonstrate how their favorite technologies can be tools towards student achievement, but should never be the culmination of a creative, authentic learning experience. . . this philosophy means creating a web of rigorous content, real-world experience, and inquiry-based experiences around the learner.

Michael Geisen
2008 National Teacher of the Year
Oregon 2008 Teacher of the Year

- from toty article – Unifying teaching and learning through creativity, collegiality, community interests as well as individual, and just a bit of what he calls craziness, defines Michael Geisen's approach to working with, in his words, "my fellow human beings. . .my students."
- "In my teaching I strive to bring together creativity and science, to unite my students into a community, and to help each person in this community connect with the big ideas of science."
- "Some of my lessons are based on ideas that colleagues or students have shared with me, but many of them I simply dream up while in the shower or while driving to work. However they originate, I try to put a bit of myself, a bit of Prineville, and a good dose of humor and creativity into each activity, project or assignment."
- "when students are interested, they start to ask real questions. And when they ask questions, theyre on their way to becoming great scientists and learners. This enthusiasm becomes contagious. . .even the non-mathematical/non-scientific kids get into it when creativity and science fuse together."
- "developed a capstone project that gave students a chance to apply their new knowledge about energy and electricity into an Electric Creation of their own making. "
- found another way to help students integrate science and creativity into a service project that is both beautiful and educational: we have shrunk the geographic enormity of Oregon into a 150′ long courtyard outside of the science wing. The courtyard has long been considered the bane of aesthetics at the middle school. . .so the science teachers and students decided to take matters into our own hands and create an outdoor learning laboratory that was both beautiful and a scientifically accurate model of the native vegetation zones from the Oregon coast to the high desert. . .we transformed the courtyard into a place of beauty and pride, complete with trees, shrubs, native grasses, walkways, benches, topography and a drip irrigation system.
- Philosophy of teaching includes unifying science, creativity and aesthetics, and to unite students into a community that connects with the big ideas of science.

Robert Stephenson
Michigan 2010 Teacher of the Year

- "I strive every day to be authentic, caring, creative. . ."
- "I believe that all learners require hands-on opportunities to understand the world around them, and honor the Confucian saying, I hear and I forget. I see and I remember. I do and I understand.Ẅith that in mind, curriculum is presented with unique activities that encourage students to experiment, manipulate, observe, hypothesize, and synthesize their learning.
- "At any given moment students may build series and parallel circuits, videotape commercials, dissect owl pellets, write travel brochures, design Power Point slide shows, make colloids and polymers, study chromatography, play math games, act out plays, explore cultural artifacts, gather Internet research and post their learning, write songs, or read peer-authored books."

- As one who loves to learn and teach, I would advocate for the *preservation of innovation and creativity in the classroom*. One of the things that sets the United States apart from other countries is our innovation and creativity, which is fostered by the dedicated educators within our schools.
- In the 21′ century, it is imperative that we continue to honor this ideal within the classroom in order to meet the future demands for originality in the work force. Innovative classroom experiences foster higher student achievement. Students become flexible, motivated, independent thinkers who are capable of reasoning and solving unfamiliar problems.
- Encouraging and promoting creativity in the classroom is what educators have unknowingly done for years, but now is the time to reflect and honor how it is done and pledge that we will not squeeze it out in exchange for teaching designed only to satisfy standardized assessments. Higher order thinking skills result from engaging methods of instruction that exploit student curiosity and offer relevant open-ended challenges.

Kelly Kovacic
California 2010 Teacher of the Year

- "I believe students learn best when they analyze historic and current events and then form their own opinions through critical thinking. For instance, when teaching governmental policy towards Native American tribes, I have my students examine sources (e.g., documents, journals, music, dances, etc.) from the perspectives of the federal government, the settlers, and the Native Americans. I continue to bring the content back to the issue of humanity and the importance of mutual understanding and respect."
- "Teaching history is about storytelling. It is about making the past come alive. Being a student in my classroom . . .is an opportunity to enter a world of fascinating individuals, amazing examples of strength and courage, scandalous corruption and treason, war, peace, and everything in between. It is a chance to learn not only about the victors but also the victims; to learn not only about success but also disaster. A student in my classroom is provided a direct connection to our past."
- "Her close attention to detail, her innovative lesson planning, her belief in individualizing instruction, and her sensitivity is evident in the. . .work her students do. One of the projects she assigns her students at the end of the AP U.S. History class is The Decades Project. Students select a decade and depict it visually, or in written or oral fashion.

Lewis Chappelear
California 2008 Teacher of the Year

- "The only way I can explain the profession to the non-teachers in my life is by using the analogy that it is like putting on a different Broadway show everyday — a seven and one-half hour show at that. This is not just a show to watch, but one of interactions with the audience members who challenge, inspire, and encourage. It is a careful blend of improvisation and scripting, constantly morphing itself to fit the moment and never failing to surprise."
- "My classroom is full of everyday stories like these that describe my philosophy of teaching. One day is never like the rest. . . . When you walk into my classroom, it looks like Santa's toyshop in the North Pole, with groups of students working on different projects all over the place. There are natural wood butcher-block workstations carefully scattered throughout the room with beautiful dark red rolling office chairs at each table. At the front of the room is a large robot competition playing field that is rarely quiet. There are robots, computers, electrical training centers, large printers, and mechanical doodads in every nook and cranny."
- Teaches engineering — incorporates robotics, sound editing software in a musical context, 3-d modeling software, etc — all to connect with students geared toward more "creativity".

June Teisan
Michigan 2008 Teacher of the Year

- ". . .to encourage a sense of wonder in the world around them, to invite students to tap into their talents and express their unique personalities in innovative ways is a source of joy for me."
- "Effective science instruction at the middle school level has a certain flavor of managed chaos, and your heart's gotta be in it as you 'go with the flow.' I love the off-kilter antics and mercurial personality quirks of my little darlings, and I think my students pick up on that sentiment."
- "What could be to some a ho-hum microbiology unit is transformed into a food safety investigation, complete with several labs for my concrete-operational thinkers, short video clips for the visual learners, and in-depth sessions exploring websites like a food safety tutorial on the web."
- Coordinating these types of experiences (students may choose from a range of options to show their grasp of content — creating a brochure about proper hand washing or evaluating the safety of their home kitchen) pave multiple avenues for students to make sense of core curriculum. I make up goofy songs and sing them off-key because students will stop what theyre doing long enough to listen to the directions I needed to clarify (to the tune of Old MacDonald or Blue's Clues).
- "Albert Einstein could have been exhorting us today with his comment, Imagination is more important than knowledge. For knowledge is limited to all we now know and understand, while imagination embraces the entire world, and all there

ever will be to know and understand. Educators for the new millennium face multiple challenges to public education armed with knowledge and ready to power the imagination of students!"
- "RocketMath!, funded by a grant from the local natural gas company, students will do the work of aeronautical engineers as they test straw rockets, calculate trajectories, and construct and launch their own solid-fuel rockets."
- "Building educational experiences that foster student creativity, innovation, cooperation, ingenuity, vision and resource-fulness. . all traits vital for success in our global community!"

Thomas Smiegal
North Carolina 2008 Teacher of the Year

- "I worked to develop a curriculum that would make Earth Science relevant to our students and developed objectives that could be taught in a way that would allow creativity and rigor."
- "My style is about making my lesson invigorating. Worksheets out of ancient filing cabinets do not teach students. Students need opportunities to discover who they are as thinkers and learners. They like to be challenged with real-life scenarios and develop solutions to problems"
- "My philosophy is about empowering my students by giving them the opportunity to be leaders in the classroom, school and community. This philosophy encourages me to be creative everyday with my lessons, whether in Teen Leadership or Earth Science. Being creative is not just thinking outside the box. It is about thinking outside of the room that the box is in."
- "After receiving the NASSP grant. . .(it) allowed me to be flexible in presenting creative ideas to help our ninth graders reach success."

Andrea Peterson
Washington 2007 Teacher of the Year

- "Music is an amazing opportunity for children to experience pattern development. Melodic and rhythmic patterns are internalized actually creating connective pathways in a student's brain. These pathways transfer to other subjects, enabling our children to achieve more complex patterns in math, reading and other subjects."
- "It is truly exciting to see how my music teaching can transfer back to other classrooms."
- "Because I compose many of the musicals my students perform, they see me struggle through the creative process. I share my frustrations, creative road blocks and bursts of creative energy with my students, inspiring them to achieve their own goals of excellence."
- "As a music specialist, it is my responsibility to teach my students, not only music, but reading, writing, math, social studies, science and anything else I can find a way to meld into the music curriculum. This needs to be the attitude of every teacher, every parent and every community."
- "Through lesson studies done in my school, I have had the opportunity to teach symmetry, geometrical sense, inference and prediction. Some of these lessons have had nothing to do with music, but have had everything to do with teaching in a way that's best for kids··· State test scores in all areas have steadily increased since instituting Lesson Study."
- "Teaching is an amazingly complex combination of science and art. Scientifically, teachers must know how to teach to students individual learning styles, breaking down the components of knowledge and skill into attainable pieces. Artistically, teachers must be able to inspire their students to excellence, showing them a world that is bigger than their own."

Tamra Tiong
New Mexico 2007 Teacher of the Year

- From school principal – "At any time you could observe Ms. Tiong differentiating lessons to match the wide range of needs of her students. She uniquely incorporated creativity and ingenuity to match the students must learns with music, songs, drawing, sketching and movement."
- "My philosophy of education involves recognizing, valuing, and addressing the needs of students of various cultural, linguistic, and socio-economic backgrounds; of learning styles, abilities and preferences; of multiple intelligences, interests, personalities, and family types. I use much movement, music, art and compassion to achieve this."
- "They (students) need their classroom experiences to be interesting, meaningful, and relevant so that their brains say, Oh, I see! instead of "So what?" They need teachers who will take them beyond mere recall of facts, providing opportunities for critical thinking, analyzing, synthesizing, comparing, evaluating, and applying. They need to learn how to have conversations with texts, how to agree or disagree with an author or character, how to acknowledge confusion and forge through it, and, ultimately, how to determine their own truths."
- ". . .my goal as a teacher is to do everything I can to keep this sense of wonder alive, to encourage all children to question and learn, explore with all their senses, to revel in both the complex and the simple things of the world, to celebrate their uniqueness."

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