Making Student Thinking Visible through Thinking Tools in Technology-Enhanced Assessment for Learning

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Abstract

Using thinking tools engages students in a variety of critical and complex thinking, such as evaluating, analyzing, and decision making. The aim of this study was to explore patterns in student critical thinking performance and motivation in Evidence-Centered Concept Map (ECCM) mode, compared to basic notepad mode. One hundred ninety 14-year-old students from the United States, United Kingdom, Singapore, and South Africa participated in the study. Students in both modes were able to analyze a multifaceted dilemma by using similar information resources. In the ECCM mode, students used ECCM to organize their thinking; in another mode, students were provided with a basic online notepad to make records as needed. Overall, the findings showed that students assessed in ECCM mode outperformed their peers in notepad mode in critical thinking skills. Student who worked with ECCM provided more informed recommendations by using supporting evidence from the available resources and discussing alternative points of view on the topic. In addition, the results demonstrated that it did not matter for students' motivation whether they analyzed the dilemma with or without ECCM. Directions for future research are discussed in terms of their implications for large-scale assessment programs, teaching, and learning.

Keywords: critical thinking, concept map, computer-based assessment

Introduction

Measuring complex skills such as critical thinking, creativity, and collaborative problem solving requires designing and developing assessments that address the multiple facets implied by these skills. One of the possible ways to achieve these changes in educational assessment is by providing visible sequences of actions that students have taken by using various tools within the contexts of relevant societal issues and problems that people care about in everyday life. Thinking tools are computer applications that enable students to represent what they learned and know using different representational formalisms. Studying the role of thinking tools in computer-based assessment of higher-order thinking skills is crucial to determining whether these types of scaffolding tools can bring a real added-value into large-scale computer-based assessment programs. The purpose of this study was to provide empirical evidence of what can be achieved in terms of possible differences in student achievement and motivation by intertwining a thinking tool in a performance assessment of student critical thinking. This paper addresses these challenges by introducing a new methodology for scalable use of thinking tools in computer-based assessment of higher-order thinking skills, providing findings from an empirical pilot study conducted in four countries, as well as discussing implications of the findings for further research and development.

Defining Critical Thinking

Ennis (1993) defines critical thinking as “reasonable reflective thinking focused on deciding what to believe or do.” (p. 180). Critical thinking requires the component interdependent competencies of evaluating the credibility of sources, analyzing the quality of arguments, making inferences using reasoning, and making decisions or solving problems (see Lai & Viering, 2012, for a literature review). Critical thinking often appears in Program for International Student Assessment (PISA) and US National Assessment of Educational Progress (NAEP) in assessment of science, math and reading. Critical thinking was part of problem solving assessment in PISA 2012, with major emphasis on evaluation of the available information, assumptions, and possible solutions, as well as looking for additional information or clarification (OECD, 2010). In our research, an operational definition of critical thinking refers to *the capacity of an individual to effectively engage in a process of making decisions or solving problems by analyzing and evaluating evidence, arguments, claims, beliefs, and alternative points of view; synthesizing and making connections between information and arguments; interpreting information; and making inferences using reasoning appropriate to the situation*. In identifying critical thinking skills, this research attempts to incorporate skills identified in other assessment frameworks, such as the Partnership for 21st Century Skills (2009) and Assessment and Teaching of 21st Century Skills (Binkley et al., 2012).

Assessing Critical Thinking Skills

Critical thinking assessment tasks should provide adequate collateral materials to support multiple perspectives and include process as well as product indicators. Problems underlie such tasks should use ill-defined structure that often involve multiple goals that are in conflict, have more than one defensible solution and require students to go beyond recalling or restating learned information (Mayer & Wittrock, 2006; Moss & Koziol, 1991). Critical thinking assessment tasks should make student reasoning visible by requiring students to provide evidence or logical arguments in support of judgments, choices, claims, or assertions (Fischer, Spiker & Riedel 2009; Norris, 1989). Embedding computer-based thinking tools in critical thinking performance assessment, which makes student thinking visible, is one of the promising approaches that should be further explored.

Concept Map as a Thinking Tool in Critical Thinking Assessment

Thinking tools (or mindtools) are computer applications that enable students to represent what they learned and know using different representational formalisms. There are several classes of thinking tools, including semantic organization tools, dynamic modeling tools, information interpretation tools, knowledge construction tools, microwords, and conversation and collaboration tools (Jonassen, 2006; Jonassen, & Reeves, 1996). Assessment thinking tools represent thinking processes in which the student is engaged, such as evaluating, analyzing, connecting, elaborating, synthesizing, designing, problem solving, and decision making. Using Perkins's (1993) terminology, the unit of analysis in these assessments is not the student without the technology in his or her environment — the *person-solo* — but the *person-plus* the technology, in this case the student plus the thinking tool.

Concept maps have been widely used as thinking tools for teaching, learning, and assessment as a way to help the student think and represent his or her thinking processes (Jonassen, 1996; Kinchin et al., 2000; Novak & Cañas, 2008; Ruiz-Primo, 2004). A concept map is a semi-formal knowledge representation tool visualized by a graph consisting of finite set of nodes, which depict concepts, and finite set of arcs, which express relationships between pairs of concepts (Novak, 1998; Novak & Cañas, 2008). Concept mapping is a cognitively challenging task that requires various higher-order thinking processes, such as assessing and classifying information, recognizing patterns, identifying and prioritizing main ideas, comparing and contrasting, identifying relationships, and logical thinking (Jonassen, 1996; Kinchin et al., 2000). These processes require the student to elaborate and organize information in meaningful ways, which cannot be realized through simply memorizing facts without understanding their meaning and underlying associations. The thinking processes involved in concept mapping are highly related to critical thinking competency as defined by various assessment frameworks (Binkley et al., 2012; OECD, 2010; Partnership for 21st Century Skills, 2009).

In our research we use a three-phase concept map to empower the student to analyze various claims and evidence on a topic and to draw a conclusion, or Evidence-Centered Concept Map (ECCM) in short. The stages of student work with ECCM on a critical assessment task include: (a) gathering various claims and evidence from the resources provided (some claims and evidence contradict one another); (b) organizing the claims with supporting evidence gathered in the previous phase on ECCM without hierarchical relationships; and (c) linking claims and specifying the kind of a relationship between claims. It should be noted that *no hierarchical order* is required in ECCM. The three-phase working structure of ECCM was designed to increase the cognitive and measurement interdependency between the three distinctive competencies in critical thinking as they are identified in our research: (a) analyzing and evaluating evidence, arguments, claims, beliefs, and alternative points of view; (b) synthesizing evidence, arguments, claims, beliefs, and alternative points of view; and (c) making connections between information and arguments. By using ECCM in a critical thinking assessment, we provide scaffolding for the student thinking process by enabling the construction of a well-integrated structural representation of the topic, as opposed to the memorization of fragmentary information, and we externalize the student's conceptual understanding of the topic.

Research Questions

The study addressed empirically the following questions regarding student performance and motivation in critical thinking assessment in ECCM and notepad modes:

1. What are the differences in student critical thinking performance between ECCM and notepad modes of assessment as reflected in the student recommendation?
2. How are a student's abilities to develop ECCM, and create a linkage within ECCM, related to student performance in critical thinking assessment, as reflected in the student recommendation?
3. How are a student's GPA, ELA, and Math achievement, as measured by the traditional school assessments, related to the student recommendation in ECCM and notepad modes of assessment?
4. What are the differences in student motivation and time-on-task while working on a critical thinking assessment task with and without ECCM?

Method

The study participants included 190 students, all 14 years old, from the United States, United Kingdom, Singapore, and South Africa. The results presented in the current article came from a larger study in which students from six countries were recruited to participate in a 21st Century Skills Assessment project study investigating innovative ways of developing computer-based assessment in critical thinking, creativity, and collaborative problem solving. The researchers collected data from November 2012 to January 2013. Recruitment of participating schools was achieved through collaboration with local educational organizations based on the following criteria: (a) the school is actively involved in various 21st Century Skills projects, (b) population of 14-year-old students proficient in English, and (c) sufficient technology infrastructure (e.g., computers per student, high-speed Internet). In all, 102 students participated in ECCM mode, and 88 participated in notepad mode. Of the total students who participated, 112 were boys (58.9%) and 78 were girls (41.1%). Table 1 summarizes the country and gender distribution of participating students between the ECCM and notepad groups.

No significant differences were found in GPA, ELA, and Math average scores between participants in ECCM and notepad modes within the countries. This similarity in student background allowed comparability of student results in critical thinking assessment tasks between the two modes.

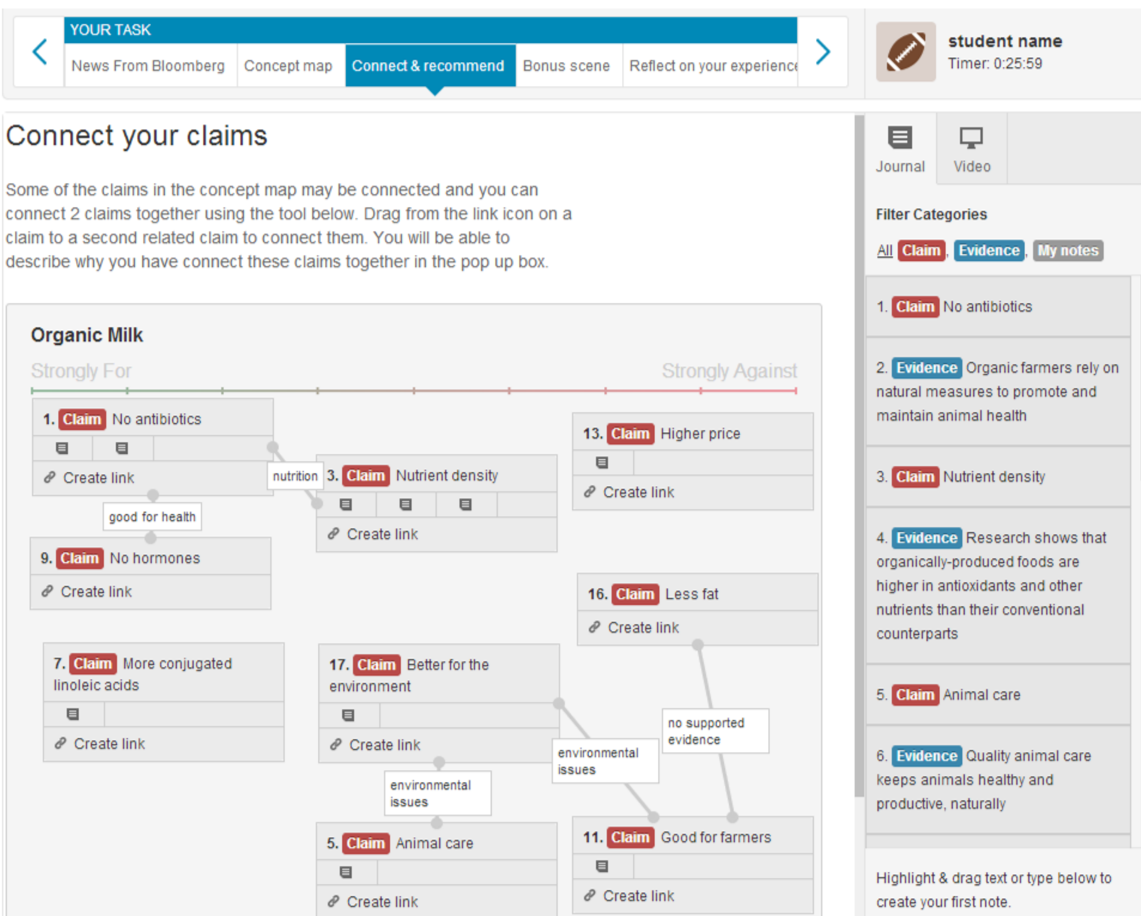
Critical Thinking Assessment

In this critical thinking computer-based assessment task, the student was asked to analyze various pros and cons of whether or not to buy organic milk for the school cafeteria and write a recommendation to a school principal. Students who participated in ECCM mode were required to use a concept map during the analysis of web-based pre-determined resources, while students who participated in notepad mode were able to take notes by using an embedded free text notepad, but were not provided any kind of thinking tool. Among the websites that were accessible to the students in both modes were: organic milk company website along with an interview script/video with the CEO of the organic milk company, independent organic milk association, dairy farmers of North America, anti-organic milk along with an interview script/video with the blogger (a past worker of an organic milk company), Disease Control Center, and a news website. The resources included various content orientations (pros and cons related to the organic milk issue), relevancy, and level of reliability. Due to the exploratory nature of the study, the students were not limited in time-on-task. The task was checked by teachers from the four participating countries to ensure that students would be able to work on the task, and that the task could differentiate between high and low levels of critical thinking ability. Interviews were conducted with students representing the target population to validate the ECCM approach. The teachers and the students that participated in the design sessions were not included in the main study.

The students in both modes are asked to gather various claims and evidence that stand for and against buying organic milk: “You should make a note of any claim made that supports either organic milk or traditional milk and look for evidence that supports these claims.”. It should be noted that the resources that are provided in both modes are identical. In ECCM mode the student was able to classify the notes into claims and evidence in preparation for constructing the concept map. *Similar resources* were accessible to the students in both modes.

Students in ECCM mode are asked to create relationships between claims. Those are created by dragging from the link icon on a claim to a second related claim and typing a short description of how they are related. Figure 1 shows an example of a screen for relationships created in a task.

Figure 1. The student-created relationships within the concept map



In both modes of assessment the students are asked to support the claims by relevant evidence from the resources. Additionally, both modes allow the students to navigate back and gather more information, if needed.

Scoring of the student responses was provided independently by two teachers from participating schools in the United States. Inter-coded agreement of recommendation scoring was 94% and 100% for the concept map and the relationships. It should be noted that student responses were scored based on the rubrics presented in Tables 2-4, while spelling and grammar issues did not affect the student score.

Motivation Questionnaire

The questionnaire included 4 items to assess the extent to which students were motivated to work on the task. Participants reported the degree of their agreement with each item on a 4-point Likert scale (1 = strongly disagree, 4 = strongly agree). The items, adopted from motivation questionnaires used in previous studies, included (Rosen, 2009; Rosen, Beck-Hill, 2012): I felt interested in the task; The task was fun; The task was attractive; I continued to work on this task out of curiosity. The reliability (internal consistency) of the questionnaire was 0.81.

Students were also asked to indicate background information, including gender, Grade Point Average (GPA), and Math and English Language Arts (ELA) average scores. This information was collected because of potential interaction with study variables.

Results

All results are presented on an aggregative level beyond the countries because no interaction with country was found. First, the results of student performance in a critical thinking assessment are presented to determine whether there is a difference in the student critical thinking score as a function of working with an evidence-based concept tool. Next, the results regarding the relationship between student performance in critical thinking assessment and the ability to develop ECCM, and create a linkage within ECCM, are shown. Then, gender-related results are presented to indicate possible differences in student performance in ECCM and notepad modes, as well as the relationship with the student's school achievement. Last, student motivation, and time-on-task, in both modes are demonstrated.

Student Critical Thinking Performance

The results of the critical thinking scores indicated that students who worked with ECCM on an assessment task significantly outperformed the students who were assessed in notepad mode (M=69.9, SD=27.2 in ECCM mode, compared to M=54.5, SD=19.0 in notepad mode; ES=.7, $t(df=188)=4.7$, $p<.01$). Students who worked with ECCM provided more informed recommendations by using supporting evidence from the available resources and discussing alternative points of view on the topic.

ECCM-related Performance and Student Critical Thinking

To better understand the relationship between student critical thinking and the ability to develop ECCM, and create a linkage within ECCM, analysis of correlations between the variables was conducted. The findings showed a significantly positive relationship between student critical thinking score and both the ability to develop ECCM, and the ability to create a linkage within ECCM ($r=.62$, $p < .01$ and r=59, $p < .01$, respectively). Although the student's ability to develop ECCM and his or her ability to create a linkage are related to the same bigger construct of working with ECCM, the results indicated that these two sub-constructs are relatively distinctive (r=.40, p<.01).

Student School Achievement and CPS Performance

Correlations between the variables were conducted in order to determine potential relationships between student GPA, ELA achievement, and Math achievement as measured by traditional school assessments and student performance in critical thinking in ECCM and notepad modes of assessment. The findings showed low positive correlation between student critical thinking score in ECCM mode and student school achievement as reflected by GPA and ELA ($r=.20$, $p < .05$ and $r=.22$, $p < .05$, respectively). No significant correlations were found between student critical thinking score and school achievement in notepad mode.

Student Motivation and Time-on-Task

Data were analyzed to determine possible differences in student motivation of being engaged in working with ECCM versus a notepad mode. The results demonstrated that it did not matter for the student's motivation whether he or she analyzed the dilemma with or without ECCM (M=2.7, SD=.6 in ECCM mode, compared to M=2.6, SD=.6 in notepad mode; ES=.1, $t(\text{df}=188)=.9$, $p=.37$). No significant difference was found in time-on-task (ES=.2, $t(\text{df}=188)= 1.4$, $p=.16$). On average, time-on-task in ECCM mode was 33.2 minutes (SD=15.1), while students in the notepad mode each spent 2.9 minutes less on the task (M=30.3, SD=13.7).

Discussion

Policymakers, researchers, and educators are engaged in vigorous debate over leveraging the power of technology to measure what matters for student college and career readiness in valid, reliable, and scalable ways. Technology can support measuring performance that cannot be assessed with conventional testing formats, providing educational systems with opportunities to enable more effective and engaging assessments of important competencies and aspects of thinking (Beller, 2013; U.S. Department of Education, 2010; National Research Council, 2011). In order to understand how students perform on critical thinking computer-based assessment with thinking tools that can provide scaffolding for the student's thinking process, it is necessary to examine empirically student performance with these tools. The goal of this study was to explore patterns in student critical thinking performance and motivation in ECCM mode, compared to notepad mode of assessment. The findings showed that students assessed in ECCM mode outperformed their peers in notepad mode in their critical thinking. Overall, decision making with a concept map involved significantly higher levels of analysis and evaluation of evidence, claims, and alternative points of view, as well as synthesis, making connections between information and arguments, interpreting information, and making inferences by using reasoning appropriate to the situation. Moreover, it was found that student ability to construct ECCM and the ability to create relationships within ECCM are positively linked to student performance in critical thinking. Concept mapping as a thinking tool supports, guides, and extends the thinking process of the student. The thinking tool does not necessarily reduce information processing, but its goal is to make effective use of mental efforts of the student to create a *person-plus* the technology in computer-based assessment (Jonassen, 2006; Perkins, 1993). To successfully make a decision or solve a multifaceted problem, the student must mentally construct a problem space by analyzing various pieces of information, and mapping specific relationships of the problem. ECCM facilitates the analysis that students conduct and requires them to think more deeply about the multifaceted topic being analyzed than they would have without the thinking tool. The results demonstrated that it did not matter for a student's motivation whether he or she analyzed the dilemma with or without ECCM, which suggests that the ECCM introduced no motivational obstacles for students in terms of being required to work with a thinking tool. To the degree that students do not give full effort to an assessment test, the resulting test scores will tend to underestimate their levels of proficiency (Eklöf, 2006; Wise & DeMars, 2005). One may claim that adding the ECCM-based thinking process to the assessment could be perceived negatively by the student as an additional assessment requirement and not as a scaffolding tool. Thus, the evidence of equivalent motivational level during both modes of critical thinking assessment is a positive indicator for the use of thinking tools in general and ECCM in particular in computer-based assessments.

One major possible implication of the score difference in critical thinking between the ECCM and the notepad modes is that assessments delivered in multiple modes may differ in score meaning and impact. Each mode of CPS assessment can be uniquely effective for different educational purposes. For example, an assessment program that has adopted a vision of a conceptual change in assessment may consider the person-plus the thinking tools approach for higher-order thinking assessment as a more powerful avenue for next generation computer-based assessment, while the person-solo approach may be implemented as a more conventional computer-based assessment. While technology tools can promote fundamental improvements in assessment of higher-order thinking skills (Bennett, 1999; Bennett et al., 2007; Pellegrino, Chudowsky & Glaser, 2001; Tucker, 2009), assessment of foundational knowledge, skills, and abilities can rely on more traditional person-solo oriented assessment approaches. Thinking tools can enable scaffolding and visibility in the student thinking process while working on complex problem solving or decision-making situations that require mindfulness and thinking beyond WYSIATI (Langer, 1989; Kahneman, 2011).

Similarly to more conventional person-solo oriented assessment, students may benefit differently from qualitatively different types of assessment item types or environments. In this assessment the thinking tool was introduced before the actual measurement of student performance started. However, no examples of a constructed ECCM or teacher-led instructions were provided as part of this pilot study. One may consider adding these introduction components to such an assessment to promote student familiarity with the tool, as well as support student meta-cognitive awareness of the potential benefits of using this tool in an assessment context.

In summary, computer-based performance assessment methods described in this article offer one of the few examples today of a direct, large-scale assessment targeting higher-order thinking skills. Embedded thinking tools bring new opportunities and considerations for the design of effective formative assessment approaches because it moves the field beyond standard summative assessment design. The assessment must incorporate concepts of how humans solve problems in situations where information is multi-faceted and considerations of how to provide meaningful scaffolding in the computer-based environment in ways sufficient for valid and reliable measurement of individual skills. The quality and practical feasibility of these methods are not yet fully documented. However, these methods rely on the abilities of technology to engage students in interaction, to simulate rich tasks, to track students' ongoing responses and thinking processes, and to draw inferences from those responses. The results of this study suggest that by using ECCM in a critical thinking task the students were able to show their skills more optimally, compared to their peers who worked with basic notepad. ECCM enables students to visually and verbally organize complex information, and transform information into active forms of understanding beyond the traditional linear structures most often used in educational assessments. However, learning to construct this visual representation of information appropriately may take considerable time that may not be available in assessment settings. Thinking tools should be in limited use when the formation of verbal generalizations is what is expected from the learner and not necessarily in-depth concept understanding. Therefore, the benefits of using thinking tools in assessment must be weighed against the time invested in creating them and measurement appropriateness.

The current study had several limitations. First, it is based on a relatively small and non-representative sample of 14-year-old students in four countries. However, due to a lack of empirical research in the field of computer-based assessment of critical thinking skills with embedded thinking tools, it is necessary to conduct small-scale pilot studies in order to inform more comprehensive approaches of critical thinking person-plus assessment. Further studies could consider including a representative sample of students with a wider range of ages and backgrounds. Second, the study operationalized the thinking tool in critical thinking assessment through ECCM, while other approaches could be considered, including semantic organization tools, dynamic modeling tools, information interpretation tools, knowledge construction tools, microwords, and conversation and collaboration tools (Jonassen, 2006; Jonassen & Reeves, 1996). Finally, it is possible that the comparability findings between ECCM and notepad performances in other critical thinking contexts will be different. Future studies could consider exploring differences in student performance in a wide range of problems and decision-making situations.

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