UNIVERSITY OF SZEGED
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HAO WU

IDENTIFYING THE INFLUENCING FACTORS OF PROBLEM SOLVING: A CROSS-NATIONAL STUDY

SUMMARY OF THE PHD DISSERTATION

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THE CONTEXT AND STRUCTURE OF THE DISSERTATION

Nowadays, our society and environment keep changing all the time, the technologies used in almost every industry sector are also developing quickly. This situation means that the content of applicable knowledge evolves rapidly. People are facing problems almost every day:simple or complex ones, fixed or dynamically changing ones, familiar or completely new ones. Problem solving is thus considered to be one of the most important 21st-century skills (Dede, 2010). Improving students' problem-solving skills has become one of the main aims and challenges in contemporary education (Greiff, Holt, & Funke, 2013). This study focuses on one specific kind of problem solving, which is called interactive problem solving in the MicroDYN approach.

Problem solving is a transversal skill (Greiff et al., 2014), operating several mental activities and cognitive skills (see Molnár, Greiff, & Csapó, 2013). Thus, defining its direct development in general is not a realistic research task, but we can define the development of solving different kinds of problems and we can map the skills, which have an effect on its development.

This study aims to detect the component skills of interactive problem solving in the MicroDYN approach (IPS). It tests structural relations and the predictive value of cognitive background variables on the development of IPS, thus provide the possibility to develop an effective training program on problem solving based on the research results regarding the component skills of IPS. Detecting and identifying differences in the mental and cognitive aspects for students with different cultural backgrounds in the IPS environment (see e.g. OECD, 2014; Wüstenberg et al., 2014) is also one of the emphases of this study. China (mainland) and Hungary were involved in this cross-national study. Generally, the study aims to contribute to further understanding of the cognitive construction of interactive problem solving in the MicroDYN approach; and to highlight the similarities and differences regarding development and component skills of IPS in Hungarian and Chinese educational context.

The literature review part of the dissertation starts with a discussion of the definitions of the basic terms of this study: problem, and problem solving. There are still no universally accepted definitions available for these two terms. The dissertation reviews the definitions which have been offered in the past, and discusses different definitions proposed at different times or with different theoretical bases. It also introduces different types of problem solving (e.g. domain-specific & domain-general; static & dynamic; interactive; ill-defined & well-defined).

We also introduce the development of different approaches which focus on measuring problem solving and we provide an overview of the evolving problem-solving assessment methods: from paper-and-pencil to computer-based, and from first generation computer-based to third generation computer-based assessment of problem solving. Beyond the illustration of the different assessment methods for varying types of problem solving (analytical, interactive, collaborative), we discuss more deeply the challenges and potentials in computer-based assessment of problem solving, where log-file analysis – an unique feature provided by modern technologies – plays an important role.

Several thinking skills and non-thinking skill factors have the potential to influence one's problem-solving achievement (Greiff et al., 2014; Molnár, Greiff, & Csapó, 2013). This dissertation selects those cognitive skills (e.g., inductive reasoning, combinatorial reasoning, creativity) and socio-economic or affective factors (e.g., gender, parental education, test-taking motivation) which proved to be the most influential ones in small or large scale national studies (Casakin, 2007; Greiff et al., 2015; Molnár, Greiff, & Csapó, 2013; OECD, 2014) and which have been the most frequently mentioned in the literature (Bisanz, Bisanz, & Korpan, 1994; Hamers, De Koning, & Sijtsma, 2000; Herrmann, 1995; Molnár et al., 2017). We illustrate the relations between these selected, mostly reasoning skills and different background factors with problem solving.

Finally, the theoretical section reviews the available research results regarding Chinese and Hungarian students' problem solving performance in cross-cultural context. We strongly lean on the referring PISA results, as both China (represented by Shanghai) and Hungary attended the PISA 2012 problem-solving assessment. This part analyzes and evaluates their performance in this assessment, and analyzes their advantages and disadvantages. It also reviews the problem-solving research in China and in Hungary, separately. And finally, this part discusses why this study is important and necessary to be conducted across China and Hungary.

Base on the literature review, the theoretical analyses, and the research aims, the dissertation formulates eight research questions and puts forward corresponding hypotheses. Using the Hungarian experiences regarding assessment of IPS in educational context (Molnár, Greiff, & Csapó, 2013; Molnár et al., 2017), two studies, one pilot study in China and one comparison study across China and Hungary were designed and conducted to answer the research questions and testify the hypotheses.

The pilot study was implemented with the aim to test and prove the feasibility of computer-based online assessment of thinking skills in China. Beyond the regular information such as the sample of the study and the procedures, the instruments part of the method section introduces the used assessment instruments in a very detailed form, including the original sources, development histories, operating methods and provides sample items. As a result of the pilot study conducted in China, we concluded that computer-based online assessment of thinking skills is feasible in China independently of the type of tests (first, second or third generation).

The design and realization of the cross-national comparison study draws on the experiences collected from the Chinese pilot study and was carried out earlier regarding the Hungarian online assessments of IPS. In the pilot study section we also follow the regular introduction of an empirical project, thus the method part discusses the sample, the instruments (some modification were made after the pilot study), and the procedures. The structure of the result part follows the order of the research questions. Because of their novelty, complexity and importance, the results referring to the research questions on Chinese and Hungarian students' exploration strategies in interactive problem-solving environment using log-file analyses with state-of-art procedures for answering research questions, which could not have been answered by means of traditional assessment techniques and analyzing methods, are discussed in a separate section.

The final part of the dissertation summarizes the results and briefly answers shortly the research questions. Furthermore, the limitations and originality of this study are also stated.

THEORETICAL BACKGROUND

Several definitions and theoretical models of problem solving have been published in the literature (for an overview see Sternberg, 2013; Frensch, & Funke, 1995). This study adopted Frensch and Funke's (1995, p. 18) definition of problem solving which states that problem solving is a goal-directed "thinking that occurs to overcome barriers between a given state and a desired goal state by means of behavioral and/or cognitive, multistep activities." The problem solver has to organize information and to deal with ill-defined or more or less well-defined goals. The problem solver does not immediately know, how to solve the problem or how to reach the goal (Frensch, & Funke, 1995).

Most of the early research on problem solving were typically conducted with relatively simple, and laboratory tasks which were novel to subjects.For example, Ewert and Lambert (1932) used the disk problem (now it has a more common name: Tower of Hanoi) in their problem-solving research. However, starting from 1970s, it has been gradually realized that empirical findings and theoretical concepts which came from simple laboratory tasks were not generalizable to more complex real-life problems (Frensch, & Funke, 1995).

Moreover, these realizations have led to rather different research directions in North America and in Europe (Anzai, & Simon, 1979; Bhaskar, & Simon, 1977; Funke, 1991). North American research on problem solving has typically concentrated on domain-specific problem solving, examining the development of expertise in separate, natural knowledge domains, such as mathematics (Sokol, & McCloskey, 1991), reading (Stanovich, & Cunningham, 1991), computer skills (Kay, 1991), etc., and on the task - problem solver interaction; while much of the European research is about general problem solving, which focuses on solving processes of complex, real-world, unknown problems (commonly performed with computerized scenarios), and on the characteristic features of problems to be solved (Funke, 1991).

Meanwhile, problem solving can also be divided into static and interactive problem solving. In static problem solving environment, the task itself, thus the information provided for the problem solver stays static and non-changeable. The problem solvers need to analyze these pieces of information to be able to solve the problem (Greiff et al., 2013). Along with the development of problem-solving theory and technology (especially computer technology), interactive problem solving gradually replaced analytical problem solving as the mainstream in academic research (Frensch, & Funke, 1995). Interactive problem solving (IPS) is "characterized by the interaction between a problem solver and the problem to generate and integrate information about the problem" (Greiff et al., 2013, p. 76). And in IPS, relevant information needs to be actively generated, problem solvers need to have direct interaction with the problem to uncover and discover relevant information (OECD, 2010). In the interactive problem-solving environment, the problem solver has to use *knowledge acquisition* and *knowledge application* to apply non-routine actions to reach a certain goal state (Greiff, Holt, & Funke, 2013). *This study focuses on domain-general interactive problem solving.*

Currently, computer-based assessment is becoming increasingly popular. There are three ways for using computer to measure cognitive skills as well as 21st-century skills (Molnár et al., 2017). The first generation computer-based test was close to static paper-pencil based assessment. The stimulus for this kind of test is still static, just the delivery platform has evolved to computer (Molnár et al., 2017; Pachler et al., 2010). The second generation computer-based test started to use new stimuli formats which cannot be realized by the paper-and-pencil assessment, such as multimedia. Meanwhile, it also employs some techniques, including but not limited to constructed response, automatic item generation, and automatic scoring (Molnár et al., 2017; Pachler et al., 2010), thus boosts the assessment efficiency and makes some forms of assessment (e.g. self-assessment, adaptive testing, etc.) possible to be implemented. Many cognitive skill assessment types are designed in the scope of second generation computer-based testing (e.g. Kambeyo, & Wu, 2018; Molnár, Greiff, & Csapó, 2013). However, second generation computer-based tests are still not able to implement the assessment of interactive problem solving, because they cannot realize “interaction”, the key feature of IPS. Therefore, the third generation computer-based test was created to “allow students to interact with complex simulations and dynamically changing items” (Molnár et al., 2017, p. 126). Currently, information and communication technologies provide new opportunities that can revolutionize the educational assessment and evaluation process (Csapó, Lőrincz, & Molnár, 2012). One of the major advantages is that the current ICT technology is able to support computer-based testing to provide a unique assessment environment, where both dynamic and interactive situations are available (Greiff et al., 2014).

The assessment approach MicroDYN, which is based on multiple complex systems within the linear structural equation (LSE) framework (Funke, 2001), is widely accepted and employed by researchers for designing interactive problem-solving assessment (see Csapó, & Molnár, 2017; Greiff, Krkovic, & Hautamäki, 2015; Greiff, & Wüstenberg, 2014). It has also been applied in one of the most prominent large-scale assessment projects in the PISA 2012 problem-solving assessment (OECD, 2014). Each MicroDYN task contains up to three input variables, which are related to up to three output variables. The relations between input variables and output variables can be described by linear structural equations (Greiff et al., 2013). In the knowledge acquisition part, problem solvers have to interact with the system by changing the values of the input variables, and observe the corresponding changes of the output variables, so as to find out the relationships between input and output variables. In the knowledge application part, problem solvers have to solve the given problems by assigning appropriate values to the input variables, to make the output variables reach the required range (Molnár, & Csapó, 2018).

Several theoretical and empirical studies have discussed that students' problem-solving achievement can be impacted by their working memory (Andersson, 2006; Bühner, Kröner, and Ziegler,2008; Greiff et al., 2015; Söderqvist et al., 2012), and some cognitive skills such as inductive reasoning (Greiff et al., 2015; Hamers et al., 2000; Molnár et al., 2013), combinatorial reasoning (Batanero, Godino, & Navarro-Pelayo, 1997; Csapó, 1999; OECD, 2014), and creativity (Binkley et al., 2012; Casakin, 2007; Herrmann, 1995; Pásztor, Molnár, & Csapó, 2015). Previous studies have also pointed out that problem-solving achievement can also be impacted by some non-cognitive factors, such as test-taking motivation (Frensch, & Funke, 1995; Hackman, & Oldham, 1976), gender (Wittmann, & Hattrup, 2004; Wittmann, & Süß, 1999), parental education (Dubow, Boxer, & Huesmann, 2009; OECD, 2014), and learning strategies (Csapó, & Molnár, 2017; Molnár et al., 2017). In order to detect the influencing factors of interactive problem solving, these skills and factors have been measured in this study.

Wüstenberg et al. (2012) stated that creation and implementation of strategic exploration are the core actions of the problem-solving task. Effective information exploring and generating is the key to successfully solve a problem. The isolated variation exploration strategy has been frequently discussed and mentioned in interactive problem solving research. The isolated variation strategy can also be referred to as the "Vary-One-Thing-At-A-Time-Strategy" or VOTAT (Vollmeyer, Burns, & Holyoak, 1996). To be more specific, with the VOTAT strategy "the problem solver systematically varies only one input variable, while the others remain unchanged. This way, the effect of the variable, that has just been changed, can be observed directly by monitoring the changes in the output variables" (Molnár, & Csapó, 2018, p. 2). Some previous studies have indicated that students who are able to apply VOTAT are more likely to achieve higher performance in a problem-solving environment (Greiff et al., 2018), especially if the problem is a minimal complex system (such as MicroDYN) (Fischer et al., 2012).

Domain-general interactive problem solving has been widely assessed in Europe, but not outside of it, in the USA or in China. Much of the research in China has focused on domain-specific and not on domain-general problem solving. Both China (represented by Shanghai) and Hungary participated in the PISA 2012 problem solving assessment (OECD, 2014). On the one hand, Chinese students belong to the top performers in the PISA 2012 problem solving assessment (OECD, 2014), but, on the other hand, the achievement proved to be significantly lower than expected based on the achievement in the three main areas (mathematics, reading and science). By contrast, Hungarian students' problems solving performance in PISA 2012 was unsatisfactory (ranked to the 33th place out of 44, OECD, 2014). Thus, both Chinese and Hungarian students had the necessity and possibility to improve their problem solving skills. In order to reach this goal, we need to measure and analyze the developmental level of Chinese and Hungarian students' problem-solving skills, to detect cognitive and noncognitive factors influencing their achievement, and to map and compare the component skills of problem solving in China and in Hungary.

RESEARCH AIMS, QUESTIONS, AND HYPOTHESES

The study aimed to contribute to our further understanding of the cognitive construction, of the component skills of interactive problem solving (IPS), and highlight the similarities and differences existing in students from Hungarian and Chinese cultures. Particularly, at the first stage, the study aimed to testify the feasibility and reliability of computer-based assessment in Chinese educational context. Moreover, the study aimed to detect the nature of problem solving, especially interactive problem solving in the MicroDYN approach, by analyzing the dimensionality of IPS, testifying the component skills of IPS, and exploring further cognitive and affective factors, which influence students' achievement in the IPS environment. Moreover, a comparison study between Chinese and Hungarian students was conducted to explore the similarities and differences in the cognitive construction and exploration strategies of IPS in European and Asian educational contexts.

The study thus intended to answer 8 research questions and examine the corresponding hypotheses.

RQ1. Is computer-based assessment feasible in educational context in China? Particularly, how reliable can the third-generation online test of IPS, the second generation online tests of inductive reasoning, combinatorial reasoning, and creativity be applied in the Chinese cultural and school network environment?

H1: Computer-based assessment, as well as the tests in this study can be reliably applied in the Chinese cultural and school network environment.

RQ2. Is the behaviour of the tasks measuring knowledge acquisition and knowledge application as two dimensions of IPS in the MicroDYN approach independent of cultural context?

H2: IPS is composed of two different processes, knowledge application and knowledge acquisition, independently of the cultural context. That is, a two-dimensional model was expected to show significantly better fit than a one-dimensional model with the two processes combined as one factor.

RQ3. Can IPS be measurement invariant across gender and nationality both in the contexts of Europe and Asia?

H3: IPS can be measurement invariant between male and female, and Hungary and China.

RQ4. Can developmental differences in IPS be detected between Hungarian and Chinese 12-year-old students, 3 years before the PISA age?

H4: Developmental differences in IPS can be detected between Hungarian and Chinese 12-year-old students.

RQ5. What kind of developmental differences can be identified across gender and nationality, between Chinese males and females, and between Hungarian males and females?

H5: Chinese 12-year-old students have significantly better performance than Hungarian students in the same age group; Chinese and Hungarian boys' performance is statistically higher or equal to that of the girls.

RQ6. Are inductive reasoning, combinatorial reasoning, and creativity component skills of problem solving? How strong is their predictive power on the problem solving achievement of Chinese and Hungarian 12-year-old students?

H6: Inductive reasoning, combinatorial reasoning, creativity are component skills of problem solving, which have significant predictive power on the problem solving achievement by Chinese and Hungarian 12-year-old students.

RQ7. Which factors influence Chinese and Hungarian students' IPS achievement beyond thinking skills? How strong is the influential effect?

H7: The selected non-thinking skill factors (working memory, parents' education, learning strategies, and test-taking motivation) have a significant influential effect on Chinese and Hungarian students' IPS achievement.

RQ8. Do Chinese and Hungarian students employ different exploration strategies during the problem-solving process? How do their exploration strategies influence their problem-solving performance?

H8: Chinese and Hungarian students employ different exploration strategies during the problem-solving process. The adoption of different exploration strategy can lead to different problem-solving performance.

PILOT STUDY: THE FEASIBILITY OF COMPUTER-BASED ASSESSMENT OF REASONING SKILLS IN CHINA

Aims

The pilot study aimed to answer research question RQ1 and verify hypothesis H1.

Samples

This study aimed to explore students' developmental level of problem solving at the beginning of the developmental phase (around 12 years of age, see Molnár, Greiff, & Csapó, 2013). The participants for the pilot study were drawn from a group of 12-year-old students. 50 Chinese students (27 boys; 23 girls) attended the pilot study. All of the participants were six graders (age M=12.28, SD=.50).

Assessment instruments

The computer-based test of IPS was developed in the MicroDYN approach (Greiff et al., 2012; Wüstenberg et al., 2012). The language was translated into simplified Chinese with language experts' double checks. This study adapted the Hungarian version of the inductive reasoning (four-dimension: figural series, figural analogy, number analogy, and number series; Csapó, 1997; Csapó, Molnár, & Tóth, 2009; Molnár, 2011), creativity (Pásztor, Molnár, & Csapó, 2015), and working memory (Kyttälä et al., 2014) tests into Chinese. A background questionnaire was delivered to the students. The questionnaire asked about the students' age, gender, parental education, and learning strategies (adapted from PISA 2003, Artelt et al., 2003).

Procedure

The tests were carried out using the eDia (Electronic Diagnostic Assessment) platform (Csapó & Molnár, 2019) in the school's ICT room in June, 2016. Test completion was divided into three sessions, each lasting approximately 45 minutes. In session 1, students worked on the inductive reasoning test. In session 2 students had to complete the IPS test, while in session 3 they worked on the working memory test, the creativity test, and the questionnaire. Students' score for each test (except for the creativity test) is automatically calculated by the eDia platform. As the theoretical part introduced, combinatorial reasoning is also very much possible to be one of the component skills of problem solving. However, the combinatorial reasoning assessment instrument was not fully prepared before the pilot study implementation. Thus, it was not included in the pilot test.

Results and Discussions

The pilot test was successfully implemented. According to the interviews after the assessment, students had no problem with the operation of our computer-based assessments. Students' mean performance for problem-solving, inductive reasoning, and creativity tests was 47.73% (SD=21.78%), 80.33% (SD=8.63%), and 2.91 (SD=4.02) respectively. The Cronbach's alpha for these three tests ranged from .72 to .90. To answer research question RQ1, the results proved that computer-based assessment of thinking skills is feasible and reliable in China, and the tests are also reliable to measure Chinese 12-year-old students' thinking skills. (RQ1) Thus, *hypothesis H1 was supported*.

Rasch analysis was conducted to analyze whether the difficulty level of the IPS test fits to students' ability level. The results indicate that some IPS items proved to be difficult for the students. All of the hard items contained eigendynamics (see Greiff et al., 2013), which increased the difficulty level of the item in a significant manner. As for the inductive reasoning test, there were a great number of items which were too easy for the participating students. These items mainly belonged to the figural analogy and figural series subtests.

Based on the literature, we tested the two-dimensional measurement model including the IPS processes knowledge acquisition and knowledge application to confirm the dimensionality of IPS in China. Beyond the two-dimensional measurement model, we also tested a one-dimensional model with both processes combined under one general factor. Both models showed a good model fit, and there was no significant difference detectable between these two models ($p>.05$). The result suggested that IPS can be explained as both one-dimensional and two-dimensional construct; however, due to the small sample size of the pilot study, we cannot make large generalizations of it. As the two-dimensional model is favored and empirically proved in all large-scale assessments in Europe, and its Chi-square value was smaller, we decided to use it in our later analyses.

A correlation matrix was built to indicate the relations between the developmental level of the different thinking skills. Significant correlations were detectable between problem solving - inductive reasoning ($r=.440$, $p<.01$) and inductive reasoning - creativity ($r=.363$, $p<.05$). But there was no significant correlation between problem solving and creativity. However, since the correlation analysis was based on the small sample size, some correlation relationships were hard to be detected and confirmed in the statistical means. Working memory also showed significant correlations with problem solving ($r=.522$, $p<.05$), but no significant correlation was detected between working memory and inductive reasoning; and working memory and creativity.

The independent t-test analysis results showed there was no significant gender difference detectable ($p>.05$). Students with different parental educational levels also indicated statistically equal performance in the thinking skill tests ($p>.05$). Students who preferred memorization strategies in their studies had a significantly lower performance in the inductive reasoning test than students who did not prefer memorization during learning ($t= -2.94$, $p<.05$). In the meanwhile, students who preferred control strategies performed significantly better in the problem solving ($t=2.20$, $p<.05$), in the inductive reasoning ($t=2.81$, $p<.05$) and in the creativity ($t=2.20$, $p<.05$) tests than their peers.

A structural equation model (Fig. 1) was built to test the component skills of problem solving, and the factors influencing students' problem solving skills. The model showed a good model fit (RMSEA=.00; SRMR=.03; CFI=1.00; TLI=1.02).

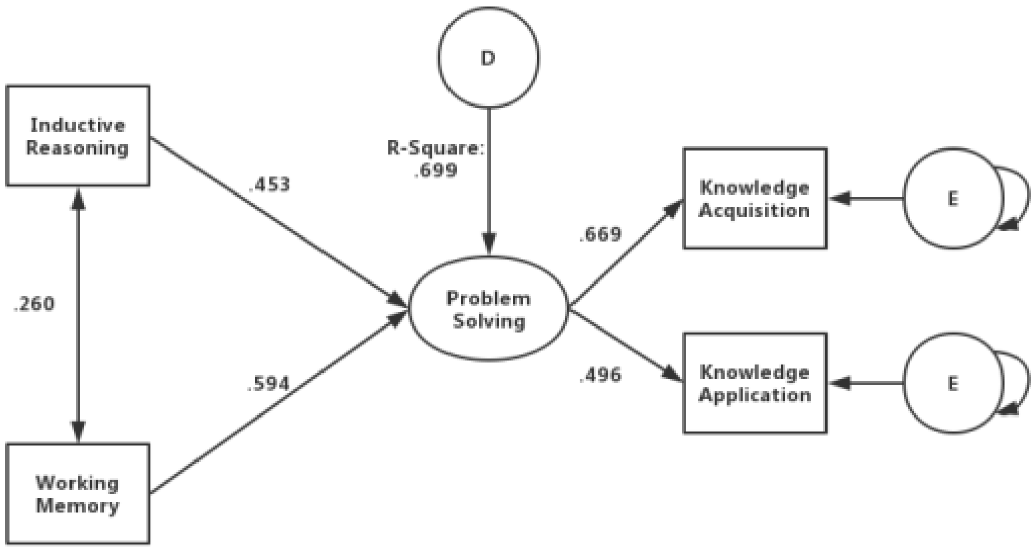

Fig. 1 Structural equation model of problem solving and its influencing factors - pilot study

This model applied problem solving as a latent construct in the model, which can be explained by knowledge acquisition and application (β=.496-.669; $p<.01$). Inductive reasoning and working memory showed significantly positive influence (β=.453-.594, $p<.05$) on one's problem solving achievement in the SEM model, while working memory and inductive reasoning proved to be significantly correlated constructs (r=.260, $p<.05$). Other factors did not show any statistically significant effect on problem solving in the SEM model, however the pilot study had a very strong limitation with its small sample size.

CROSS-NATIONAL COMPARISON STUDY OF PROBLEM SOLVING AND ITS INFLUENTIAL FACTORS IN EDUCATIONAL CONTEXT

Aims

This comparison study aimed to answer research questions RQ2-RQ7, and test hypotheses H2-H7. The creativity test was excluded from the comparison study because its scoring process is extremely time consuming. Corresponding changes were made in research question RQ6 and hypothesis H6.

Samples

The sample was drawn from 6th grade. 12-year-old students in Hungarian and Chinese primary schools. 187 Chinese students (85 boys and 102 girls; mean age =11.93, SD=1.06) and 835 Hungarian students (382 boys and 453 girls, mean age=11.86, SD=.43) took part in the study. The sampling process emphasized the background matching, thus these two groups of students had similar social and family backgrounds.

Assessment instruments

Some modifications were made in the tests based on the results of the pilot study. From the IPS test we deleted all the problems having eigendynamics, because those proved to be too difficult for the 12-year-old students based on the pilot study. We also increased the difficulty level of the inductive reasoning test for Chinese students by deleting easy items and adding harder items to the test. A combinatorial reasoning test was adapted (two-dimension: verbal and figural; Csapó, 1999; Pásztor, & Csapó, 2014) and included in the comparison study. The items delivered to Chinese and Hungarian students were not completely the same. However, both the Chinese and the Hungarian test versions contained a certain proportion of anchoring items, thus, by means of items response theory we were able to represent Chinese and Hungarian students' ability level on a common scale.

Procedure, data analyses

The whole assessment was carried out using the eDia platform in the schools' ICT room in June and July, 2017. The assessment took two hours in total, divided into three 40-minute sessions.

Session 1: IPS assessment (combined with test-taking motivation questionnaire).

Session 2: Inductive reasoning assessment, working memory assessment.

Session 3: Combinatorial reasoning assessment, background questionnaire.

All the items were administered in simplified Chinese in China and in Hungarian in Hungary. For all the tests (IPS, inductive reasoning, combinatorial reasoning, and working memory) students' performance were scored as dichotomous variable (1: provided correct answer; 0: did not provide correct answer). Students' scores were automatically recorded and calculated by the eDia platform.

Results and Discussions

The reliability indices were satisfactory for every test, for both the Chinese (ranging from .90 to .96) and Hungarian (ranging from .84 to .92) samples. The high internal consistencies confirmed that the assessment was reliable. The means for the problem-solving, inductive and combinatorial reasoning tests ranged from 40% to 60% for the Chinese sample and from 33% to 68% for the Hungarian sample, which were close to the assumed optimal value (40%-60%) and ideal for analysis. Based on the Rasch model analysis, the difficulty levels of all the thinking skill tests generally fitted the students' ability levels.

In the theoretical model of the IPS test, the two subscales were knowledge acquisition and knowledge application. Based on confirmatory factor analysis, we tested both with the one-dimensional (with both processes combined under one general factor) and the two-dimensional models, whether the processes knowledge acquisition and knowledge application could be empirically distinguished or not. Chi-square-difference test showed that the 2-dimensional model fitted significantly better than the 1-dimensional model (CN: Chi-square=12.98, $p<.01$, HU: Chi-square = 78.57, $p<.01$) in both cultures. That is, IPS should be described as a two-dimensional construct; the processes of knowledge acquisition and knowledge application could be empirically distinguished. (RQ2) Thus, *hypothesis H2 was supported*. Moreover, the confirmatory factor analysis showed that combinatorial reasoning should be considered as a two-dimensional construct (verbal & figural) for both the Chinese (Chi-square=152.53, $p<.01$) and Hungarian (Chi-square=34.30, $p<.01$) samples. Similarly, inductive reasoning showed best model fits as four-dimensional construct (figural series, figural analogy, number analogy, and number series) in both cultures ($p<.01$).

A measurement invariance analysis was conducted across gender and nationality to check if IPS can be measured invariant across gender and nationality both in Hungarian and Chinese contexts. The measurement invariance analysis started with identifying the baseline model which fits within the overall sample and in each subgroup (Byrne, & Stewart, 2006). Configural invariance was firstly tested by estimating the parameters of the baseline model in a multi-group model. Then strong factorial invariance was tested by constraining the factor loadings and thresholds to be equal across groups (nationality and gender) (Byrne, & Stewart, 2006). The results based on multi-group (CN-HU) confirmatory factor analyses showed that the configural invariance model was significantly different with the strong factorial invariance model (Chi-square=122.82, $p<.05$), which indicated measurement non-invariance of IPS across nationality. The multi-group (Boy-Girl) confirmatory factor analyses showed that the configural invariance model was equal with the strong factorial invariance model in both cultures (CN: Chi-square=11.83, $p>.05$; HU: Chi-square=15.90, $p>.05$). Thus, IPS proved to be measurement invariant across gender within the same culture. (RQ3) Therefore, *hypothesis H3 was partly denied.* As the tasks required a minimal amount of reading, we assumed that the reason for non-invariance could be found in students' different cognitive styles during the problem-solving progress. This is supported by the research result that cognitive styles can be impacted by cultural background (Nisbett, & Miyamoto, 2005), and there is a significant cultural difference between China and Hungary.

As introduced, the items delivered to Chinese and Hungarian students were not completely the same. Item response theory was employed to analyze Chinese and Hungarian students' performance on the same scale. Chinese and Hungarian students showed statistically equal performance in the IPS test (CN: M=-.81, SD=2.07; HU=-.81, SD=1.48) ($p>.05$). That is, our Chinese and Hungarian sample had the same developmental level regarding interactive problem solving. (RQ4) *Hypothesis H4 was denied.* In the IPS test, Hungarian males (M=-.66, SD=1.58) showed a statistically equal performance with Chinese males (M=-.75, SD=1.40) and Chinese females (M=-.87, SD=2.02) ($p>.05$). Therefore, Hungarian males, Chinese males, and Chinese females had the same developmental level of problem solving at the age of 12. Only Hungarian females (M=-.93, SD=1.40) showed a significantly lower performance than the Hungarian males ($t=-2.68$, $p<.01$). (RQ5) Therefore, *Hypothesis H5 was partly supported.*

Two SEM models were built to examine the relationships among problem solving, combinatorial reasoning and inductive reasoning in the Chinese and Hungarian contexts (Fig. 2 & 3). Based on the dimensionality testing, all three thinking skills were construed as latent variables composed of their sub-dimensions. The fit indices of the SEM model were good (Chi-square=25.83, df=17, CFI=1.00, TLI=1.00, RMSEA=.03, SRMR=.02) for the Hungarian sample, and were lower but still acceptable for the Chinese sample (Chi-square=42.34, df=17, CFI=.97, TLI=.96, RMSEA=.09, SRMR=.04). Based on the models, we can conclude that combinatorial and inductive reasoning are significant predicting factors of problem solving, and they are important component skills of problem solving, independently of the cultural context. (RQ6) Thus, *hypothesis H6 was confirmed.* There were detectable differences in the cognitive styles of Chinese and Hungarian student. Combinatorial (β=.319) and inductive reasoning (β=.376) had basically equal influence on the problem solving achievement in case of Hungarian students; while Combinatorial reasoning (β=.611) played a much more important role than inductive reasoning (β=.241) in the Chinese samples. Therefore, the detected IPS assessment measurement non-invariance across nationality could be explained by students' different cognitive styles during the problem-solving progress.

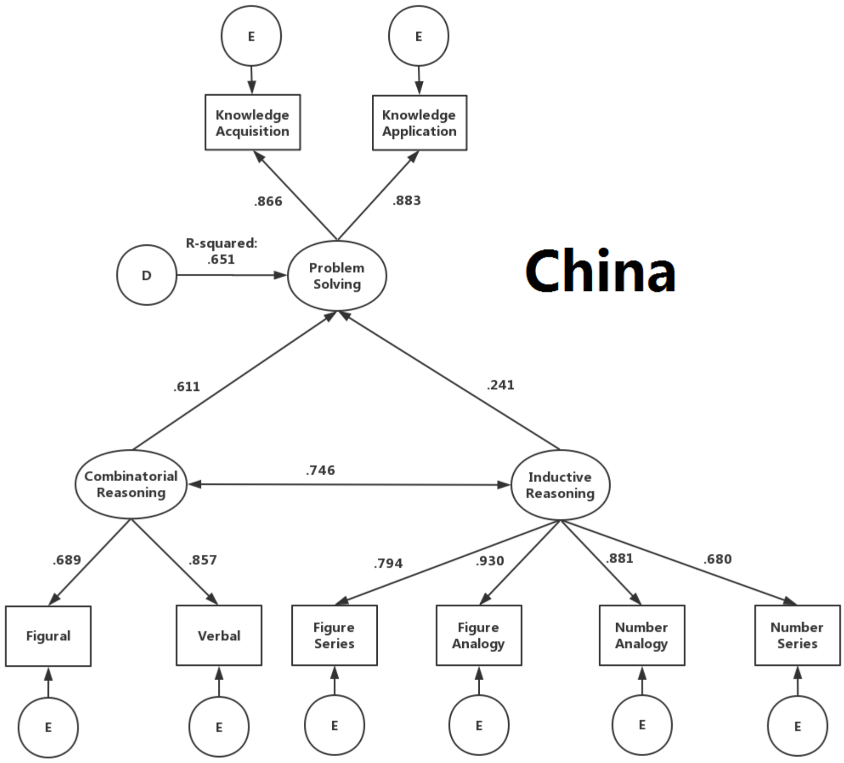

Fig.2 A structural model presents the relationships among problem solving, combinatorial reasoning and inductive reasoning - Chinese sample

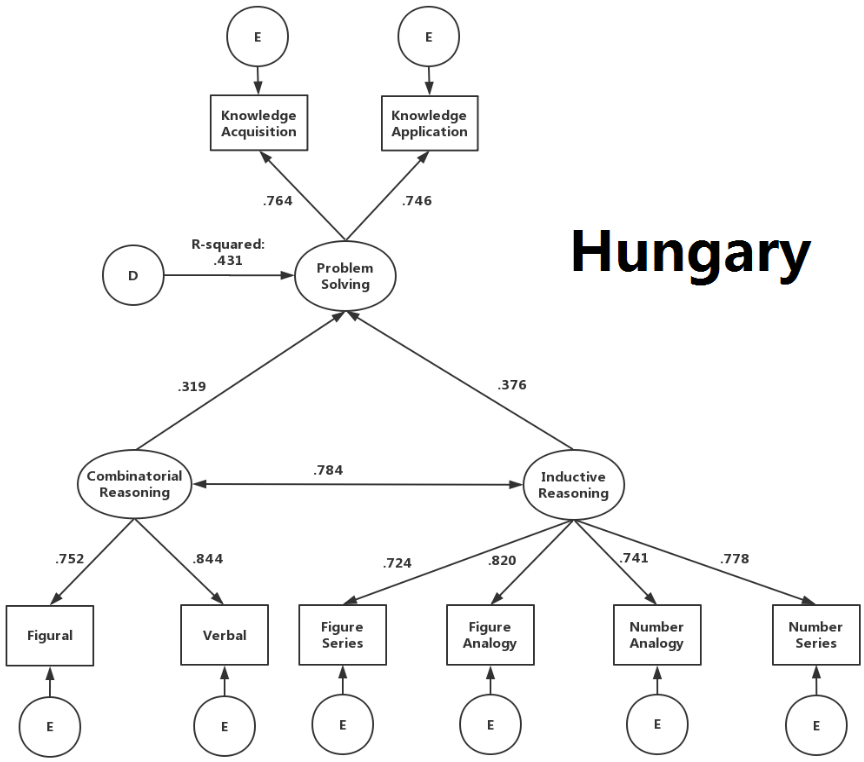

Fig.3 A structural model presents the relationships among problem solving, combinatorial reasoning and inductive reasoning - Hungarian sample

Students’ IPS achievement also highly correlated with their working memory in both cultures (CN: $r=.530$, $p<.01$; HU: $r=.390$, $p<.01$). Test-taking motivation significantly correlated with IPS achievement for the Chinese sample ($r=.505$, $p<.05$) but not for the Hungarian sample ($p>.05$). The Rasch model analysis showed that Chinese students had a higher test-taking motivation. Students’ mothers’ (CN: $r=.330$, $p<.01$; HU: $r=.155$, $p<.01$) and father’s (CN: $r=.232$, $p<.01$; HU: $r=122$, $p<.01$) educational level showed positive and significant correlations with IPS achievement in both cultures. Structural equation modeling was used to analyze the predictive power of students’ learning strategies as regards their problem-solving achievement in both groups. The fit indices were acceptable for both the Chinese (Chi-square=222.34, df=111, $p<.01$, CFI=.93, TLI=.93, RMSEA=.08, SRMR=.08) and the Hungarian (Chi-square=244.01, df=110, $p<.01$, CFI=.96, TLI=.95, RMSEA=.04, SRMR=.04) samples. Chinese students who often study by memorizing proved to be less successful problem solvers ($\beta=-.531$, $p<.01$), while the opposite effect was observed in Hungary ($\beta=.213$, $p<.01$). Students who tend to use elaboration ($\beta=.450$, $p<.01$) or control ($\beta=.320$, $p<.01$) strategies for learning proved to be better problem solvers in China. However, the use of these two learning strategies had no significant effect on problem-solving performance in the Hungarian group. The three learning strategies involved in the study had significantly different impacts on students’ problem-solving achievement between groups. Based on this finding, it is proposed that the Chinese and Hungarian students used different exploration strategies during the problem-solving assessment process, and that the different exploration strategies were impacted differently by the three learning strategies. To sum up, all the selected non-thinking skill factors (included working memory, learning strategies, test-taking motivation, parental education) influence students’ problem solving achievements in both cultures. (RQ7) Even though the influential powers were varied in two cultures (especially for learning strategies), still *hypothesis H7 was supported*.

CROSS-NATIONAL COMPARISON STUDY OF STUDENTS’ PROBLEM SOLVING STRATEGIES: LOG-FILE ANALYSIS

Aims

Research question RQ8 is expected to be answered by the log-file analyses results. Moreover, hypothesis H8 is going to be verified by the results as well.

Samples and procedure

The study was a follow-up analysis of the same assessment project which was introduced in the previous sections. Thus, the participants and procedure of this study were same as it was in the previous study.

Log-file data preprocessing

With the log-file analyses we focus on students’ exploration behaviour, thus on the first phase in the problem-solving process, on the knowledge acquisition phase.

Molnár and Csapó (2018) developed a labeling system and a mathematical model to classify whether students' exploration strategies are theoretically effective, and belong to the VOTAT scope. This study employed this labeling system.

Results and discussions

Log-file analyses indicated that the use of a theoretically effective strategy (the strategy which extracts all information required to solve the problem; see Molnár & Csapó, 2018) had a greater chance, but did not always lead to high performance. Chinese students employed theoretically effective strategies – including the most effective VOTAT (vary-one-thing-at-a-time) strategy – more frequently than Hungarian students. Based on the information extracted, they were better able to find the right solution to the problems, they managed to represent the information that they had obtained from the system more effectively, and they made good decisions in the problem solving process compared to their peers in Hungary. Using latent class analyses, we identified four qualitatively different class profiles: (1) 37.5% of the Hungarian students and none of the Chinese students were among the low-performing students; (2) 45.5% of the Chinese students and 28.4% of the Hungarian students were intermediate performers on the easiest problems, but low performers on complex ones with a very slow learning effect. (3) The proportion of Chinese proficient strategy users (51.5%) was much higher than that of the Hungarians (34.1%). (4) A small group of Chinese students (3.1%) proved to be rapid learners. These students started out as non-performers in their exploration behaviour, showed a rapid learning curve afterwards and reached the top performers' proficiency level of employing the VOTAT strategy by the end of the test. There were no rapid learners detected in the Hungarian sample. To sum up, Chinese students showed a significantly higher learning effect than their Hungarian peers. These results indicate the differences between Hungarian and Chinese students' exploration behaviour in an interactive problem-solving environment (*hypothesis H8 was confirmed*).

GENERAL DISCUSSION

This study contributed to our further understanding of the nature of problem solving, and explored the differences between students with Chinese and Hungarian cultural backgrounds. Currently, enhancing students' ability to solve problems has become one of the main targets in school education. With no doubt, a deeper understanding of problem solving in an international context has an important meaning. This study has successfully discovered several pieces of valuable information. Firstly, it has proved the reliability and feasibility of conducting the computer-based cognitive assessment in the Chinese culture and network environment. Computer-based cognitive assessment has not been commonly be used by the Chinese psychologists. This study proved that, in the Chinese context, computer-based assessment in the domain cognitive sciences can still show its high efficiency. The findings could be the base for future cognitive research to be implemented in China by means of technology..

This study further confirmed the structure of problem solving. The modeling results supported the hypothesis proposed by previous studies, namely that problem solving should be formulated as a two-dimensional measurement model (e.g. Bühner et al., 2008; Wüstenberg et al., 2012), independently of the cultural context. This study proved that combinatorial reasoning and inductive reasoning have significant predictive effects on the problem-solving process for both Chinese and Hungarian students. The results suggested that schools can improve instruction methods in these subjects by paying more attention to reasoning skills enhancement. Similarly, some non-thinking skill factors which have the power to influence students' problem-solving achievement (e.g. test-taking motivation, working memory) are also worth to be focused on by educational designers and psychologists. Moreover, one of the biggest advantages of Chinese students is still to be identified, namely that Chinese students were more willing to use theoretically effective exploration strategies, and they were better proficient strategy users. Findings highlighted the importance of explicit enhancement of problem-solving strategies as a tool for applying knowledge in a new context during school lessons.

Limitations of the study include the low sample size for both countries; furthermore, repetition of the study is required for validation. The detected measurement non-invariance and students' different level of test-taking motivation might also influence the comparison results. Moreover, this study chose China and Hungary as the representatives for Asian and European culture, but this may cause concern about the generalizability of the findings. Some studies (e.g. Wüstenberg et al., 2014) have pointed out that students from different nations (even from similar cultural backgrounds, e.g. Hungary-Germany) could possibly have different levels of development in problem-solving performance, while the relationships between the components within problem-solving skills could also vary. A future study will continue to include more countries to discover such differences in the cognitive structures for problem solving that exist between students with Asian and European cultural backgrounds, and thus address the generalizability limitation of the present study.

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