Using a Computer Game to Assess the Critical Thinking Skills of Preschoolers: A Pilot Study

Siew Hock Ow
Chia Ming Tan
Department of Software Engineering
Faculty of Computer Science & Information Technology, University of Malaya
Kuala Lumpur, Malaysia
show@um.edu.my, tcmingkoo@gmail.com

***Abstract*—Many employers find today's graduates are lacking in critical thinking (CT), creativity and problem solving skills. Research findings show that these skills, especially critical thinking skills, can be taught during early childhood education. To develop and foster CT skills among children, an assessment need to be made to identify which of the CT components that they are weak in. Currently, there are many CT skills evaluation instruments for job employment and school enrollment. However, there are no assessment instruments for preschool children aged 4-6 years. This paper presents a pilot study on the assessment of CT skills among 20 preschool children aged 5-6 years using a computer game. The CT skills components evaluated include knowledge, comprehension, application, analysis, evaluation, and inference. The findings of the pilot study show that computer game can be a useful and practical tool for assessing and fostering the CT skills of preschoolers. Based on the game scores, the 20 children were found to perform well in Classification, Sequence of Events and Word Match sub-games, but poorly in Facts or Opinion, Divide and Conquer and Transformation sub-games. These outcomes imply that they comprehend what they learned in kindergartens, but they are weak in analysing, evaluating, applying, and making inference during problem-solving.**

Keywords—computer game; critical thinking skills; preschoolers; pilot study

I. INTRODUCTION

The term critical thinking (CT) has many definitions. The National Council for Excellence in Critical Thinking defines CT as the "Intellectually disciplined process of actively and skillfully conceptualising, applying, analysing, synthesising, and/or evaluating information gathered from or generated by observation, experience, reflection, reasoning, or communication, as a guide to belief and action" [1]. Basically, the core aspects of the CT process are analysis, evaluation and inference [2].

CT is regarded as one the important soft skills that is highly desired and needed across all employment sectors [3]. In the very competitive and challenging world today, organisations that can attract, retain and develop the best critical thinkers will have a huge competitive advantage. This makes it crucial, therefore, for universities and institutions of higher learning to produce graduates who can meet these requirements. Many employers, however, have expressed that today's graduates and many of their employees lack CT skills [4, 5], which makes it necessary for them to provide training to acquire this much-needed skill. It has been suggested that efforts to foster CT skill at this stage would affect staff productivity and significantly impact a nation's capability to sustain its economic edge [6]. For these reasons, efforts have been made on finding effective ways on teaching, developing, training, and improving CT skills among students in universities, schools, and even preschools [7, 8, 9, 10].

In this research, there are two main purposes of CT assessment – diagnosing the CT levels of preschoolers to identify areas of strengths and weaknesses, and using the CT test results to guide in devising teaching approach to help the preschoolers in CT.

The aspects of CT skills selected for assessment were determined based on the outcomes of a literature review of some well-established frameworks and models proposed by experts in education and the thinking processes. These skills cover three components – knowledge, comprehension, and analysis of Bloom's taxonomy.

II. THINKING TAXONOMIES AND FRAMEWORKS

There have been many educational taxonomies to foster the thinking processes since the 1950s [11]. Bloom's taxonomy – which considered knowledge, comprehension, application, analysis, synthesis and evaluation, arranged hierarchically – was the first framework to characterise thinking as an array of both lower-level and higher-order thinking processes [12]. Influenced by Bloom's taxonomy, Romiszowski's framework for knowledge and skills presents a skill-cycle that describes the interaction and development of cognitive processes that an individual perceives, recalls, makes plans and performs based on knowledge of facts, procedures, concepts, and principles [13].

Anderson and Krathwohl [14] introduced another taxonomy which follows Romiszowski's general principles by transforming Bloom's taxonomy from noun form to verb form. For example, Bloom's application becomes applying. However, knowledge is highlighted as metacognitive knowledge – strategic knowledge, knowledge about cognitive processes and tasks, and self-knowledge. Metacognition refers to knowledge, awareness, and control of one's own cognition [15]. Marzano [16] introduced a taxonomy that includes a knowledge domain as well as processes comprising knowledge retrieval (i.e., memory/recall), comprehension (i.e., knowledge representation), analysis (i.e., classifying, identifying errors, generalising, matching and specifying) and knowledge utilisation (i.e., decision-making, problem-solving, investigation and experimental enquiry). All these four taxonomies and frameworks consider the thinking processes and the links among them. Krathwohl [17] and Moseley et al. [18], however, expressed that the taxonomies and frameworks do not adequately elaborate on the manner in which one applies the higher-order thinking processes – missing reflective judgement an individual exerts in the application of knowledge. Reflective judgement (RJ) is an individual's understanding of the nature, limits, and certainty of knowing and how this can affect how he/she defends judgement and reasoning. It involves the ability of an individual to acknowledge that his/her views might be falsified by additional evidence obtained at a later time. It is the conclusion and also the manner in which one arrives at the conclusion that matters [19]. Thus, Dwyer, Hogan, and Stewart [11] proposed an integrative framework of CT that identifies long-term memory/knowledge and comprehension as fundamental processes which are necessary to apply CT successfully, and to integrate it with reflective judgement and self-regulatory functions of metacognition that dictate how well each thinking process will be conducted.

Although various terminologies are used in these thinking taxonomies and frameworks, they seemingly refer to similar components or further elaboration of CT skills. Table I shows a summary of the common and distinctive key components of CT of the five thinking taxonomies and frameworks. Knowledge (metacognitive knowledge) and comprehension are the two basic components of CT. Analysis/Analysing, and evaluation/evaluating are found to be the focus of CT in at least three of these taxonomies and frameworks. In the Delphi report, a majority of the panel members (95% consensus) agreed that analysis, evaluation, and inference are the core skills necessary for CT [20]. A recent research also found strong, significant, and positive correlations among the three skills – analysis-evaluation-inference – whereby the coefficients of relation for analysis-evaluation is $r = 0.40$, analysis-inference is $r = 0.36$, and evaluation-inference is $r = 0.48$, at level of confidence of $p < 0.001$ [21].

TABLE I. SUMMARY OF KEY COMPONENTS OF THINKING TAXONOMIES AND FRAMEWORKS

Thinking Taxonomy/ Framework	**Components of Critical Thinking (CT)**	
	Common Components	**Distinctive Components**
Bloom's taxonomy (1956)	• Knowledge • Comprehension • Application • Analysis • Synthesis • Evaluation	
Romiszowski's framework for knowledge and skills (1981)	• Knowledge • Perception (Comprehension)	• Recalls • Performs • Makes plans based on knowledge of facts, procedures, concepts and principles.
Anderson and Krathwohl's taxonomy (2001)	• Metacognitive knowledge • Understanding • Applying • Analysing • Synthesising • Evaluating	
Marzano's taxonomy (2001)	• Knowledge Domain • Comprehension (Knowledge Representation) • Analysis (Involves classifying, identifying errors, generalising, matching and specifying)	• Processes of knowledge retrieval (Memory/recall) • Knowledge utilisation (Involves decision-making, problem-solving, investigation and experimental enquiry) • Self-system (Includes motivation, attention, and beliefs).
Dwyer, Hogan, and Stewart's integrated framework of CT (2014)	• Knowledge (Long-term memory) • Comprehension • Analysis, evaluation and inference (Components of reflective judgement)	• Self-regulatory functions of metacognition.

III. Method and Procedures

A comprehensive literature review was conducted on the various cognitive theories and models to identify the relevant components of CT skills. Eleven online computer games and activities for fostering CT skills were reviewed to determine the game features and functionalities. Interviews were conducted with kindergarten teachers as well as parents to learn about the children's behaviour, preferences and cognitive levels, which must be considered in the development of the computer game. A computer game for evaluating CT skills was first designed based on a storyline that maps the components of CT skills. It was then developed using Java programming language and the libGDX game engine [22]. After the game had been fully developed and thoroughly tested, a 5-year-old child was selected to play the game to determine whether the game had been appropriately designed for the cognitive level of children aged 5. Based on the outcomes of this pilot test, minor modifications were made to the user interface design. The game was then used for evaluating the CT skills of preschool children in two kindergartens. Following the evaluation, the children were interviewed to obtain their feedback on the game. A questionnaire survey was also conducted to obtain feedback from the teachers on the storyline of the CT skills, the difficulty level, and the user interface design of the game. The feedback and comments from both the children and the teachers were analysed.

A. Participants

In this study, three preschool teachers and the participating parents were interviewed, respectively, to understand the teaching methods used in the kindergartens, the behaviour, learning abilities and capabilities, and preferences of children aged 5-6. The findings show that children prefer to play mobile apps rather than read story books, love animated stories with motion and sound and have interesting storyline. Based on the interview, a storyline for CT skills game that maps with the cognitive theory of Bloom's taxonomy was developed. The CT skills evaluation involved 20 preschool children from two kindergartens. Altogether, 10 boys and 10 girls aged 5-6 years participated in the study. After playing the game, they were interviewed to gather feedback regarding ease of playing the game, its difficulty level, and its graphical user interface design.

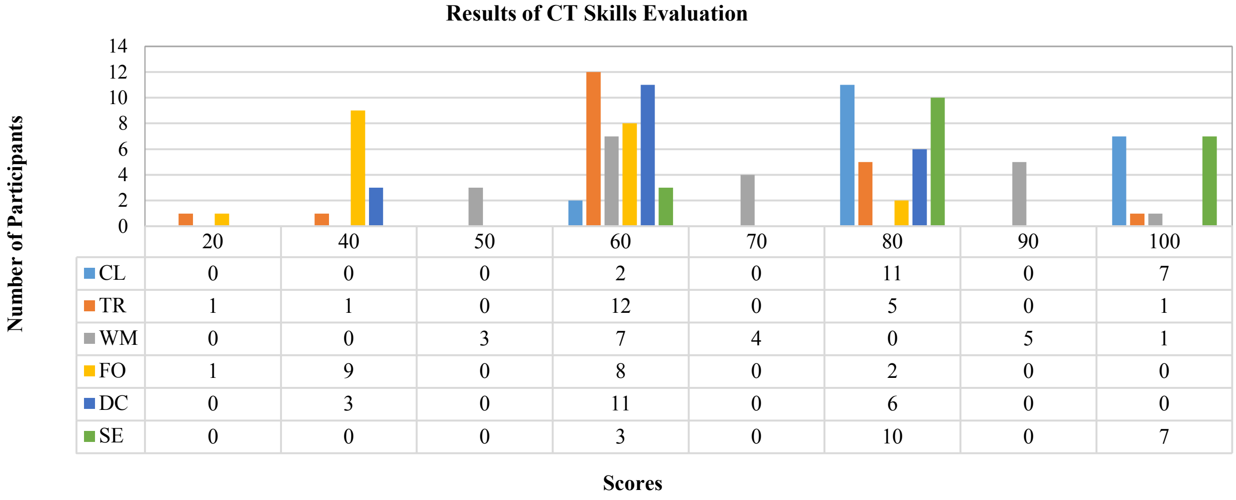
IV. Results

Five boys and five girls from the two age groups, respectively, participated in the evaluation.

The results, shown in Fig. 1, indicate that among the six sub-games, most of the children are weak in the Fact or Opinion sub-game. Ten children were unable to answer more than two questions, and only two children were able to answer four questions correctly. The children are also weak in the Divide & Conquer, and Transformation sub-games. In the Divide & Conquer sub-game, three children were able to answer two questions only, but most of them were able to answer three questions correctly. In the Transformation sub-game, two children were unable to answer more than two questions, and 12 of them were able to answer three questions correctly. Among these three sub-games, Fact or Opinion and Divide & Conquer can be considered the most difficult sub-games for the children as none of them were able to answer all the questions correctly.

On the other hand, the children performed well in the Classification, Sequence of Events, and Word Match sub-games. Eighteen children were able to answer four to five questions, and only two children were able to answer three questions correctly. This is followed by Sequence of Events sub-game with 17 children who were able to answer four to five questions, and only three children were able to answer three questions correctly.

Generally, most of the children are able to apply the knowledge gained to answer (solve) the questions (problems). They are rather weak in differentiating facts, and also in applying, analysing, making inference and in evaluating the knowledge gained to answer implicit questions (problems). Hence, there should be more focus on these aspects. Parents and preschool teachers can play important roles in fostering and improving these important soft skills at home and in the preschools, respectively



	20	40	50	60	70	80	90	100
CL	0	0	0	2	0	11	0	7
TR	1	1	0	12	0	5	0	1
WM	0	0	3	7	4	0	5	1
FO	1	9	0	8	0	2	0	0
DC	0	3	0	11	0	6	0	0
SE	0	0	0	3	0	10	0	7

Fig. 1: Scores of CT skills evaluation

A. Interview with Preschool Children

An interview was conducted with each of the children after they had played the game to find out whether the computer game is attractive, and whether the questions in each sub-game are appropriate for their cognitive level. They were asked to comment and rate the storyline, user interface design, and identify the difficult sub-game. The interview outcomes show that all the preschool children like the storyline, like to play the game, and find the appearance, design and the main characters of the game to be attractive.

However, nine children found the game difficult to play, and were asked to identify the sub-game concerned. Fig. 2 shows that four preschool children (two boys and two girls) aged 5 have poor differentiation skills. This shows that they are still unable to differentiate a "fact" and an "opinion". Thus, further explanation on this aspect is needed for children of this age. Three children (two girls aged 5, and one boy aged 6) indicated that they find the Transformation sub-game to be difficult.

Again, the findings show that children aged 5 are not as good as children aged 6 with regard to visualisation, application and analysis of a problem. Two children (a boy aged 5, and a girl aged 6) indicated that the Divide & Conquer sub-game is difficult. These two children were found to be weak in counting, division, application, and making analysis, inference, and evaluation. Generally, the thinking skills of preschool children aged 5 (six children) are not as good as those aged 6 (three children) as more children aged 5 commented about the difficulty of the game. The findings also show that all the preschool children did not face any problem playing the Classification, Word Match, and Sequence of Events sub-games. This implies that all the children are able to apply their knowledge in analysing and evaluating the sequence of tasks for solving problems which they had encountered previously.

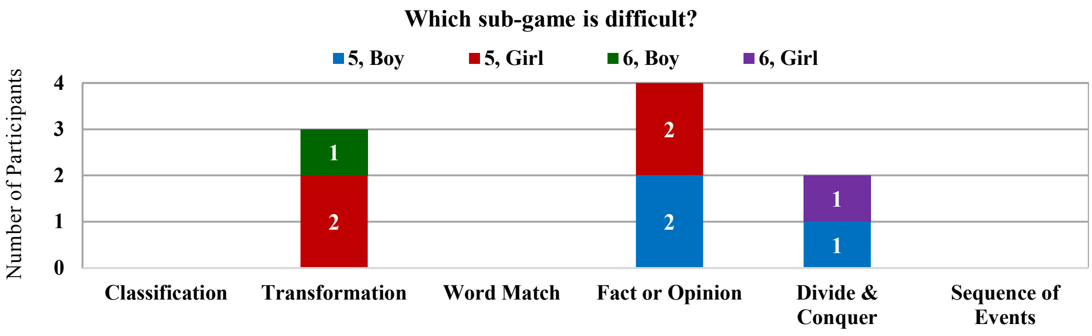


Fig. 2: Sub-games difficult to play

B. Feedback from the Preschool Teachers

Ten teachers from the two kindergartens were interviewed to obtain their feedback regarding the game design such as the game theme, and creativeness, and opinion on playing the game. The following section presents outcomes of the feedback.

i. Game Design

Fig. 3 shows that all 10 kindergarten teachers gave a rating of either 4 or 5 to the game theme, creativeness, uniqueness, and educational value, respectively. The overall rating shows that the CT game is well designed as all the 10 teachers had rated it either good (three teachers) or excellent (seven teachers). This view is also supported by at least 70% of the teachers who rated as excellent regarding the game theme, creativeness, and educational value, except for uniqueness, where only 50% of the teachers rated as excellent.

ii. Opinion on Playing the Game

The children found the Word Match, Classification, and Sequence of Events sub-games to be easy to ply while all 10 teachers also rated these three sub-games as easy or fairly easy to play. The Transformation and Divide and Conquer sub-games are considered fairly easy and average difficulty sub-games to play, respectively, as two and four teachers rated these two sub-games as average difficulty to play, respectively. Overall, the only sub-game that is considered quite difficult to ply for children aged 5-6 is Fact or Opinion as one teacher rated it as fairly difficult, five teachers rated as average difficulty, and four teachers rated as fairly easy, as shown in Fig. 4.

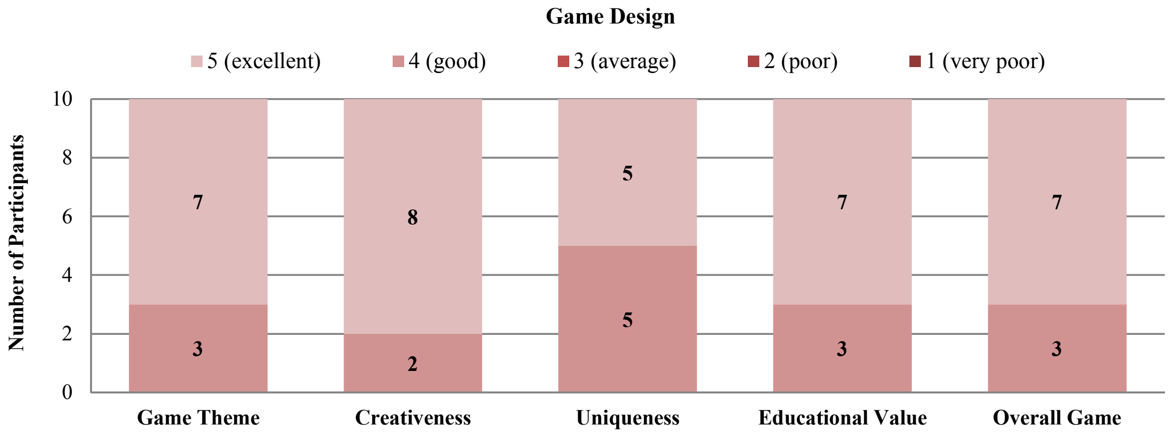


Fig. 3: Comments on the game designs

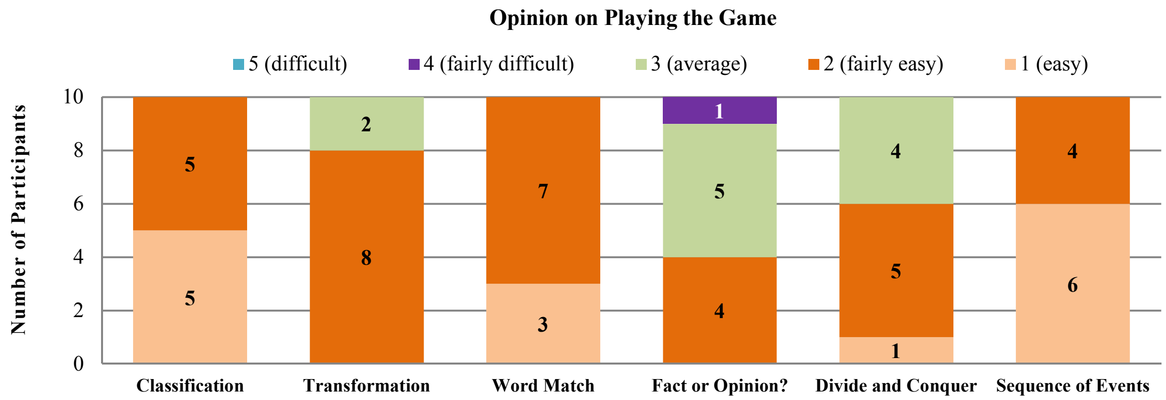


Fig. 4: Comments on game difficulty

V. Conclusion

The findings of the pilot study show that computer game can be a useful and practical tool to assess and foster CT skills among preschoolers. The game scores of the 20 children aged 5-6 years show that they performed well in Classification, Sequence of Events, and Word Match sub-games, but poorly in Facts or Opinion, Divide and Conquer and Transformation sub-games. Based on the mapping of Bloom's taxonomy to the game theme, these outcomes imply that they had acquired knowledge in the kindergartens, but are weak in analysing, evaluating, applying and making inference of information for problem-solving. These findings can serve as useful guidelines for curriculum designers to incorporate learning materials and activities for preschoolers that emphasise the relevant aspects for CT skills development.

On the other hand, the lower scores, especially for Facts or Opinion, and Divide and Conquer sub-games, could be attributed to the difficulty in playing these two sub-games, based on the feedback from the children. Hence, the design of these two sub-games should be improved to suit the cognitive level of the children, and at the same time enhance their analytical, evaluation, and inference skills.

A few children aged 5 had performed slightly better than some of the children aged 6, but overall, those aged 6 had performed better as they have attained higher order thinking skills due to the additional year they spent in the kindergarten. As this pilot test involved only 20 preschoolers, it is premature to make a correct assessment on the weakest aspect of the CT skills among the ethnic groups. It would also be interesting to find out which aspect of CT skills each ethnic group is good at or weak in, and the reasons behind, respectively. Thus, in-depth studies on larger sample size of preschool children should be carried out in future to explore these interesting issues so that the curriculum for the preschoolers can be oriented towards CT skills development to produce good critical thinkers in the country.

Acknowledgment

The authors would like to acknowledge the assistance of the three kindergarten teachers from Tadika Didik Pandai and Tadika UM, who participated in the interviews and evaluation of the computer game. Their invaluable comments as well as the feedback from 10 parents are greatly appreciated. Their willingness to share their experiences had contributed greatly to the success of this research.

References

[1] The National Council for Excellence in Critical Thinking, "The critical thinking community," 2014. Retrieved on 18 March 2015, from https://www.criticalthinking.org/pages/the-national-council-for-excellence-in-critical-thinking/406.

[2] C. P. Dwyer, M. J. Hogan, and I. Stewart, "An integrated critical thinking for the 21st century," Thinking Skills and Creativity, vol. 12, pp. 43-52, 2014. doi: 10.1016/j.tsc.2013.12.004.

[3] "Employability skills - skills you need for a job," 2015. Retrieved on 28 January 2015, from http://www.skillsyouneed.com/general/employabilityskills.html, SkillsYouNee.com.

[4] S, Jaschik, "Well-prepared in their own eyes," Inside Higher Ed., 2015. Retrieved on 19 June 2015, from https://www.insidehighered.com/news/2015/01/20/study-finds-big-gaps-between-student-and-employer-perceptions.

[5] American Society for Training & Development, "Bridging the skills gap: help wanted, skills lacking: why the mismatch in today's economy?" Alexandria, VA: ASTD Press, 2012.

[6] "21st century skills, education & competitiveness: A resource and policy guide," 2008. Retrieved on 10 December 2014, from http://www.p21.org/storage/documents/21st_century_skills_education_and_competitiveness_guide.pdf. www.21stcenturyskills.org.

[7] B. L. Shoop, "Developing critical thinking, creativity and innovation skills of undergraduate students," [Proc. of 12th Education and Training in Optics and Photonics Conf., Porto, Portugal, July 23-26, 2013]. doi: 10.1117/12.2068495.

[8] H. S. Hwang, "The effects of creativity training by CoRT thinking skills on young children's creativity and nature-friendly attitude," J. of Fisheries and Marine Sc. Edu., vol. 25, issue 6, pp. 1263-1272, 2013.

[9] H. Hsiao, C. Chang, C. Lin, and P. Hu, "Development of children's creativity and manual skills within digital game-based learning environment," J. of Comp. Assisted Learning, vol. 30, issue 4, pp. 377-395, 2014. doi:10.1111/jcal.12057.

[10] F. Ke, "Designing and integrating purposeful learning in game play: a systematic review," Edu. Tech. Res. and Dev., vol. 64, issue 2, pp. 219-244, 2016.

[11] C. P. Dwyer, M. J. Hogan, and I. Stewart, "An integrated critical thinking for the 21st century," Thinking Skills and Creativity, vol. 12, pp. 43-52, 2014. doi: 10.1016/j.tsc.2013.12.004.

[12] B. S. Bloom, Taxonomy of Educational Objectives. New York: David McKay Co., Inc., 1956, p. 12.

[13] A. J. Romiszowski, Designing Instructional Systems. New York: Nichols, 1981.

[14] L. W. Anderson and D. R. Krathwohl, A Taxonomy for Learning Teaching and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives. New York: Addison-Wesley, 2001.

[15] D. A. Bensley and R. A. Spero, "Improving critical thinking skills and metacognitive monitoring through direct infusion," Thinking Skills and Creativity, vol. 12, pp. 55-68, 2014.

[16] R. J. Marzano, Designing a New Taxonomy of Educational Objectives. Thousand Oaks, CA: Corwin Press, 2001.

[17] D. R. Krathwohl, "A revision of Bloom's taxonomy: an overview," Theo. into Prac., vol. 41, issue 4, pp. 212-218, 2002.

[18] D. Moseley, V. Baumfield, J. Elliot, S. Higgins, J. Miller, D. P. Newton, and M. Gregson, Frameworks for Thinking: A Handbook for Teaching and Learning. Cambridge, England: Cambridge University Press, 2005. doi: http://dx.doi.org/10.1017/CBO9780511489914.

[19] P. M. King and K. S. Kitchener, Developing Reflective Judgment: Understanding and Promoting Intellectual Growth and Critical Thinking in Adolescents and Adults. San Francisco, CA: Jossey Bass, 1994.

[20] P. A. Facione, The Delphi Report: Committee on Pre-college Philosophy. Millbrace, CA: California Academic Press, 1990.

[21] C. P. Dwyer, M. J. Hogan, and I. Stewart, "The promotion of critical thinking skills through argument mapping," in Critical Thinking, C. P. Horvart and J. M. Forte, Eds. New York: Nova Science Publishers, 2011.

[22] libGDX, 2013. Retrieved on 19 March 2014, from http://libgdx.badlogicgames.com/. [Copyright: Mario Zechner].