The handle http://hdl.handle.net/1887/25194 holds various files of this Leiden University dissertation.

**Author:** Chabani, Elaheh (Ellahe)
**Title:** Enhancing visuospatial processing skills in children
**Issue Date:** 2014-04-15
Chapter 1

General Introduction
Visual spatial processing skills (VSPS) or visual spatial intelligence as defined by Howard Gardner (in ‘Frames of Mind’) is “the ability to perceive the visual world accurately, to perform transformations and modifications upon one's initial perceptions, and to be able to re-create aspects of one's visual experience, even in the absence of relevant physical stimuli” and “while these images are typically seen as helpful aids to thinking, some commentators have gone much farther, deeming visual and spatial imagery as a primary source of thought” (p.173).

Some people have well developed visual spatial processing skills and visual reasoning, while others struggle. Nonetheless, VSPS is required for most daily living, activities, and as well for successful academic performance. More details are provided in the following chapters and sections below, however, in short reflections in the importance of VSPS’s assessment and development at early ages include, but are not limited to:

a) Visual spatial processing skills and malleability of these

The importance of VSPS in learning at any age has been widely acknowledged (Lubinski, 2010; Miller & Halpern, 2013; Sorby, Casey, Veurink & Dulaney, 2013; Uttal, et al., 2012; Wai, Lubinski & Benbow, 2009; Assel, et al., 2003; Cheng & Mix 2012) and its development has been attributed to a number of variables, including the cognitive development, spatial experiences, aptitude, age, and gender (e.g., Hegarty & Waller 2006). Furthermore, recently, Uttal et al., (2012) found that even short training procedures could significantly improve VSPS. In line with the authors it is reasonable to suggest that adding spatially-challenging activities to standard courses can further improve spatial skills and can lead to transfer to other spatially-demanding tasks.

b) Specific learning disabilities (SLD)

Regardless of the on-going debate on the issue of definition and identification of specific learning disabilities many children are “in-need” and at-risk of failure resulting in early school dropping out (European Commission, 2012). In the same vein a very recent research published by the University College of London (2013), reports that “up to 10% of the population are affected by specific learning disabilities such as dyslexia, dyscalculia and/or group of neurological or brain-based problems (e.g., autism, ADHD), translating to 2 or 3 pupils in every classroom” (p.1). Among them, there are children with language-based learning disabilities that include Visual Perceptual Processing Disorders known as well as Nonverbal Learning Disability (National Center on Learning Disabilities (NCLD), 2003, 2009) that are less well-known and less understood. Individuals with language-based learning disabilities might have normal verbal abilities and average IQ but impaired VSPS in the absence of visual acuity. Some children with language-based learning disabilities demonstrate remarkable rote memory, attention to detail, but might have deficits or weak VSPS, poor organizational skills, difficulty with inference and abstract reasoning, problems with mathematical reasoning, difficulty reading nonverbal cues, impaired fine motor skills –i.e. children with ASD
Enhancing visuospatial processing skills in children

(e.g., Bhaumik et al., 2010). Bhaumik et al., have argued that delays in social and communicative development of children with ASD may also be explained by low levels of cognitive functioning related to VSPS. However, poor VSPS extends to the whole spectrum of learning i.e., symbols, letters, words, numbers, diagrams, maps, graphs, and charts that can affect academic literacy as much as everyday life (Frederickson & Cline, 2006; Groffman, 2006; Korkman, et al., 2007). According to Butterworth and Kovas (2013) "although the majority of learners can usually adapt to the one-size-fits-all approach of whole class teaching, those with SLDs will need specialised support tailored to their unique combination of disabilities."

While there is a need to teach VSPS at early ages, and to study the neural mechanisms that underlie these skills, the domain remains under-researched (National Council of Teachers of Mathematics, 2010; National Research Council 2006; Krakowski, Ratliff, Gomez & Levine, 2010).

c) Early assessments and interventions

There is an increasing recognition that early childhood is a particularly sensitive period in the process of development, cognitive functioning, behavioural, social and self-regulatory capacities (e.g., Dyson, et al., 2010; Murray, et al., 2010). The RAND Corporation (2012) has drawn attention to the fact that “Well-designed early childhood interventions have been found to generate a return to society ranging from $1.80 to $17.07 for each dollar spent on the program” (p.1). In short, an early identification of poor VSPS with appropriate intervention would: reduce long-term challenges in an ineffective acquisition of specific basic literacy and numeracy abilities, reduce the discrepancy between the learner’s actual achievement level and the learner real potential, and increase learners psychological and emotional wellbeing.

While, assessments and interventions of typical academic contents -the 3Rs (Reading, (w)riting and (a)rithmetic) have undergone considerable development over the last decades language-based learning disabilities has not received similar attention (National Council of Teachers of Mathematics [NCTM], 2010; National Research Council (NRC), 2006; Krakowski, Ratliff, Gomez & Levine, 2010). NCTM and NRC among others have called for the need of identifying and developing methods and procedures that support VSPS enhancement at earlier ages, to consider how to integrate VSPS-related performance into the curriculum in more general ways, and to think about how and when the use of new technologies with young children can lead to improvement.

d) Leaning in digital age

Technology is shaping the world we live in, and as a result, our students’ brains are rewiring and restructuring. Through wireless devices, visual messages, information are available at the touch of a button. Among the OECD, the European Commission, UNESCO and numerous other thinkers, The Partnership for 21st Century Skills (P21) has developed a “Framework for 21st Century Learning” - a vision for student success in the new global economy, increased migration and mobility. This framework asserts “As the 3Rs serve as an umbrella for other subjects and core content, the 4Cs (Critical thinking and problem solving,
Communication, Collaboration, Creativity and innovation) are shorthand for all the skills needed for success in college, career, and life”.

Dave Gray (2008, May 23), “Our world is changing fast – faster than we can keep up with our historical modes of thinking and communicating. Visual literacy – the ability to both read and write visual information; the ability to learn visually; to think and solve problems in the visual domain – will, as the information revolution evolves, become a requirement for success in business and in life.” "We’re leaving an industrial age and entering an information age, yet we continue to teach, and operate our schools, as if they were factories. In an information age, visually literate societies will succeed and thrive. Shouldn’t we be one of them?”(p.1)

Where do we go from here?

If we are to help students succeed in a 21st-century, to meet the needs of struggling children that can have an average or gifted IQ but may also have SLD, we must find ways to diagnosis and to enhance VSPS as we do for the 3R’s. Indisputably, there is a need for both assessment and integration of Visual spatial processing skills - “the neglect of a needed skill” within curriculum at early ages.

Given the volume of studies and publications available that shown encouraging results in learning all kind of skills and in almost in any domain through games (e.g., Egenfeldt-Nielsen, 2005; Prensky, 2010), the aim of this research project was to move one step forward into this direction. Toward this end, the “TangSolver”, which is a variation of the tangram game, was developed as an optimal solution. However, TangSolver is just a means to an end in the process of promoting the assessment, and training of VSPS within standard courses. It is hoped that implementing such an application in school promotes teaching and training VSPS-related skills in young children and in particular inspires researcher to further develop assessment and training procedures.

In the interest of brevity and providing a general illustration, the following sections describe the analysis of problems and the rational in the development of the TangSolver. Thereafter, an overview of this research project is provided.
Enhancing visuospatial processing skills in children

Visuospatial processing skills

Researchers and theorists in different areas have acknowledged that VSPS is not a unitary construct, but rather can be broken into a collection of sub-skills or components (Carroll, 1993; Eliot & Smith, 1983; Kaufman, 2007; Lohman, 1988; Sutton & Williams, 2007). Visual and spatial cognition emerge from a wide range of disciplines such as psychology, geography, art, science. Arguably, as consequence of diversity of approaches and related discipline, the definition, and terminology used for labelling this set of skills varies between authors and over time, and is often interchangeable (e.g., D’Oliveira, 2004; Hegary & Waller, 2005). Furthermore, the particular number of separable sub-skills is unclear (e.g., Carroll, 1993). This has resulted in a great deal of confusion regarding their definition, underlying factors, and their classification, which in turn has hindered assessment and integration of VSPS into the curriculum (NJCLD, 2010).

In response to the above issues and as well in an attempt to address SLD’s The NCLD, (2003, 2009) has identified seven key sub-skills. These sub-skills and as well the typical characteristics that children with poor VSPS may demonstrate are presented in table 1.
### Table 1
**Visual Spatial Processing Sub Skills (NCLD, 2003)**

<table>
<thead>
<tr>
<th>Skill</th>
<th>Difficulties</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spatial visualization</strong></td>
<td>With spatial relationships such as distance, size, shape and how things fit together to form a whole. Visual spatial orientation will influence the way a person reads and writes letters, words and numbers, as the orientation of the letters and numbers is specific to the position on the page and to the surrounding letters and numbers on the page.</td>
</tr>
<tr>
<td><strong>Visual Discrimination</strong></td>
<td>With spacing letters and words such as reversal problem - &quot;b,&quot; &quot;d,&quot; &quot;p,&quot; and &quot;q,&quot; all look like the same symbol; reading maps - getting from one place to another. Difficulty in grouping of stimuli based on common characteristics in order to make sense of the written word or numbers. Difficulty toward abstract thinking.</td>
</tr>
<tr>
<td><strong>Visual Figure/Ground Discrimination</strong></td>
<td>In finding a specific bit of information on a printed page full of words and numbers. In perceiving whole/part relationships- to perceive letters that form a word and words that form a sentence. In seeing an image within a competing background.</td>
</tr>
<tr>
<td><strong>Visual Sequencing</strong></td>
<td>In staying in the right track while reading a paragraph- skipping lines, reading the same line over and over, reversing, or misreading letters, numbers, and words. Influence the way a person reads and writes words, sentences and numbers greater than nine or calculations, as the order of the letters and numbers is specific to the end result of the meaning represented by the letters in the words (such as saw and was), or numbers in the calculations (39-5=34 or 93-5=88).</td>
</tr>
<tr>
<td><strong>Visual Closure</strong></td>
<td>In recognizing a picture of a familiar object from a partial image (A truck without its wheels). In identifying a word with a letter missing.</td>
</tr>
<tr>
<td><strong>Visual Motor Processing</strong></td>
<td>In copying from a board or book. In participating in sports that require well-timed and precise movements in space.</td>
</tr>
<tr>
<td><strong>Visual Memory</strong></td>
<td>When the image is forgotten between taking it in and transposing it. These individuals have difficulty retaining spelling rules and unusually spelled words. Copying from the blackboard or any source for that matter is wrought with mistakes.</td>
</tr>
</tbody>
</table>
The role played by VSPS in learning

In today’s classrooms, and in many fields, textbooks, instruction materials, graphs, flowcharts are designed to use VSPS mentioned in table 1 as a key to mastering academic’s subjects matter (Kaufman, 2007; Lohman, 1988). Whereas the development of such materials continues to be an important concern, the increasing recent technological developments (Web 2.0, applications and concept maps) that rely heavily on VSPS have added further emphasis to the issue.

During the last decades, the relationship of separated visual spatial sub-skills and academic skills in young children has been widely investigated. To cite a few, for example in reading, even though both visual and auditory are fundamental, the initial cornerstone of reading is recognizing letter and words graphs - orthographic knowledge. Orthographic knowledge involves visual perception, visual memory, visual discriminatory, spatial orientation, (see table 1) and analytical aspects (e.g., Edelsky, 2006; Retief & Heimburge 2006). Alternatively, in a resolution of multi-digit problem, keeping track of the order in which to write numbers, their presentation on the page and the recognition of separate columns are required. The inability to keep track of these numbers is not due to weakness in mathematical concept understanding or in vision acuity but rather to poor VSPS, which is refer as “Spatial Acalculia” (Forrest, 2004; Geary, 1993). In understanding diagrams, Mayer & Sims (1994) have argued that students with low VSPS need to allocate more cognitive resources to construct an imagery object in working memory. This cognitive load decreases the amount of resources that students allocate to connect verbal and visual information leading in low performance. There is as well evidence that not only poor VSPS can lead to difficulties with learning, but also in overall school performance and even sports (e.g., Groffman, 2006; Korkman, et al., 2007; Frederickson & Cline, 2006).

Undeniably, some individuals have more developed VSPS than others, and even individuals with SLD differ in severity of the problems they encounter, which means that we are not talking about homogenous groups. Good visuospatial learners with SLD blossom when their right hemisphere is activated through imagery and visualization, hands-on activities and examination (Golon, 2008; Silverman, 2002). These learners outcompete people with SLD and poor VSPS with respect to intuition, originality, and the ability to synthesize information from a variety of sources. They are able to see detail and appreciate graphs, charts, and representations to make sense of, and develop an understanding of concepts and ideas (Fliss, 2006; Gregory, 2005; Silverman, 2002). Despite their visual spatial strength, they are at a disadvantage with class and achievement tests that are timed. Silverman (2001) states, “Being required to show their work is nearly impossible for some visual-spatial children, because they see it all at once, rather than arriving at answers through traditional steps and are poor at rote memorization”, “they just know. They don’t know how they know and they can’t explain to anyone else the route they took to the knowing—they just see it.” Both the one with weaker or strengthened VSPS sometimes appears to others as "self-absorbed" or "out to lunch". These children need the most support in elementary school when the
need to understand, manipulate, and build on visual symbols is most important (Davis, Rimm & Siegle, 2011; Golon, 2008; Subotnik, Olszewski-Kubilius & Worrell, 2011).

Given this, for learners who are experiencing VSPS challenges, learning becomes a tortuous task. These learners apply extensive effort on decoding visual instruction and manual output within the allocated timeframe, resulting in fatigue, stress, and lack of concentration on the content. More importantly, this stress can result in a cascade of emotions and behavioural problems (e.g., task avoidance or refusal within a classroom situation, irritable or aggressive behaviour) that interfere with everyday functioning in school, at home and in the community (Goldstein, 2005; Gordon & Browne, 2008; Kuhn & Siegler, 2006).

While there is limited amount of literature on assessment and interventions for school age children, there is evidence that VSPS can improve through practice and training of adolescents and adults (e.g., Uttal, et al., 2012). Among others, Butterworth and Kovas (2013) have stressed the attention to the specificity of the child’s cognitive profile and the fact that if we are to support our children there is a need to monitor and adapt to the learner’s current repertoire of skills and knowledge. Butterworth and Kovas said that “a promising approach involves the development of technology-enhanced learning applications - such as games - that are capable of adapting to individual needs for each of the basic disciplines.” Indeed, one potential solution and particularly for disengaged students who are not performing as well as they could, is to combine games with coursework.

Problems related to VSPS measurements

In the literature, measures of VSPS can be grouped into recognition tests (e.g., copying task, embedded figure and visual memory, mental rotation of shapes) and manipulation tests (e.g., block counting, block rotation, solving mazes, and paper folding) (Eliot & Smith, 1983). Despite the availability of numerous tests that have been devised to assess various aspects of spatial ability Johnson and Meade (1987), among others, have drawn attention to the fact that tests such as mental rotation (e.g., Shepard-Metzler Mental Rotation Test, Flags and Cards), spatial visualization (e.g., Hidden Patterns, Paper Form Board, Progressive Matrices, and the Vandenberg test, Block Design, and Guilford-Zimmerman spatial visualization), and tests for spatial perception (e.g., the Rod and Frame Test and the water level task) were originally designed for adults and adjusted to be used with children. Such adjustment for children involve clarifying the test instructions, reading aloud instructions or showing model items—all of which is likely to alter the nature of the test.

Others are debating the purpose and goal of standardized tests. For instance, current neurological or intelligence psychometric tests for children (e.g., Pattern Reasoning, Block Design of WISC or Matrix Reasoning of Kaufman Assessment Battery for Children) can provide an objective and standardized measure of particular VSPS sub-skills of a sample. However, the test is limited to assessing only the current performance, which may not be the best manner to assess how well a child can learn (Benson, 2003; Flanagan & Kaufman, 2004; Stenberg & Grigorenko, 2002).
Typically, psychometric (norm-referenced) tests focus on detecting learning disabilities, and the candidate’s eligibility for special education or related services. Such testing is considered as a “Discrepancy Model”—if a student’s score on the IQ test is at least two standard deviations (30 points) higher than his or her scores on an achievement test, the student is described as having a significant discrepancy between IQ and achievement and, therefore, as having a learning disability (e.g., NCLD, 2003, 2009). As pinpointed by psychologists and educators, this method has several limitations: (a) such measures do not provide enough information that educators can use to create programs to remedy a child’s learning problems (e.g., Grigorenko, 2009; Haywood & Lidz, 2007); (b) they do not allow schools to identify children as having learning disabilities while they are still in the primary grades; and (c) students often struggle for years prior to being identified as having learning disabilities rather than receiving the support they need in the early grades (e.g., NCLD, 2003, 2009). The National Research Center on Learning Disabilities (2010) reports that “a variety of factors can cause students to be misidentified as having learning disabilities, yet many states and districts have experienced a disproportionate representation of students from culturally and linguistically diverse backgrounds, based on traditional identification method”. The current trend favours classroom based assessments or formative evaluation as an added method to psychometric test.

Classroom based assessment or Formative assessment as coined by Black and Wiliam (1998) refers to "all those activities undertaken by teachers, and/or by students, which provide information to be used as feedback to modify the teaching and learning activities in which they are engaged." Classroom based assessment models can best be described by contrasting a traditional testing situation and assessment within training. In a traditional testing situation, one may receive a short instruction such as “Solve the following problems or select the best fit option below in the empty box” and an example problem may be provided. Typically, the test-taker is asked to proceed solving a number of such problems without receiving further help or feedback and generally within a limited time frame. Assessment within training differs to testing in regard to guidance and feedbacks that are provided through the problem solving process. In this process individuals are guided toward more successful achievements (e.g., Shute, 2008).

Despite the promises of such assessments, the implementation of these techniques remains challenging (for overviews see, Hale, et al., 2010). Some of the barriers include, but are not limited to the complexity of the interventions in term of materials and resources, time required implementing them, and lack of evidence of the effectiveness. More importantly, many forms of cognitive assessment are not related to training and intervention (Fletcher-Janzen, 2008; Hale, et al., 2010). Given this state of affairs, one of the main challenges in designing TangSolver was to circumvent these barriers (for more details see chapters 2, 3 and 4).

**Steps toward the development of a VSPS assessment and intervention: The TangSolver**

There is increasing interest in the use of games as an educational technology, and there is evidence that ‘good’ games already embody sound pedagogy (e.g., Prensky, 2006, 2010). However, while
Uncountable educational games exist, the number of games that are designed for VSPS assessment and enhancement in children is very limited. In the following chapters, more detail on structure and use of the application developed is provided; so here I will restrict myself to the very first steps taken toward the development of TangSolver.

Typically, teaching visuospatial problem solving can be addressed through learning theories (how individual can learn and the development concepts), and individuals in their approaches to learning (Omrod, 2008; Pashler, McDaniel, Rohrer & Bjork, 2008), and different instructional type such as dual coding theory (DCT) (Paivio, 1986), and cognitive theory of multimedia learning (CTML; Mayer, 2001, 2009; Mayer & Moreno, 2003). In designing TangSolver, three issues discussed by these theoretical frameworks were of particular importance:

**The game type: computerized vs. manipulative**

One of the hindering difficulties of assessment and training is that both are time consuming—a cost effectiveness issue that seems to favour computer-based assessment and intervention. Unfortunately, there is no conclusive evidence that computerized assessment and training produces equal or even better performance gains than face-to-face instruction (e.g., Pennington, 2010; Ramdoss, et al., 2011). However, computerized applications have a number of practical and methodological advantages, including the promotion of autonomy and self-learning, and the generation of more accurate measures of the learning process, such as the time between mouse clicks, solution moves etc., that are tapping into the use of strategies (e.g., Aleven et al., 2010; Baker et al., 2010; Feng & Heffernan, 2010; Shute & Zapato-Rivera, 2012).

**Individual differences in response to instruction**

Individuals differ greatly with respect to their preference for face-to-face instruction or autonomous, computerized learning without much personal interaction (Omrod, 2008; Pashler, McDaniel, Rohrer & Bjork, 2008). Furthermore, games used for teaching are distinct from other forms of classroom teaching, so that the instructional design for games is also distinct. Arguably, what matters for efficient instruction is not just the medium being used, but much more research effort has been spent on the type of instruction that supports literacy down to the type of instruction supporting the enhancement of VSPS. Indeed, a wide variety of theories and instructional approaches exist, as I will describe in more detail in chapters 2 and 3. In short, instructional or guidance can be purely verbal (i.e. check this part, give concrete examples, suggestions for what to do next), purely visual (scaffolding, showing partial or complete solution), or both. Clearly, “different modes of instruction might be optimal for different people because different modes of presentation exploit the specific perceptual and cognitive strengths of different individuals” (Pashler et al., 2008, p.109).
Adapting existing games or designing new ones

Obviously, designing a new game requires a lot of effort, time, and money, so that our first consideration was to adapt an existing game for our purposes. However, even though many Tangram games are freely available, none of them allowed for integrating the program parts necessary for testing and assessment of particular VSPS sub-skills. Adjusting existing games, in turn, was impossible because of legal issues, because the source code was not available, and because the necessary structural modifications would have taken more time than developing an independent game—an frequently observed cost-effectiveness issue (Iuppa, Borst & Terry 2009). Given these problems, we developed “TangSolver”, together with an equivalent manipulative version of the game suitable for face-to-face training; see chapters 2 and 3. In this project a pretest-training-posttest format was used. The computerized TangSolver Test was administered for pre- and post-testing, whereas in the training we used either the TangSolver Training application for the face-to-face version; see chapters 2, 3 and 4.

Measures of VSPS sub-skills

Geometric knowledge has been used to evaluate various visuospatial problem solving abilities (Dehaene et al., 2006; Lovett & Forbus, 2010, 2012; Van Hiele, 1999). For example, Raven's Matrices, Block Design of WISC, or Kohs’ blocks, measure an individual’s ability to analyze, synthesize, and reproduce an abstract design. To evaluate children's performance on a visuospatial task we have chosen the puzzle-like Tangram game. The classical Tangram puzzle consists of creating particular shapes or figures by assembling seven geometrical forms. Importantly for our purposes, there is evidence that dealing with puzzles of that sort tap into spatial visualization abilities (for a review see, Hegarty et al., 2007). However, there is no unique method and/or procedure of assessing VSPS, and the definitions and numbers of components mentioned earlier vary among authors; in the development of TangSolver we focused on two of these components: spatial visualization and mental rotation.

Spatial visualization. A widely accepted definition proposed by Linn and Petersen (1985) is that “spatial visualization is the ability in which complex spatial information is manipulated when several stages are needed for solving the tasks” and spatial visualization skills involve multi-step manipulations of spatially presented information that require analysis of the relationship between forms and different spatial representations. TangSolver can be compared to the pattern modeling tasks of Block Design (BD) of WISC are that measure spatial visualization. The BD tasks consists in assembling red-and-white blocks to recreate a constructed model or a picture from the stimulus book. While such tasks are good predictors of individual’s variance in spatial visualization performance, they do not allow an evaluation of visual discrimination (distinguishing whole/part relationships). To overcome this issue we adopted a method from researchers in the domain of autism (Shah & Frith, 1993), who used the BD test to evaluate whole/part relationships (global vs. detail) visual processing of autistic individuals. They argued that while the standard
picture of the stimulus book represents a whole figure (the composite parts of the figure were not visible) taps global processing, segmented figures (the composite parts of the figure were visible) tap details processing. Shah and Frith thus state that the BD test can be used to assess both top-down (whole) and bottom-up processing, based on whether local connections (lines, contours) between the puzzle pieces are applied globally or to detail. As I will explain in more detail in chapters 2 and 3, I have used a similar technique to assess global and local processing in my participants.

Mental rotation. Mental rotation involves the ability to rapidly and accurately rotate mentally two- or three-dimensional figures (Linn & Petersen, 1985). Solving tasks employed in my experimental material required that one notices different possible shape transformations. I constructed two sub-tests: One did not require any mental rotation but could easily be solved by media dragging and dropping puzzle pieces—a condition that I will refer to as “simple transformations test.” The other did require mental rotation, an initial flip or rotation of MPs followed by drag and drop—a condition I will refer to as “complex transformations test.”

Selection of item pool

According to Flaugher (2000), in the development of any assessment there is a need for a systematic approach that entails an analysis of the pedagogical quality of the items, evaluation of the degree of discrimination, satisfactory number of items for each level of ability, and a reasonable estimated testing times (notably, there is little that educational technology can contribute to improve formal or informal student learning without intensive involvement of teachers and pedagogically knowledgeable instructional designers). Accordingly, I developed a pool of test items together with six teachers of primary schools, who were also involved in the final item pool construction. The results of several pilot studies (not reported in this thesis) and suggestions were considered and discussed prior to the eventual study design.

For item construction, we used the Simple Logistic Model of Rasch (one-parameter logistic model within item response theory), that is based on the probability of a specified response to a set of items (such as score 0/1 for in/correct response). The two parameters, one for the respondent’s (person’s) ability, and one for item difficulty are estimated on a single scale in the form of a graph which allows comparison of the person distributions with the item distributions. From both statistical analysis as well as clinical judgment, we made the choice on the final item inclusions and the development of the manipulative material (see chapter 2). Based on our primary results of the manipulative material and other pilot studies the current TangSolver application was developed.

The reliability of the computerized TangSolver test is reported in chapter 3, however, item pool construction, and the design of strategies and the process of finding successful interventions is a dynamic and ever changing process that cannot be reached straightforwardly. Hence, a single statistic cannot determine the validity or the reliability of any test or experiment material. Furthermore, outcomes vary according to individuals who are being tested. It is acknowledged that TangSolver is just a means to an end.
in the process of promoting the assessment and training of VSPS within standard courses, and that there is a need for further experiments.

**Overview of the research**

The major aim of this research project was to move one step toward assessment and training of VSPS of school age children. To this end, we have developed a computerized application called TangSolver. Such project entails a holistic multidisciplinary approach and requires a thorough understanding of programming and software design, as well an understanding of learning theories, their application, and instructional design theories. Ultimately mapping the terrain for such project requires more than one introductory chapter and as well further report on the almost unlimited potential of measurement and interpretation of findings. Although the development of the application has been an important concern of the author, we do not seek to provide a review of technical and software design that is beyond the scope of a psychological thesis. I will thus confine this thesis to the conceptual framework of VSPS, VSPS enhancement, and the evaluation of the relative effectiveness of TangSolver for this purpose.

This introductory chapter has outlined the challenges associated with the importance of assessment and training of visuospatial processing skills - almost an unexplored arena in particularly among young children (Spatial Intelligence and Learning Center). Chapter 2 provides a theoretical rational for the development of the manipulative set and evaluation of its effectiveness. Chapter 3 describes the effectiveness of TangSolver as compared to a conventional face-to-face training regime and a non-training control group. The efficacy of visual cues (picture scaffolding) vs. multimodal teacher instruction, and the effect of training in a simple transformation test vs. a complex transformation test is reported. Chapter 4 tests a specific hypothesis related to possible differences in global and local VSPS between children with autism and typical children. Chapter 5 concludes with a general discussion of findings.

My main hypotheses were that: (a) learning by doing can improve VSPS (Shute, 2007); (b) multimodal instruction (verbal and visual cue) and visual cues can be used to further support students’ VSPS; and (c) both computerized and face to face instruction can improve VSPS. Ultimately, it is hoped that implementing such applications in school promotes teaching and training VSPS and related skills in young children and inspires researchers to further develop VSPS assessment and training procedures. Finally, the data obtained in my experiments are likely to motivate changes to the gaming environment and the creation of new assessment and intervention games (e.g., Aleven et al., 2010; Baker et al., 2010; Feng & Heffernan, 2010; Shute & Zapato-Rivera, 2012).