Personality and Individual Differences 116 (2017) 410–416

Contents lists available at ScienceDirect

Personality and Individual Differences

journal homepage: www.elsevier.com/locate/paid

Review

Learning styles theory fails to explain learning and achievement: Recommendations for alternative approaches

Donggun An [a,*], Martha Carr [b]

[a] Department of Education, Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul 08826, Republic of Korea
[b] Department of Educational Psychology, University of Georgia, 110 Carlton St., Athens, GA 30602, United States

ARTICLE INFO

Article history:
Received 12 February 2016
Received in revised form 21 April 2017
Accepted 22 April 2017
Available online 27 April 2017

Keywords:
Learning styles
Individual differences
Achievement
Cognition
Expertise

ABSTRACT

The purpose of this paper is to propose a multiple approaches to explaining and predicting individual differences in learning. First, this article briefly reviews critical problems with learning styles. Three major concepts are discussed: lack of a clear, explanatory framework, problems of measurement, and a failure to link learning styles to achievement. Next, this paper presents several alternative approaches to learning styles that do a better job of explaining how learning styles might predict achievement. Alternatives to learning styles include individual differences in verbal and visual skills, expertise and domain knowledge, self-regulation and inhibition, and perfectionism. For expertise and domain knowledge, knowledge representation and fluency are specifically discussed. It is recommended that the new approach that focuses on individual differences in learning be used by teachers.

The term of learning styles has been used in education to explain individual differences in the ways students approach learning (Kozhevnikov, 2007). It is assumed that instruction based in learning styles theory produces better achievement (Sternberg, Grigorenko, & Zhang, 2008). Despite considerable interest in learning styles there are a number of critical problems with the theory and the activities developed for schools based on the theory (Coffield, Moseley, Hall, & Ecclestone, 2004; Henson & Hwang, 2002; Joniak & Isaksen, 1988; Price, 2004). The problems include the lack of solid explanatory theory, a lack of research supporting the theory, poor reliability and validity of constructs, and a failure to link learning styles-based instruction to achievement. The goal of this paper is to present a better way to understand and respond to individual differences teachers see in their students. In this article, we will briefly review the problems with learning styles and then present several alternative approaches to explaining individual differences in learning. These approaches will be based in research in educational psychology and cognition and will explain individual differences in learning and achievement in terms of differences in expertise, development and personality.

1. A brief critique of learning styles

Learning styles theories have a number of significant problems that make them useless for explaining learning or achievement. Specifically, the theories describe and categorize behaviors, but fail to explain the developmental processes and causal mechanisms that underlie these behaviors. Another problem is that learning style measures often use rank ordering which forces individuals to rank one style higher or lower than another, creating differences that are not evident in measures that separately assess the different styles. Furthermore, many of the measures of learning styles lack reliability and validity. Finally, the work on learning styles assumes that gearing instruction to learning styles produces better achievement, but the research either does not exist or does not support that assumption (e.g., Massa & Mayer, 2006; McKay, 1999; Price, 2004).

1.1. Lack of clear, explanatory framework

One of the critical problems with learning styles theory is the lack of clear, explanatory framework. Even learning styles researchers have acknowledged this limitation. Sternberg (2001) stated that it is difficult for learning styles researchers to interact with each other as well as with other researchers in psychology because each learning styles theory has its own different conceptual framework. Sternberg also pointed out that learning styles researchers do not consider cognition or personality theories or research even though many of the learning styles include constructs from these theories. The lack of explanatory framework contributes to the following specific problems: a failure to explain the underlying mechanisms, a blend of borrowed constructs or measures, and an ignorance of the research contradicting learning styles theories.

* Corresponding author at: Department of Education, Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul 08826, Republic of Korea.
E-mail address: bonnet413@naver.com (D. An).

http://dx.doi.org/10.1016/j.paid.2017.04.050
0191-8869/

1.1.1. Failure to explain the underlying mechanisms

A good learning styles theory should explain the common processes and causal mechanisms that underlie the learning styles described in the theory. Instead, learning styles theories tend to consist of lists of preferences with no explanation as to the underlying cognitive, motivational and personality mechanisms that underlie the preferences. Nor is there any theoretical or empirical rationale for including a preference on the list. For example, Gregorc (1982, 1985) has created two learning style dimensions (concrete/abstract and sequential/random) each with its own attributes. Concrete processors enjoy processing through physical expression, and abstract people desire a more figurative expression. Random learners are disorganized in their learning while sequential learners are systematic. No explanation is given as to the developmental processes that determine whether an individual becomes one type of learner and not another or the relationship between the two dimensions. Individuals simply have these characteristics and there is no explanation about what produces these differences. As another example, Riding and Cheema (1991) described students as being either holist or analytic. No explanation is given as to the cognitive processing that would result in a student being one or the other. Instead, these categories are justified through differences in behavior with holists being students who like seeing context from an overall perspective, whereas analytics refer to people who enjoy seeing a situation as a group of parts. Theory and research must explain why students have these characteristics. Simply describing a behavior is not an explanation.

1.1.2. A blend of borrowed constructs or measures

Often learning styles theories are a blend of borrowed constructs or measures from other, better-developed theories. Several researchers include styles that reflect differences in personality or self-regulatory skills. For example, Kagan (1965, 1966) used a task in which respondents were asked to match the same figures to measure impulsive/reflective styles. Dunn, Dunn, and Price (1989) included persistence as one of many unrelated learning styles. Persistence and impulsivity are better described and explained in the temperament literature as one of a number of temperament or personality traits (e.g., Martin & Holbrook, 1985; Martin, Wisenbaker, & Huttunen, 1994). A number of learning styles describe students as being visual or verbal learners (e.g., Richardson, 1977; Riding & Cheema, 1991), ignoring a considerable body of theory and research on verbal and visuo-spatial processing in working and short-term memory that does a better job of explaining individual differences in learning. Other research involves measuring spatial ability (visual processing), but under a different name. For example, Riding's (1991, 1998) measure of holistic/analytic styles and Witkin, Oltman, Raskin, and Karp's (1971) measure of field dependent/field independent styles are essentially measures of spatial visualization. Such measures assess one's capacity to find a simple figure hidden within a more complex figure (see Linn and Petersen (1985) for a review of the different spatial measures). Unlike the learning styles literature, the literature on spatial skills and personality includes research on the development of these skills and how these skills impact learning.

1.1.3. An ignorance of the research contradicting the theories

Most important, learning styles theorists have ignored the research that directly contradicts learning styles theories. There is substantial research showing that students are often skilled at both verbal and visual processing and that the two are correlated, that both types of processing are important for learning (as opposed to gearing instruction to only one learning style), and that both can be improved through instruction (as opposed to instruction designed to work within a given learning style). Other researchers (e.g., Gregorc, 1982, 1985; Honey & Mumford, 1989; Kolb, 1976, 1985) described students as being either concrete or abstract but ignore the considerable body of research showing that students who are concrete are either immature or delayed in their learning whereas more abstract learners tend to be advanced learners (e.g., Chi, Feltovich, & Glaser, 1981; Slotta, Chi, & Joram, 1995; Taasoobshirazi & Carr, 2009). In the case of the concrete/abstract dichotomy, the dichotomy is not a set of attributes but reflects the level of development of expertise and an individual's educational experiences.

1.2. Problems of measurement

Learning styles theories have critical problems with measurement. Specifically, the theories often use rank ordering, thus forcing a false dichotomy. Another problem is that many measures of learning styles use a self-report instrument that may not be a valid measure of behavior or skill level. Finally, most of the measures of learning styles have poor reliability and validity.

1.2.1. Use of less valid measures

Many measures of learning styles use rank ordering (e.g., Gregorc Style Delineator, Gregorc, 1982; Learning Style Inventory, Kolb, 1976, 1985), forcing individuals to be high in one learning style and low in the other. Rank ordering produces negative correlations between the constructs that are being measured so that the construct validity is inflated (Cornwell & Dunlap, 1994; Henson & Hwang, 2002). In addition, the false dichotomy created by rank ordering is not supported by measures that independently assess each construct.

A self-report instrument (e.g., Gregorc Style Delineator and Learning Style Inventory) may be affected by the respondents' honesty, memory (Runco & Okuda, 1988), and concern for social desirability. Specifically, social desirability may push examinees to report what they believe is preferred to be true rather than what is actually true. If reported interests are not matched with actual behaviors, any conclusions drawn from correlations with achievement are suspect.

1.2.2. Poor reliability and validity

The measures of learning styles do not have good reliability. The reliability of the Gregorc Style Delineator (Gregorc, 1982) has been reported as poor (Joniak & Isaksen, 1988; O'Brien, 1990; Reio & Wiswell, 2006). Neither the original Learning Style Inventory (Kolb, 1976) nor revised Learning Style Inventory (Kolb, 1985) has good test-retest reliability (Atkinson, 1989, 1991; Freedman & Stumpf, 1980; Henson & Hwang, 2002). The Cognitive Style Analysis (Riding, 1998) showed a poor test-retest reliability (Rezaei & Katz, 2004). The reliability of the Verbalizer-Visualizer Questionnaire (Richardson, 1977) has been reported as poor (Sullivan & Macklin, 1986). If a teacher cannot replicate test performance using the same test then it is of little value.

The measures of learning styles have poor validity. The Gregorc Style Delineator (Gregorc, 1982) has been shown to have poor construct validity (Joniak & Isaksen, 1988; O'Brien, 1990). Several studies have found that the Learning Styles Inventory has poor construct validity (Cornwell, Manfredo, & Dunlap, 1991; Freedman & Stumpf, 1980; Kolb, 1976, 1985; Platsidou & Metallidou, 2009). The Verbalizer-Visualizer Questionnaire (Richardson, 1977) has poor construct validity (Boswell & Pickett, 1991) and external validity (Edwards & Wilkins, 1981). The Cognitive Style Analysis (Riding, 1991) has poor external validity with measures that would assess verbal and visual abilities (Massa & Mayer, 2006).

1.3. Failure to link to achievement

Despite the claim that teaching to a learning style results in better achievement, there is little research showing that this is the case. Learning styles researchers assume that their measures will predict learners' preferences of instructional materials. They assume that teaching to a learning style will result in better academic achievement. However, a number of studies have shown that learning styles measures do not correlate with preferences of instructional materials nor does achievement correlate with learning styles (e.g., Mayer & Massa, 2003; McKay, 1999; Price, 2004; Riding & Agrell, 1997; Riding & Pearson, 1994). Research by Price (2004) indicated that learning styles as measured by the Learning

Style Questionnaire (Honey & Mumford, 1992) and the Group Embedded Figures Test (Witkin et al., 1971) did not predict a preference for learning materials in computer science. Massa and Mayer (2006) found that verbal/visual learning styles measures did not correlate with verbal/visual cognitive abilities (e.g., SAT verbal and mathematics). To make matters worse, matching learning styles to instructional materials has been found to produce worse performance than the use of instructional materials that include both preferred and non-preferred styles (McKay, 1999).

2. Multiple alternative approaches

Learning styles theories clearly do a poor job of explaining the causes of individual differences in student learning. More important, the recommendation to "teach to learning styles" does not result in improved learning. In many cases teaching to a learning style will result in stymied development and poor achievement because the approach to teaching does not address weaknesses. Below we will present alternative explanations for individual differences or "styles" that are supported by cognition and development theories, and by temperament and personality theories. Specifically, the verbal/visual and concrete/abstract dimensions will be linked to the research on sensory-based representation and expertise, respectively. The impulsive/reflective dimension is better explained by theory and research on fluency or temperament and personality, specifically, the work on self-regulation, inhibition, effortful control, and perfectionism. Instead of focusing on a learning style we recommend that teachers focus on work done by cognitive and developmental psychologists and personality theory as explanations for the individual differences they see in their classrooms when considering how to modify instruction.

2.1. Individual differences in sensory-based skills better explain verbal-visual styles

Learning styles theory (e.g., Richardson, 1977; Riding, 1991, 1998) describes students as being either verbal or visual learners. It is assumed that verbal learners represent information during learning verbally, whereas visual learners process information in mental pictures. The existence of sensory-based representation and processing of information is well established in cognitive psychology. People encode and represent information using five sensory-based codes including visual, auditory, tactile, smell, and taste (e.g., Barsalou, 2008; Goldman-Rakic, 1995; Lyman & McDaniel, 1990; Richardson, Spivey, Barsalou, & McRae, 2003). Work by Baddeley and Hitch (1974) shows that working memory consists of three systems: the phonological loop, a temporary holding site of verbally coded information, the visuo-spatial sketchpad, a temporary store of visual or spatial information, and the executive workplace that carries out activities related to comprehension and problem-solving. Other work by Barsalou (2008) indicates that we have sensory-based representations in long-term memory that develop as people have repeated experience with a phenomenon. Given the findings of Barsalou and others, learning styles that divide students into either verbal or visual learners make no sense.

What we do know from research is that people are able to encode and represent information in multiple ways, and the activation of the multiple representations increases memory, learning and achievement. Based on the work of Barsalou and others we know that we create multiple representational codes for a given phenomenon. For example, we might have a mental image of a sunflower but also a verbal representation of the word. These linked sensory representations are constructed together and linked in long term memory. Unless an individual has a learning disability there is no reason to assume that they are either a verbal or visual learner.

We also know that activating multiple sensory representations improves learning. For instance, the memory of a smell improved when other sensory processing, such as verbal (naming the smell) or visual (mental picturing of the smell) was activated (Lyman & McDaniel, 1990). The activation of multiple representations including visual and verbal representations is linked to better learning in mathematics and reading (DeStefano & LeFevre, 2004; Mastropieri & Scruggs, 1997). In sum, it is not matching instruction to a learning style that produces good learning, but the activation of multiple representations. The more representations activated, the better the learning.

The research suggests that combining both verbal and visual/spatial processing would promote learning and achievement. Mathematics involves visual/spatial processing to hold and process numbers (Casey, 1996; Casey, Nuttall, & Pezaris, 2001; Geary & Burlingham-Dubree, 1989), but it also involves verbal processing (Campbell, 1994; DeStefano & LeFevre, 2004; Floyd, Evans, & McGrew, 2003; Lee & Kang, 2002). Likewise, reading achievement is dependent not only on verbal skills (Edwards, Walley, & Ball, 2003; Eldredge, 2005; Stanovich & Siegel, 1994), but also visuo-spatial skills (Denis, 1996; Mastropieri & Scruggs, 1997; Pressley, Cariglia-Bull, Deane, & Schneider, 1987). Students with learning disabilities often have difficulty representing information using one or more modalities. In the case of students with reading disabilities, deficits occur in the phonological loop, which is used to represent and process verbal material, but these students often also have deficits in visual processing (Siegel & Ryan, 1989). Similarly, students with mathematics disabilities show deficiencies not only in visual/spatial processing (Siegel & Ryan, 1989), but also in retrieval of basic math facts (Geary & Brown, 1991) in strategy use (Geary, Brown, & Samaranayake, 1991), and in inhibition and verbal working memory (e.g., Andersson & Lyxell, 2007; Bull & Scerif, 2001; Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; Mabbott & Bisanz, 2008; Passolunghi & Siegel, 2004). As such, focusing on only one representation that "matches" the learning style will be counterproductive.

Our memories are the product of the interaction of multiple sensory-based memories. Certainly, there are individual differences in how well a student might verbally or spatially represent or process information but these differences are frequently small. More important, there is clear and consistent evidence that we can improve these sensory-specific processes. We can improve the visuo-spatial skills through instruction (Terlecki, Newcombe, & Little, 2008) and this instruction has been found to improve mathematics competency (Cheng & Mix, 2014; Martinez et al., 2008). Likewise, verbal processing can be improved (Pressley, Samuel, Hershey, Bishop, & Dickinson, 1981). Given this, it makes no sense to focus exclusively on modalities that are strong and ignore less well-developed skills when selecting activities.

2.2. Expert-novice differences better explain concrete-abstract styles

Several learning styles theories (e.g., Gregorc, 1982, 1985; Honey & Mumford, 1989; Kolb, 1976, 1985) categorize students as either concrete or abstract learners. It is assumed that concrete learners perceive or represent information through interaction with concrete objects, whereas abstract learners encode or process information through symbolic representations. The concrete versus abstract dichotomy commonly found in learning styles theory is better understood as differences in the way novices (concrete learners) and experts (abstract learners) represent knowledge. Novices' understanding of a topic is limited to their concrete experiences and they have not yet abstracted general rules. As a result, they tend to focus on superficial, concrete features, such as physical characteristics and they need specific and concrete examples of a concept to make sense out of it. In contrast, the abstract nature of expert knowledge is evident in experts' ability to comprehend abstract patterns of the features that may not be evident on the surface. Hmelo-Silver and Pfeffer (2004) found that people who were new to aquariums (novices) tended to focus simply on the physical structures of the aquarium, whereas experts who had considerable experience with aquariums focused on the interaction of the physical structures, aquarium functions and fish behaviors; a higher and abstract level of understanding that required in-depth knowledge.

This abstract understanding of the topic is not a "style" but the result of repeated experiences that have allowed the student to understand a topic on a deeper and more abstract level.

The more abstract nature of expert knowledge is also evident in problem-categorization. Expert physics students tend to categorize physics problems based on abstract principles or laws involved in solving the problems whereas novice students tend to focus on concrete, surface features (Chi & Slotta, 1993; Williams & Noyes, 2007). Children who are "dinosaur experts" classify dinosaurs using categories that require an in-depth knowledge of the animal, such as whether the dinosaur is a meat-eater or a plant-eater, whereas novice adults tend to focus on surface features, such as whether it has a horn (Chi, 1983). Concreteness reflects a superficial or immature understanding of the topic whereas abstractness reflects a mature, in-depth understanding of underlying principles and rules. The latter emerges out of the former through instruction.

The majority of the research examining the development of expertise indicates that students begin as concrete learners and transition to abstract learners (Piaget, 1970, 1977). As an example, Ojose (2008) found that when students first learn about equations, they are not able to generate an abstract representation and must have a concrete representation (e.g., Ann has three times as many books than Brian. Together they have 20. How many books does Ann have?). Through instruction involving repeated experiences with this type of problem novices abstracted a more general rule or representation (e.g., $x + 3x = 20$). As another example, through repeated experiences counting objects young students acquire an abstract understanding of number. This transition occurs when teachers instruct students to use more abstract representations and press them to abandon concrete manipulatives that are no longer needed. This transition will not occur if the teacher matches the instruction to the learning style and makes no effort to move the students to a more abstract representation.

It makes more sense to think of concrete learners as novices or beginners and abstract learners as more advanced, expert students. There is certainly more research supporting this conceptualization of concreteness and abstractness. More important the research shows that with proper instruction students can transition from concrete to abstract representations. The focus should be on developing activities to move students from the former to the latter. What should be absolutely avoided is the belief that concrete learners will not change through instruction. For most students that transition will occur through regular instruction that focuses on moving students forward. However, some students will require substantially more effort by teachers.

2.3. Individual differences in cognitive processes and personality better explain impulsive-reflective styles

2.3.1. Focus on fluency

Learning styles theories, such as those by Butter (1979) and Kagan (1965) describe students as being either impulsive or reflective learners. Impulsive learners are characterized by fast and inaccurate problem solving whereas reflective learners are characterized by slow, accurate problem solving. The impulsive versus reflective dichotomy seen in several learning styles does not recognize that students can be fast and accurate, fast and inaccurate, slow and accurate, slow and inaccurate, or much more likely, somewhere in between. The research on fluency better explains these individual differences in speed and accuracy. While it is not necessarily bad to be slow and accurate the research is pointing to the importance of speed and accuracy (fluency) with more advanced, expert students being both fast and accurate. Fast and accurate processing is evidence of experts' better-organized knowledge whereas slower, reflective processing may indicate that the student is a novice, with limited knowledge that is less well-organized and accessible.

There is considerable evidence that being more knowledgeable, or expert, in a domain results in more fluent retrieval and problem-solving. For example, expert chess players showed faster and more accurate reconstruction of a mid-play chess board than novice players (Chase & Simon, 1973), and expert pilots read back and remembered pilot communication messages faster and more accurately than did novices (Morrow, Menard, Stine-Morrow, Teller, & Bryant, 2001). Even children who are expert in a certain area show similar performance. Research by Chi (1978) found that child experts were able to recall the chess positions faster and more accurately than adult novices. This advantage was specific to chess; they did not show the same advantage on a simple recall test of digits. Other research found that children who have more domain knowledge about baseball or soccer had faster and more accurate recall or comprehension of domain specific stories or text (Gaultney, Bjorklund, & Schneider, 1992; Recht & Leslie, 1988; Schneider, Körkel, & Weinert, 1989).

Fluent and accurate processing of information is an important foundation for subsequent skill development. Fluent computation is the basis of an upward trajectory in the development of mathematics achievement (Carr & Alexeev, 2011) and it is also important for the development of reading skills (Kirby, Parrila, & Pfeiffer, 2003). Experts are not always fast, they will shift from making fast and accurate responses to reflective and accurate responses when it is necessary for the student to make a plan of action before proceeding (Davidson & Sternberg, 1984; Shore & Lazar, 1996).

Students need to become fluent in basic skills and knowledge that support the new material they are learning, but they also need to know how and when to slow down and reflect on problem solving when necessary. Given this, it makes no sense to categorize students as either impulsive or reflective and teach to that style, at least when we are talking about accurate performance both "styles" need to be promoted. Teachers need to focus on improving accurate and fast (fluent) responses but also teach students to stop and think (reflection) when necessary to produce the correct response.

2.3.2. Focus on self-regulation, inhibition, and effortful control

A second explanation why some students tend to be more impulsive whereas others are more reflective involves individual differences in self-regulation of attention and inhibition. The research on self-regulation of attention and inhibition shows that more attentive students are more reflective whereas less attentive students are more impulsive (e.g., Fischer, Barkley, Edelbrock, & Smallish, 1990; Schweitzer & Sulzer-Azaroff, 1995). Specifically, students with attention deficit disorder with hyperactivity (ADHD), or attention deficit disorder without hyperactivity (ADD/WO), are considered to be less able to self-regulate and inhibit distractions (Barkley, 1994). For example, ADHD boys are less able to regulate or inhibit distracters such as toys while watching television for a long time (Lorch et al., 2000). In Barkley, Grodzinsky, and DuPaul's (1992) study, children with ADHD were less able to inhibit the ink colors that were printed in color words when they had to read the color words. Attention deficit disorders and concurrent impulsivity result in poor achievement (e.g., Felton, Wood, Brown, Campbell, & Harter, 1987; Fischer et al., 1990; Rasile, Burg, Burright, & Donovick, 1995). Fast and inaccurate responses result in poor outcomes.

Individual differences in attention and inhibition are also linked to differences in temperament, specifically effortful control. Students with better "effortful control" are more reflective because they are able to regulate attention and suppress impulses (Ahadi & Rothbart, 1994; Kochanska, 1991; Martin et al., 1994). These temperament differences predict cognitive and academic achievement throughout life. Effortful control also is linked to better verbal, reading, and mathematics achievement (Liew, Mctigue, Barrois, & Hughes, 2008; Valiente, Lemery-Chalfant, & Swanson, 2010). Even in preschoolers, an effortful control system, in the form of delayed gratification, predicts future cognitive and academic performance in adolescence (Shoda, Mischel, & Peake, 1990). Similarly, college students who are less persistent

show poor academic achievement (Blinne & Johnston, 1998; Dubey, 1982). The impulsive learning style that is linked to fast but inaccurate responses most likely reflects students with poor self-control accompanied by poor outcomes. Impulsiveness when it produces poor outcomes is not a learning style, but a deficit in self-regulatory skills.

2.3.3. Focus on perfectionism

A final explanation for the impulsive versus reflective dichotomy seen in several learning styles (e.g., Butter, 1979; Kagan, 1965) is a need by reflective students to be perfect. Perfectionism is a double-edged sword in that it can either improve or suppress achievement (Stoeber & Otto, 2006). For example, research by Stoeber and Eismann (2007) found that musicians with high perfectionist strivings are more reflective (spent more time on tasks) and gained better grades in class than musicians with less perfectionist strivings. Research by Stoeber, Chesterman, and Tarn (2010) showed that perfectionist strivings influenced performance on a letter detecting task as medicated by reflection (spend more time on the task). These types of reflection are linked to better academic achievement (e.g., Stoeber & Eismann, 2007; Stoeber & Rambow, 2007; Stoll, Lau, & Stoeber, 2008). Some perfectionist, however, are reflective but do not achieve because their reflection is a function of worry about failure and other people's evaluations as opposed to problem solving (Stoeber & Otto, 2006). In this case, perfectionist concerns and the reflective behavior that accompanies it are linked to negative outcomes, including performance anxiety, stress, and depression (Stoeber & Otto, 2006) that result in poor academic achievement (e.g., Ader & Erktin, 2010; Ashcraft & Kirk, 2001; Peleg, 2009).

3. Practical implications for classroom teachers

Unlike learning styles theory we can have some confidence in the recommendations for teachers because these recommendations are supported by research evidence. Teachers can improve outcomes for their students in the following ways. First, we recommend that teachers to provide multiple sensory representations of information in class. We know that multiple sensory representations result in multiple, linked representations in memory that improve understanding and recall of the material. For example, when students learn a new vocabulary about food in a foreign language class, its spelling, image, sounds (pronunciation), smell, or taste can be provided together. Using a multimedia software system, in which texts, pictures, sounds, movies, and animation, and other media can be combined, is one of the good examples of activating multiple representation simultaneously. Considerable research suggests that effective instructional methods in multimedia learning according to the fields of studies (see Mayer, 2014).

In contrast to the learning styles literature we do not recommend that teacher teach to strengths and ignore weaknesses. Students who tend to have weak spatial or visual processing skills can improve these skills through instruction (Pressley et al., 1987) and this results in improved mathematics outcomes. Likewise, improving verbal skills in students will have a significant impact on learning overall because these skills underlie and predict academic performance. Teachers who choose to ignore weaknesses in verbal or spatial skills do their students no favors.

Regarding differences in concreteness and abstractness, teachers need to shift from viewing these as indelible "styles" to developmental levels of expertise. Teachers need to search out or develop techniques to move students from concrete representations to abstract representations. This can be accomplished in two ways. Teachers can give students diverse concrete examples of a concept with the goal of the child abstracting the intended concept from these examples. As an example, students of teachers who consistently use a term, such as 1/4 in their interactions with students "Give me 1/4 of the pencils, move 1/4 of the chairs" are more likely understand these concepts. Teachers can also press for the transition from concrete to abstract. For example, in transitioning students from counting objects to mental computation teachers can cover manipulatives with a sheet of paper and have student imagine the objects they are counting. The transition from concreteness to abstract representation will be faster for some students and slower for others but for the most part it can be accomplished. For students who struggle, teachers need to avoid overly complex concrete representations that may confuse students.

Regarding impulsivity, the teacher needs to determine whether the student is fast and accurate (fluent) or fast and inaccurate (impulsive). If students are impulsive and accurate, they would be fluent learners. In contrast, being impulsive-inaccurate would result in problems with attention, inhibition, and self-regulation. In the latter case, a teacher will need to work with the student to improve their self-regulation.

Typically students who are reflective do well because this reflects a high level of self-regulation but if reflective behavior is the result of high levels of perfectionism this can be a problem. Students who are highly perfectionist may be overly concerned with failure and avoid failure by never completing assignments because they are not "perfect" (Stoeber & Otto, 2006). Teachers need to address the belief systems that underlie perfectionism. Work by Dweck (2006) on mindsets orients students to view ability as the result of effort as opposed to innate ability and to focus less on avoiding failure and more on increasing ability. In line with this teachers need to avoid comments that suggest that success and high ability are qualities of students and focus on the importance of effort for success.

4. Conclusion

Learning styles theories and research have a number of problems including the lack of a solid explanatory framework, poor reliability and validity of constructs, and a failure to link learning styles to achievement. Despite this teachers are often asked to provide instruction that matches their students' learning styles. We have argued here that doing so is a disservice to students. Furthermore, it is a bigger disservice to teachers who spend valuable time teaching to "styles" when that instruction will not improve outcomes for students.

We have presented alternative approaches to learning styles theories that are grounded in research and based on solid theoretical frameworks in cognitive and developmental psychology. Unlike the learning style literature, these approaches provide teachers with evidence-based explanations for the individual differences they see in their students. Understanding student performance in terms of differences in sensory-based representations, levels of expertise, self-regulation, perfectionism and temperament will provides insight into possible interventions. Our approach is much less simplistic than the learning styles theory but promises better outcomes for students. Based on our approach, future research needs to explore the alternative solutions that would have less methodological and measurement problems than the learning styles notion.

References

Ader, E., & Erktin, E. (2010). Coping as self-regulation of anxiety: A model for math achievement in high-stakes tests. *Cognition, Brain, Behavior*, *14*, 311–332.

Ahadi, S. A., & Rothbart, M. K. (1994). Temperament, development, and the Big Five. In C. F. Halverson, G. A. Kohnstamm, & R. P. Martin (Eds.), *The developing structure of temperament and personality from infancy to adulthood* (pp. 189–207). Hillsdale, NJ: Erlbaum.

Andersson, U., & Lyxell, B. (2007). Working memory deficits in children with mathematical difficulties: A general or specific deficit? *Journal of Experimental Child Psychology*, *96*, 197–228.

Ashcraft, M. H., & Kirk, E. P. (2001). The relationships among working memory, math anxiety, and performance. *Journal of Experimental Psychology: General*, *130*, 224–237.

Atkinson, G. (1989). Kolb's learning style inventory—1985: Test-retest déjà vu. *Psychological Reports*, *64*, 991–995.

Atkinson, G. (1991). Kolb's learning style inventory: A practitioner's perspective. *Measurement and Evaluation in Counseling and Development*, *23*, 149–161.

Baddeley, A. D., & Hitch, G. J. (1974). Working memory. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory. Vol. 8.* (pp. 47–90). New York: Academic Press.

Barkley, R. A. (1994). Delayed responding and attention deficit hyperactivity disorder: Toward a unified theory. In D. K. Routh (Ed.), *Disruptive behavior disorders in children: Essays in honor of Herbert Quay* (pp. 11–57). New York: Plenum.

Barkley, R. A., Grodzinsky, G., & DuPaul, G. J. (1992). Frontal lobe functions in attention deficit disorder with and without hyperactivity: A review and research report. *Journal of Abnormal Child Psychology*, *20*, 163–188.

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology*, *59*, 617–645.

Blinne, W. R., & Johnston, J. A. (1998). Assessing the relationships between vocational identity, academic achievement, and persistence in college. *Journal of College Student Development*, *39*, 569–576.

Boswell, D. L., & Pickett, J. A. (1991). A study of the internal consistency and factor structure of the Verbalizer-Visualizer Questionnaire. *Journal of Mental Imagery*, *15*, 33–36.

Bull, R., & Scerif, G. (2001). Executive functioning as a predictor of children's mathematics ability: Inhibition, switching, and working memory. *Developmental Neuropsychology*, *19*, 273–293.

Butter, E. J. (1979). Visual and haptic training and cross-modal transfer of reflectivity. *Journal of Educational Psychology*, *71*, 212–219.

Campbell, J. I. D. (1994). Architectures for numerical cognition. *Cognition*, *53*, 1–44.

Carr, M., & Alexeev, N. (2011). Fluency, accuracy, and gender predict developmental trajectories of arithmetic strategies. *Journal of Educational Psychology*, *103*, 617–631.

Casey, M. B. (1996). Understanding individual differences in spatial ability within females: A nature/nurture interactionist framework. *Developmental Review*, *16*, 241–260.

Casey, M. B., Nuttall, R. L., & Pezaris, E. (2001). Spatial-mechanical reasoning skills versus mathematics self-confidence as mediators of gender differences on mathematics subtests using cross-national gender-based items. *Journal for Research in Mathematics Education*, *32*, 28–57.

Chase, W. G., & Simon, H. A. (1973). Perception in chess. *Cognitive Psychology*, *4*, 55–81.

Cheng, Y. L., & Mix, K. S. (2014). Spatial training improves children's mathematics ability. *Journal of Cognition and Development*, *15*, 2–11.

Chi, M. T. H. (1978). Knowledge structures and memory development. In R. S. Siegler (Ed.), *Children's thinking: What develops?* (pp. 73–96). Hillsdale, NJ: Erlbaum.

Chi, M. T. H. (1983). Knowledge-derived categorization in young children. In D. R. Rogers, & J. A. Sloboda (Eds.), *The acquisition of symbolic skills* (pp. 327–332). New York: Plenum Press.

Chi, M. T. H., & Slotta, J. D. (1993). The ontological coherence of intuitive physics. *Cognition and Instruction*, *10*, 249–260.

Chi, M. T. H., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science*, *5*, 121–152.

Coffield, F., Moseley, D., Hall, E., & Ecclestone, K. (2004). *Learning styles and pedagogy in post-16 learning. A systematic and critical review*. London: Learning and Skills Research Centre.

Cornwell, J. M., & Dunlap, W. P. (1994). On the questionable soundness of factoring ipsative data: A response to Saville & Willson (1991). *Journal of Occupational and Organizational Psychology*, *67*, 89–100.

Cornwell, J. M., Manfredo, P. A., & Dunlap, W. P. (1991). Factor analysis of the 1985 revision of Kolb's learning style inventory. *Educational and Psychological Measurement*, *51*, 455–462.

Davidson, J. E., & Sternberg, R. J. (1984). The role of insight in intellectual giftedness. *The Gifted Child Quarterly*, *28*, 58–64.

Denis, M. (1996). Imagery and the description of spatial configurations models of visuospatial cognition. In M. Vega, M. J. Intons-Peterson, P. N. Johnson-Laird, M. Denis, & M. Marschark (Eds.), *Models of visuospatial cognition* (pp. 128–197). New York: Oxford University Press.

DeStefano, D., & LeFevre, J. (2004). The role of working memory in mental arithmetic. *European Journal of Cognitive Psychology*, *16*, 353–386.

Dubey, R. S. (1982). Trait persistence, sex differences and educational achievement. *Perspectives in Psychological Researches*, *5*, 15–18.

Dunn, R., Dunn, K., & Price, G. E. (1989). *Learning style inventory*. Lawrence, KS: Price Systems.

Dweck, C. (2006). *Mindset: The new psychology of success*. New York: Random House.

Edwards, J. E., & Wilkins, W. (1981). Verbalizer-Visualizer Questionnaire: Relationship with imagery and verbal–visual ability. *Journal of Mental Imagery*, *5*, 137–142.

Edwards, J. D., Walley, A. C., & Ball, K. K. (2003). Phonological, visual and temporal processing in adults with and without reading disability. *Reading and Writing*, *16*, 737–758.

Eldredge, J. L. (2005). Foundations of fluency: An exploration. *Reading Psychology*, *26*, 161–181.

Felton, R. H., Wood, F. B., Brown, I. S., Campbell, S. K., & Harter, M. R. (1987). Separate verbal memory and naming deficits in attention deficit disorder and reading disability. *Brain and Language*, *31*, 171–184.

Fischer, M., Barkley, R. A., Edelbrock, C. S., & Smallish, L. (1990). The adolescent outcome of hyperactive children diagnosed by research criteria: II. Academic, attentional, and neuropsychological status. *Journal of Consulting and Clinical Psychology*, *58*, 580–588.

Floyd, R. G., Evans, J. J., & McGrew, K. S. (2003). Relations between measures of Cattell-Horn-Carroll (CHC) cognitive abilities and mathematics achievement across the school-age years. *Psychology in the Schools*, *40*, 155–171.

Freedman, R. D., & Stumpf, S. A. (1980). Learning style theory: Less than meets the eye. *Academy of Management Review*, *5*, 445–447.

Gaultney, J. F., Bjorklund, D. F., & Schneider, W. (1992). The role of children's expertise in a strategic memory task. *Contemporary Educational Psychology*, *17*, 244–257.

Geary, D. C., & Brown, S. C. (1991). Cognitive addition: Strategy choice and speed-of-processing differences in gifted, normal, and mathematically disabled children. *Developmental Psychology*, *27*, 398–406.

Geary, D. C., & Burlingham-Dubree, M. (1989). External validation of the strategy choice model for addition. *Journal of Experimental Child Psychology*, *47*, 175–192.

Geary, D. C., Brown, S. C., & Samaranayake, V. A. (1991). Cognitive addition: A short longitudinal study of strategy choice and speed-of-processing differences in normal and mathematically disabled children. *Developmental Psychology*, *27*, 787–797.

Geary, D. C., Hoard, M. K., Byrd-Craven, J., Nugent, L., & Numtee, C. (2007). Cognitive mechanisms underlying achievement deficits in children with mathematical learning disability. *Child Development*, *78*, 1343–1359.

Goldman-Rakic, P. S. (1995). Anatomical and functional circuits in prefrontal cortex of nonhuman primates: Relevance to epilepsy. In H. H. Jasper, S. Riggio, & P. S. Goldman-Rakic (Eds.), *Epilepsy and the functional anatomy of the frontal lobe* (pp. 51–62). New York: Raven Press.

Gregorc, A. F. (1982). *Gregorc Style Delineator*. Maynard, MA: Gabriel Systems.

Gregorc, A. F. (1985). *Inside styles: Beyond the basics*. Maynard, MA: Gabriel Systems.

Henson, R. K., & Hwang, D. Y. (2002). Variability and prediction of measurement error in Kolb's learning style inventory scores a reliability generalization study. *Educational and Psychological Measurement*, *62*, 712–727.

Hmelo-Silver, C. E., & Pfeffer, M. G. (2004). Comparing expert and novice understanding of a complex system from the perspective of structures, behaviors, and functions. *Cognitive Science*, *28*, 127–138.

Honey, P., & Mumford, A. (1989). *Learning styles questionnaire*. Maidenhead: Peter Honey.

Honey, P., & Mumford, A. (1992). *The manual of learning styles: Revised version*. Maidenhead: Peter Honey.

Joniak, A. J., & Isaksen, S. G. (1988). The Gregorc Style Delineator: Internal consistency and its relationship to Kirton's adaptive-innovative distinction. *Educational and Psychological Measurement*, *48*, 1043–1049.

Kagan, J. (1965). Impulsive and reflective children: Significance of conceptual tempo. In J. D. Krumboltz (Ed.), *Learning and the educational process* (pp. 133–161). Chicago: Rand McNally.

Kagan, J. (1966). Reflection-impulsivity: The generality and dynamics of conceptual tempo. *Journal of Abnormal Psychology*, *71*, 17–24.

Kirby, J. R., Parrila, R. K., & Pfeiffer, S. L. (2003). Naming speed and phonological awareness as predictors of reading development. *Journal of Educational Psychology*, *95*, 453–464.

Kochanska, G. (1991). Socialization and temperament in the development of guilt and conscience. *Child Development*, *62*, 1379–1392.

Kolb, D. A. (1976). *Learning style inventory: Technical manual*. Boston, MA: McBer & Co.

Kolb, D. A. (1985). *Learning style inventory*. Boston, MA: McBer & Co.

Kozhevnikov, M. (2007). Cognitive styles in the context of modern psychology: Toward an integrated framework of cognitive style. *Psychological Bulletin*, *133*, 464–481.

Lee, K. M., & Kang, S. Y. (2002). Arithmetic operation and working memory: Differential suppression in dual tasks. *Cognition*, *83*, B63–B68.

Liew, J., McTigue, E. M., Barrois, L., & Hughes, J. N. (2008). Adaptive and effortful control and academic self-efficacy beliefs on achievement: A longitudinal study of 1st through 3rd graders. *Early Child Research Quarterly*, *23*, 515–526.

Linn, M. C., & Petersen, A. C. (1985). Emergence and characterization of sex differences in spatial ability: A meta-analysis. *Child Development*, *56*, 1479–1498.

Lorch, E. P., Milich, R., Sanchez, R. P., van den Broek, P., Baer, S., Hooks, K., ... Welsh, R. (2000). Comprehension of televised stories in boys with attention deficit/hyperactivity disorder and nonreferred boys. *Journal of Abnormal Psychology*, *109*, 321–330.

Lyman, B. J., & McDaniel, M. A. (1990). Memory for odors and odor names: Modalities of elaboration and imagery. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *16*, 656–664.

Mabbott, D. J., & Bisanz, J. (2008). Computational skills, working memory, and conceptual knowledge in older children with mathematics learning disabilities. *Journal of Learning Disabilities*, *41*, 15–28.

Martin, R. P., & Holbrook, J. (1985). Relationship of temperament characteristics to the academic achievement of first-grade children. *Journal of Psychoeducational Assessment*, *3*, 131–140.

Martin, R. P., Wisenbaker, J., & Huttunen, M. (1994). Review of factor analytic studies of temperament measures based on the Thomas-Chess structural model: Implications for the Big Five. In C. F. HalversonJr., G. A. Kohnstamm, & R. P. Martin (Eds.), *The developing structure of temperament and personality from infancy to adulthood* (pp. 157–172). Hillsdale, NJ: Erlbaum.

Martinez, M. E., Peterson, M., Bodner, M., Coulson, A., Vuong, S., Hu, W., ... Shaw, G. L. (2008). Music training and mathematics achievement: A multiyear iterative project designed to enhance students' learning. In A. E. Kelly, R. A. Lesh, & J. Y. Baek (Eds.), *Handbook of design research methods in education: Innovations in science, technology, engineering, and mathematics learning and teaching* (pp. 396–409). New York: Routledge.

Massa, L. J., & Mayer, R. E. (2006). Testing the ATI hypothesis: Should multimedia instruction accommodate verbalizer-visualizer cognitive style. *Learning and Individual Differences*, *16*, 321–335.

Mastropieri, M. A., & Scruggs, T. E. (1997). Best practices in promoting reading comprehension in students with learning disabilities: 1976 to 1996. *Remedial and Special Education*, *18*, 197–213.

Mayer, R. E., & Massa, L. J. (2003). Three facets of visual and verbal learners: Cognitive ability, cognitive style, and learning preference. *Journal of Educational Psychology*, *95*, 833–846.

Mayer, R. E. (2014). Incorporating motivation into multimedia learning. *Learning and Instruction*, *29*, 171–173.

McKay, E. (1999). An investigation of text-based instructional materials enhanced with graphics. *Educational Psychology*, *19*, 323–335.

Morrow, D. G., Menard, W. E., Stine-Morrow, E. A. L., Teller, T., & Bryant, D. (2001). The influence of expertise and task factors on age differences in pilot communication. *Psychology and Aging*, *16*, 31–46.

O'Brien, T. P. (1990). Construct validation of the Gregorc Style Delineator: An application of LISREL 7. *Educational and Psychological Measurement*, *50*, 631–636.

Ojose, B. (2008). Applying Piaget's theory of cognitive development to mathematics instruction. *The Mathematics Educator*, *18*, 26–30.
Passolunghi, M. C., & Siegel, L. S. (2004). Working memory and access to numerical information in children with disability in mathematics. *Journal of Experimental Child Psychology*, *88*, 348–367.
Peleg, O. (2009). Test anxiety, academic achievement, and self-esteem among Arab adolescents with and without learning disabilities. *Learning Disability Quarterly*, *32*, 11–20.
Piaget, J. (1970). *Science of education and the psychology of the child.* New York: Viking.
Piaget, J. (1977). *Epistemology and psychology of functions.* Dordrecht, Netherlands: D. Reidel Publishing Company.
Platsidou, M., & Metallidou, P. (2009). Validity and reliability issues of two learning style inventories in a Greek sample: Kolb's learning style inventory and Felder & Soloman's index of learning styles. *International Journal of Teaching and Learning in Higher Education*, *20*, 324–335.
Pressley, M., Samuel, J., Hershey, M. M., Bishop, S. L., & Dickinson, D. (1981). Use of a mnemonic technique to teach young children foreign language vocabulary. *Contemporary Educational Psychology*, *6*, 110–116.
Pressley, M., Cariglia-Bull, T., Deane, S., & Schneider, W. (1987). Short-term memory, verbal competence, and age as predictors of imagery instructional effectiveness. *Journal of Experimental Child Psychology*, *43*, 194–211.
Price, L. (2004). Individual differences in learning: Cognitive control, cognitive style, and learning style. *Educational Psychology*, *24*, 681–698.
Rasile, D. A., Burg, J. S., Burright, R. G., & Donovick, P. J. (1995). The relationship between performance on the Gordon Diagnostic System and other measures of attention. *International Journal of Psychology*, *30*, 35–45.
Recht, D. R., & Leslie, L. (1988). Effect of prior knowledge on good and poor readers' memory of text. *Journal of Educational Psychology*, *80*, 16–20.
Reio, T. G., & Wiswell, A. K. (2006). An examination of the factor structure and construct validity of the Gregorc Style Delineator. *Educational and Psychological Measurement*, *66*, 489–501.
Rezaei, A. R., & Katz, L. (2004). Evaluation of the reliability and validity of the cognitive styles analysis. *Personality and Individual Differences*, *36*, 1317–1327.
Richardson, A. (1977). Verbalizer-visualizer: A cognitive style dimension. *Journal of Mental Imagery*, *1*, 109–125.
Richardson, D. C., Spivey, M. J., Barsalou, L. W., & McRae, K. (2003). Spatial representations activated during real-time comprehension of verbs. *Cognitive Science*, *27*, 767–780.
Riding, R. J. (1991). *Cognitive styles analysis.* Birmingham, UK: Learning & Training Technology.
Riding, R. J. (1998). *Cognitive styles analysis: Research applications.* Birmingham, UK: Learning & Training Technology.
Riding, R. J., & Agrell, T. (1997). The effect of cognitive style and cognitive skills on school subject performance. *Educational Studies*, *23*, 311–323.
Riding, R. J., & Cheema, I. (1991). Cognitive styles—An overview and integration. *Educational Psychology*, *11*, 193–215.
Riding, R. J., & Pearson, F. (1994). The relationship between cognitive style and intelligence. *Educational Psychology*, *14*, 413–425.
Runco, M. A., & Okuda, S. M. (1988). Problem discovery, divergent thinking, and the creative process. *Journal of Youth and Adolescence*, *17*, 211–220.
Schneider, W., Körkel, J., & Weinert, F. E. (1989). Domain-specific knowledge and memory performance: A comparison of high-and low-aptitude children. *Journal of Educational Psychology*, *81*, 306–312.
Schweitzer, J. B., & Sulzer-Azaroff, B. (1995). Self-control in boys with attention deficit hyperactivity disorder: Effects of added stimulation and time. *Journal of Child Psychology and Psychiatry*, *36*, 671–686.
Shoda, Y., Mischel, W., & Peake, P. K. (1990). Predicting adolescent cognitive and self-regulatory competencies from preschool delay of gratification: Identifying diagnostic conditions. *Developmental Psychology*, *26*, 978–986.
Shore, B. M., & Lazar, L. (1996). IQ-related differences in time allocation during problem solving. *Psychological Reports*, *78*, 848–850.
Siegel, L. S., & Ryan, E. B. (1989). The development of working memory in normally achieving and subtypes of learning disabled children. *Child Development*, *60*, 973–980.
Slotta, J. D., Chi, M. T. H., & Joram, E. (1995). Assessing students' misclassifications of physics concepts: An ontological basis for conceptual change. *Cognition and Instruction*, *13*, 373–400.
Stanovich, K. E., & Siegel, L. S. (1994). Phenotypic performance profile of children with reading disabilities: A regression-based test of the phonological-core variable-difference model. *Journal of Educational Psychology*, *86*, 24–53.
Sternberg, R. J. (2001). Epilogue: Another mysterious affair at styles. In R. J. Sternberg, & L. Zhang (Eds.), *Perspectives on thinking, learning, and cognitive styles* (pp. 249–252). Mahwah, NJ: Erlbaum.
Sternberg, R. J., Grigorenko, E. L., & Zhang, L. (2008). Styles of learning and thinking matter in instruction and assessment. *Perspectives on Psychological Science*, *3*, 486–506.
Stoeber, J., & Eismann, U. (2007). Perfectionism in young musicians: Relations with motivation, effort, achievement, and distress. *Personality and Individual Differences*, *43*, 2182–2192.
Stoeber, J., & Otto, K. (2006). Positive conceptions of perfectionism: Approaches, evidence, challenges. *Personality and Social Psychology Review*, *10*, 295–319.
Stoeber, J., & Rambow, A. (2007). Perfectionism in adolescent school students: Relations with motivation, achievement, and well-being. *Personality and Individual Differences*, *42*, 1379–1389.
Stoeber, J., Chesterman, D., & Tarn, T. (2010). Perfectionism and task performance: Time on task mediates the perfectionistic strivings–performance relationship. *Personality and Individual Differences*, *48*, 458–462.
Stoll, O., Lau, A., & Stoeber, J. (2008). Perfectionism and performance in a new basketball training task: Does striving for perfection enhance or undermine performance? *Psychology of Sport and Exercise*, *9*, 620–629.
Sullivan, G. L., & Macklin, M. C. (1986). Some psychometric properties of two scales for the measurement of verbalizer-visualizer differences in cognitive style. *Journal of Mental Imagery*, *10*, 75–85.
Taasoobshirazi, G., & Carr, M. (2009). A structural equation model of expertise in college physics. *Journal of Educational Psychology*, *101*, 630–643.
Terlecki, M. S., Newcombe, N. S., & Little, M. (2008). Durable and generalized effects of spatial experience on mental rotation: Gender differences in growth patterns. *Applied Cognitive Psychology*, *22*, 996–1013.
Valiente, C., Lemery-Chalfant, K., & Swanson, J. (2010). Prediction of kindergartners' academic achievement from their effortful control and emotionality: Evidence for direct and moderated relations. *Journal of Educational Psychology*, *102*, 550–560.
Williams, D. J., & Noyes, J. M. (2007). Effect of experience and mode of presentation on problem solving. *Computers in Human Behavior*, *23*, 258–274.
Witkin, H. A., Oltman, P. K., Raskin, E., & Karp, S. A. (1971). *Manual for embedded figures test, children's embedded figures test, and group embedded figures test.* Palo Alto, CA: Consulting Psychologists Press.