Available online at www.sciencedirect.com
ScienceDirect
Procedia Social and Behavioral Sciences 2 (2010) 5686–5692
Procedia
Social and Behavioral Sciences

WCES-2010

Does one-to-one access to laptops improve learning: Lessons from New Brunswick's individual laptop school initiative

Viktor Freiman[a] *, Jacinthe Beauchamp[a], Sylvie Blain[a], Nicole Lirette-Pitre[a], Hélène Fournier[b]

[a]*Université de Moncton, Moncton, New Brunswick, Canada*
[b]*National Research Council Canada*

Received November 12, 2009; revised December 2, 2009; accepted January 22, 2010

Abstract

A two-year study on the use of laptop computers by New Brunswick (Canada) grade 7-8 francophone students aimed to better understand the impact of laptops on learning. Two problem-based learning (PBL) interdisciplinary scenarios (math, science, language arts) were implemented in eight experimental classes to measure students' learning process, particularly in terms of their ability to scientifically investigate complex problems, to reason mathematically, and to communicate. Based on our findings, we argue that laptops in themselves may not automatically lead to better results on standardized tests, but rather create opportunities for more open-ended, constructive, collaborative, reflective, and cognitively rich learning tasks.

Keywords: Individual laptops; science; mathematics; language arts; problem-based learning.

1. Problem statement and context of the study

Our knowledge-based society challenges traditional teaching and learning methods. It calls for more complex non-routine problem solving which goes beyond disciplinary knowledge and skills. Skills needed for the 21st century will be a blend of information and communication skills, thinking and problem-solving skills, and interpersonal and self-directional skills (OECD, 2009). Results of New Brunswick students in the Programme for International Student Assessment (PISA, 2000), led our government to initiate changes in its school system to improve learning (Freiman and Lirette-Pitre, 2007, Ministère de l'Éducation du Nouveau-Brunwick (MENB), 2002). One such initiative was the *Dedicated Notebook Research Project*, an action research project with six participating schools, providing Grade 7 and 8 students and their teachers with access to laptop computers and wireless Internet during two school years.

The idea of using individual laptops to stimulate learning arose from encouraging results from pilot studies conducted in the early 2000s. Holcomb (2009) cited several examples of studies showing that one-to-one access may have a significant impact on writing scores and some positive impact on mathematics achievement in terms of

* Viktor Freiman. Tel.: 506 858 4437; fax: 506 858 4317
E-mail address: viktor.freiman@umoncton.ca

1877-0428 © 2010 Published by Elsevier Ltd.
doi:10.1016/j.sbspro.2010.03.929

increasing students' understanding of mathematical concepts. 'Laptop' students outscored their 'non-laptop' peers on standardized tests. Following a review of the literature, we decided to focus our research on: motivation, attitudes and beliefs, transdisciplinary learning (ICT competence and organizational skills), disciplinary learning (math, science and language arts), school leadership, teaching and classroom management, and project implementation. We adopted a pragmatic approach that favors a mixed research methodology. Several research tools were developed to collect data: questionnaires (pre- and post- tests), interviews (pre- and post- study as well as pre and post Problem Based Learning (PBL) scenarios), class observations (direct and indirect), and documents (teacher and mentor journals). Samples of students' work were also collected and analyzed. Data analysis was conducted using grids developed and validated by the research team, including the creation of assessment rubrics, SPSS (quantitative data) and Atlas.ti (qualitative data). A rationale for theoretical and methodological choices was reported elsewhere (Blain et al., 2009, Fournier et al., 2006). In this paper, we outline findings on only one component of our study: disciplinary learning (mathematics, science and language arts).

2. Theoretical framework

Our review of the literature revealed many previous studies on one-to-one access to laptops still relied on standardized tests to evaluate students' achievement. Preliminary results for year 1 of our study prompted us to opt for a model in which learning was defined as a global and open ended process in which students focus not only on the acquisition of abilities and knowledge, but also on values, attitudes and emotions (Ormrod, 2004). This called for more authentic, extensive and qualitative methods to document and evaluates the learning process. Consequently, during year 2 of our project, we developed and implemented four PBL scenarios, two for each grade (7 and 8). Students were asked to solve a real-life complex problem focused on topics and learning outcomes defined in New Brunswick's school curriculum regarding scientific literacy, mathematical reasoning and communication abilities.

The framework for *scientific literacy* developed by the Council of Ministers of Education, Canada (CMEC) emphasizes the development of abilities to work and to communicate scientifically and to use science (CMEC, 1997). These abilities are a part of the process of inquiry that fosters particular ways of reasoning using appropriate vocabulary, and making sense of the concepts and their relationships (MENB, 2006). In mathematics, easy and equitable access to powerful technological tools and endless Internet-based resources may broaden traditional pedagogical spaces and create opportunities for all students to participate in new types of authentic mathematical learning experiences. Such experiences are often based on problem solving situations that emphasize a broader view of school mathematics as a *reasoning tool* for everyday life experiences (NCTM, 2000). In language arts, the curriculum favors *a communicative approach* based on socioconstructivism (MENB, 2009). Emphasis is placed on the process instead of the product, and teaching cognitive strategies should be the aim of classroom interventions. Students should write, read and speak for authentic purposes and teachers should use every opportunity to integrate language into other school subjects. The process of reading and writing is viewed as a complex problem-solving process.

3. Methodology

The first set of scenarios was created by the research team and implemented in the beginning of the school year. Grade 7 students investigated environmental issues such as endangered species and grade 8 students researched health issues such as smoking. Students worked in small groups of three to four to explore one aspect of a given issue (learning task) and to raise awareness about that issue in their respective communities. Topics were related to the science curriculum with an emphasis on scientific investigation. Here is the example of a task given to one group of students:

The Recovery of Nationally Endangered Wildlife Program (RENEW) is a nationwide initiative to save endangered species in Canada. You should choose two endangered species and study the problem in depth in order to convince people to support the initiative. Some questions to explore: What are their characteristics (habitat, food, predators, reproduction)? Why are they in danger? How their extinction will affect our ecosystems? Your survey can be done to learn what people know about endangered species. Website to visit: http://www.ns.ec.gc.ca/wildlife/index_f.html.

The students were asked to explore the problem by searching for information, summarizing it, and building questions for a survey. After conducting their survey, student had to analyze the results and produce a report presenting them in a form suitable for a large public (ex.: flyer, exposition, conference talk).

The second set of scenarios was developed collaboratively with teachers who actively participated in the creation of learning tasks drawing on their experience from the first scenarios. The task for grade 7 students was to explore insulation techniques to recommend the best alternative for a particular house whereas grade 8 students had to figure out how to protect a computer room from possible break-ins and theft using video-surveillance cameras. The work of two groups from each class (8 groups in all) was selected by researchers for an in-depth investigation. We focused on specific and general learning outcomes at the beginning and at the end of the project using concept maps, interviews, students' reports, and videos of classroom activity, screen activity and oral presentations.

4. Results and discussion

4.1. Science/Ability to investigate scientifically complex problems

To assess students' learning in science, we used concept maps. Students produced a concept map at different stages of the project and then updated it to integrate new knowledge. The complexity of the maps was evaluated using criteria developed by Wandersee (2000), namely: use of correct terms, use of labels for links, number of levels, use of examples, use of cross links, and restructuring of the map. Use of concept maps to evaluate learning was based on works by McClure, Sonak and Suen (1999) and Yin et al. (2005) who claim that more complex maps may suggest a conceptual change (learning).

Overall, 64.1% of students improved their maps during the projects. Among grade 8 students, results were better with 78.6% and 85.7% of them with improved scores for the first and second scenario respectively. Only 50% of grade 7 students improved their maps which may be due to the novelty of the computer tool used to produce their maps. Students in this grade significantly improved their score (71.4%) in the second scenario. Scores among grade 7 students had a wider range between the highest and lowest scores, that is 32 (scenario 1) and 41 (scenario 2) compared to those of grade 8 students who had scores of 29 and 18.

Both grade 7 and grade 8 groups used significantly more scientific terms by the end of the first scenario. A list of concepts was provided to them in the beginning of the project and may explain this difference. In the second scenario, no concepts were suggested to students and they generally used 2 words in initial maps and 4-5 in their final maps. Relationships between concepts were rarely identified. As for the number of levels, we mostly found 2 levels in the original version and 3-4 at the end. Students had difficulties with the direction of arrows linking a more specific term (example) to the more general term (concept). Students frequently used examples when illustrating their maps. The first versions of their concept maps contained 8-10 examples. Generally, this number remained the same in their final maps but some students added more examples. Very few students used cross links between different branches to mark complex relationships. This kind of complex representation seemed to be learned to a lesser extent by students.

Overall, we found that concept mapping software can be a useful tool to enrich science learning allowing students to represent their knowledge in an easier, nicer and quicker manner. However, it cannot replace the need to develop better conceptual understanding of complexity in solving scientific problems.

The second part of our analysis was concerned with the evaluation of three general learning outcomes defined in the -provincial science curriculum, namely, (1) understanding of the nature of science and the ability to demonstrate scientific attitudes and skills in practice, (2) understanding of the interaction between science and technology and the ability to demonstrate scientific attitudes and skills in the contexts related to physics, and (3) understanding of social, economical, political, and environmental aspects of science and technology and the ability to demonstrate scientific attitudes and skills in the contexts related to physics.

Regarding the *first* outcome, our data indicate that 92.9% of students from our four Grade 7 focus groups showed evidence of reaching level 3 competence (can realize the task without help). They demonstrated the ability to identify pertinent questions, study them, search for information and solutions, as well as communicate their results. Samples of their work were saved electronically, as well as video-recordings demonstrating students' ability to ask pertinent questions like '*Does humidity influences heat?*'. They could also search for information, as well as conduct experiments verifying their hypotheses by measuring the temperature of two closed metallic containers and comparing effects on temperature in both cases.

For the Grade 8 students, the success rate (level 3 competence) was high but with a smaller percentage (70%). This difference can be explained by the fact that while Grade 7 students received clear step-by-step instructions of how to conduct the experiment and how to note the results, Grade 8 students faced more open-ended, ill-defined and thus more complex tasks requiring a 'winning' combination of many factors such as the shape of the room and the placement of mirrors to ensure coverage of the whole space for video-surveillance. Some students also had difficulties in describing properties of light as reflection and refraction. However, at the end of the project, most students were able to complete the task and were able to propose some good solutions.

Regarding the *second* outcome, assessment criteria were applied to experimentation, methods of work, working with data and making conclusions from data. Seventy percent of 7th graders were able to reach level 3 competence without measurable difficulties. The experiments students conducted were consistent with the questions asked, as in the example of humidity cited above. The most challenging task for them was formulating conclusions. As for grade 8 students, they showed a lot of ability with almost all steps of the scientific inquiry process. We found that the very first step of the inquiry process which involved formulating relevant questions, and another step later in the process of estimation and evaluation for sources of errors when measuring were among the most challenging for these students.

Regarding the *third* outcome, the focus for the grade 7 students was on the assessment of ability to collect and to interpret data, as well as the ability to explain and to describe properties of heat. While at least 70% of students were able to collect and to interpret data, some experienced difficulties in the interpretation and needed help from others. Our data are not sufficient to draw conclusions about the students' ability to explain and to describe results. Assessing outcomes for the Grade 8 students regarding their ability to formulate new questions based on what has been learned was also a challenge. However, at least 70% of students were able to justify their solutions based on mathematical and scientific data. Data were missing to verify whether students developed coherent conceptions of how technology functions and how to apply them in real life.

4.2. Mathematics/Ability to reason mathematically

Students used mathematics to make measurements and calculations, construct and interpret graphs and diagrams, as well as conduct statistical analyses of survey results (in the first set of scenarios). Each team produced written and oral reports. In the written report, we expected students to incorporate survey questions, collected data, produce graphs and diagrams representing data, and analyze the data. Written reports were analyzed using criteria such as presence of key elements (ex.: titles, labels) and their appropriateness, types of questions, as well as types of graphs used. Oral presentations were also an opportunity to access mathematical reasoning. Data from post-project interviews with teachers and students completed data triangulation.

Observation periods allowed us to ask students working in small groups to explain what they were doing and why. One student said that they were calculating the mean, median and mode for question 1 of their survey which would enable them to organize data and produce a graph showing how it looks and what people think about this question. He added that he was not sure what problem they were going to solve using the graph, but '*it was about stress'*. He thought data would show '*if people experienced stressful situations in their life, and if yes, then when, where, and how much stress they were experiencing*'. After analyzing data, students made recommendations on how to decrease stress. At this stage of the problem solving process, students didn't seem to be considering end goals, but they were able to explain their actions as well as importance to use of the graph to find solutions.

We also observed a group of students discussing the particular choice of the circular diagram. One student was moving back and forth through different computer provided options, each time choosing a different type of graph. One of his peers was arguing that some choices were inappropriate. Finally, both students agreed on a 3-dimensional for the graph explaining that the 3rd dimension made the diagram bigger and easier to understand. According to Poirier (1997), this kind of exchange shows that problem initiated interactions between students is a crucial step for the construction of knowledge.

This article does not allow for further sharing of details of our analysis, but only some interesting findings. *First*, the statistical procedure seems to be seen by students more as collecting and compiling data than as a source for further interpretation and questioning. Technology enabled students to produce a lot of graphs, but there was little evidence of their critical use in final reports. *Second*, students' survey questions more frequently related to concrete knowledge (*Do you know that…?)* or facts (*What do people …?*) than opinion (*Do you think it is good to …?).* Most of their questions allowed simple '*yes-no'* answers instead of the use of more complex scales. While many groups relied on paper and pencil techniques for their questionnaire, some of them created electronic forms (website) to collect their data. During the construction of their graphs, almost all groups chose to make a separate graph for each question. Grade 8 students used a larger variety of types of graphs compared to the seventh graders. Not surprisingly, computers facilitated graph construction for students, and it was done correctly in most of the reports. In a few cases, we observed incoherent data representation due to inappropriate choices of variables or scales. The technology allowed quickly made nice representations, but a higher level of critical thinking was rarely observed to validate the obtained results. Finally, only half of the reports submitted contained numbers and calculations to support quantitative reasoning about the results.

In post-study interviews, teachers and students shared their opinions on the impact of direct access to laptop computers on mathematics teaching and learning within a real-world contextual problem-solving environment. *Students* stated that the arrival of laptop computers changed the way they learned. They found the computer as useful tool to help them better understands mathematics because it simplified the task of constructing graphs which could be done automatically once the data was entered. Graphs could also help students visualize and understand the relationships between variables and scales. According to students interviewed, Excel® was the most frequently used software for making diagrams. Students liked this kind of work and found that it was of better quality. Some students explained that the more complex the graph, the more difficult its construction. Also, some also expressed concern about becoming dependent on computers, making it difficult for them to do the work without a computer.

Teachers found that one-to-one access to laptops reinforced students' abilities to communicate mathematically, especially, for those students who did not like writing long texts. By typing their text on the computer, these students gave more detailed explanations for their mathematical solutions. According to teachers, computers also helped students understand the text of a word problem because it allowed them to highlight unknown words and move slowly from one part of the sentence to another. While teachers confirmed the advantage of having individual access to computers for the rapidity and quality of students' work, they felt that students need to develop better trans-disciplinary abilities in communication, critical thinking, creativity, reasoning, and in work methods. They also mentioned that the use of spreadsheets enabled students to make links with real life, applying mathematical methods learned in class. The rapidity of calculations and better access to multiple sources of virtual information gave them concrete examples of mathematics use in everyday situations. Teachers underlined that a problem-based learning environment seemed to help students to establish more links between mathematics and other subjects. Teachers revealed that the number of students with improved mathematical learning increased with the use of laptops, especially regarding problem solving abilities. At the same time, teachers were aware about limited students' capacities to analyze the context of the problem and lack of critical evaluation of computer mediated results. They expressed the need of more efficient strategies to help students linking different parts of the problem solving process.

4.3. Language art/Ability to communicate

In the context of our scenarios, students had to write research reports, letters, as well as experimental reports. We examined what was learned about writing, regarding the writing-process according to Hayes's model (1996) and the quality of texts produced as measured by Blain's (2003) analytical grid, and the impact of direct access on the overall learning of writing. Data collected included recordings of students' screen activity, texts produced, interviews, and observations.

With respect to writing process, data revealed students often used automatic correction tools as well as virtual dictionaries. According to teachers and mentors, this also developed a strategy of self-questioning throughout the writing and proofreading stages. However, students did not seem to use the full potential of the word processor. Data showed that they made few substantial changes to their texts other than rather minor changes mainly involving sentence grammar. We couldn't observe how they planned their text, because this first stage of the writing process was not done on the computer.

We examined strengths and weaknesses of texts produced with a word processor, in terms of communication efficiency, textual cohesion, and organization. Texts analysed contained more good points than bad points. These results were corroborated by teachers who noted that the content and style of students' compositions were better than before laptops were used. Students also claimed that their writing was better and quicker. Numerous challenges remained regarding grammar. In fact, students experienced more difficulties, particularly in grammar and syntax. Nevertheless, both groups of students successfully improved their syntax between scenarios. As for spelling and vocabulary, the percentage of mistakes was very low in both categories.

Table 1: Percentage of mistakes in the texts written by 7th and 8th grade pupils for both projects

	Scenario 1 7th grade	**Scenario 2 7th grade**	**Scenario 1 8th grade**	**Scenario 2 8th grade**
syntax	2.07	1.19	1.38	0.14
punctuation	3.31	2.95	1.24	1.39
vocabulary	1.28	2.73	0.35	0.77
spelling	1.09	0.79	0.17	0.49
grammar	5.7	5.3	5.1	4.7

Participants' perceptions concerning what was learned in grammar were divided. In fact, while most agreed that a word processor's automatic correction tool had eliminated a large number of mistakes, at least with respect to spelling, several wondered if what students learned would last and be transferable. Traditionally, writing is not students' favourite activity, even among learners who are good at it. In fact, children see writing, proofreading, and especially re-writing as unpleasant and long when done by hand. The laptop's principal contribution is improving pupils' motivation to write. The results obtained corroborate those of numerous previous studies: increased motivation leads students to write longer texts. These apprentice writers appreciated the speed of the correction tool in the word processor and how quickly they could access Internet-based resources. Some students mentioned their grades improved due to the use of laptops. Teachers added that direct access to laptops promoted more interdisciplinary approaches, focused on problem solving. Integrating language teaching in every other subject matter allowed students to consider the importance of language and the quality of their communication. Publishing students' texts on the Internet also helped learners understand the importance of the written language; it motivated them to correct their mistakes. Laptops also seemed to facilitate tailoring of teaching of knowledge specifically related to writing. When questioned about grammar rules, teachers easily accessed Internet-base resources to help students learn it. Students could visit suggested websites and do the exercises.

The results presented above suggest several advantages of direct access to laptops when learning to write: students' motivation is increased; they write longer texts of better quality with respect to grammar, spelling, and vocabulary; texts can be published on the Internet; importance is given to language in every subject matter through interdisciplinary approaches; pedagogical differentiation. However, many questions emerged that our data could not answer. How is the planning stage managed by students during the writing process? Some participants mentioned using software to create graphical organizers, but there was no evidence of it in the screen activities recorded.

Word processors also lighten the cognitive load because writers do not have to make the effort of finding all of their spelling or grammar mistakes. Students we observed seemed to be able to correct as they went along without losing track of their ideas. Is this the case for all students? Automatic correction tools are limited and students have to develop other proofreading strategies to overcome these limits and detect mistakes themselves. It would be preferable to deactivate the "check spelling as you type" and "mark grammar errors as you type" functions, and to activate them only when the text is finished. In this way, writers would pay attention to the content and only correct the form once the text is finished. This raises interesting questions regarding students' dependence on correction tools. Will they be able to transfer what they learned when writing without a word processor and virtual dictionaries? This is an important question, because they are subjected to standardized tests and summative paper and pen tests within the school system. Further, we cannot guarantee that these future workers will never have to write by hand in their profession.

5. Conclusion

PBL scenarios initiated a process of problem solving within a meaningful context and in relation to students' experience. Rooted in a science curriculum, problem solving made it possible to integrate several learning outcomes as much in science as in mathematics. The problem-solving process also created multiple opportunities for oral and written communication enabling the emphasis to be placed on learning language arts. Similarly, during open and complex problem solving, with or without direct access to laptops, students are often placed in a situation where they no longer know what to do (where to turn, what task to accomplish, and why). Direct access to laptops offers more choices and variety in terms of tools and resource management. Instead of making the students move forward in the task, this situation can slow them down or even force them to backtrack. Giving students the appropriate educational support to acquire good work methods becomes a crucial element of success with this type of pedagogical approach.

During the projects, students had to produce a large quantity and variety of documents and models. Indeed, laptops enabled them to produce work of higher quality, particularly in terms of presentation. However, we noted in many cases that the quantity and quality of production did not necessarily lead to more profound reflections and more in-depth content. PBL requires a non-linear process with constant back and forth movement between problem, solution and reflection. It is this back and forth process that stimulates intellectual work and ensures better learning and transfer conditions. Using laptops could sometimes act against this process if the focus is a final product. An important paradigm shift is already occurring in education regarding the significance of the process versus the product. These changes must take place if the potential of direct access to laptops in schools, as much in learning as in teaching, is to be maximised.

References

Blain, S. (2003). L'enseignement de l'écriture en milieu minoritaire canadien : problématique particulière et complémentarité des cadres théoriques en L1 et L2. In *Langue et communication et classe de français : convergences didactiques en langue maternelle, langue seconde et langue étrangère*. (p. 185-200). Fernelmon : Éditions Modulaires Européennes.

Blain, S., Freiman, V., Esseimbre, C., Cormier, M., Lirette-Pitre, N. et Beauchamp, J. (2009). L'accès direct à l'ordinateur portatif chez des élèves francophones de 7e et 8e année au Nouveau-Brunswick et l'apprentissage par problèmes : développement d'un cadre conceptuel pour favoriser la littératie en matière de TIC. In D. Masny (Ed), *Les littératies multiples et la croissance des communautés francophones en situation minoritaire : bilan et perspective* (pp. 53-78). Les presses de l'Université d'Ottawa..

Council of Ministers of Education, Canada. (1997). *Common Framework of Science Learning Outcomes K-12: Pan-Canadian Protocol for Collaboration on School Curriculum*. Toronto: Council of Ministers of Education, Canada.

Fournier, H., Blain, S., Essiembre, C., Freiman, V., Lirette-Pitre, N., Villenneuve, D., Cormier, M. & Clavet, P. (2006). Project ADOP: A Conceptual and Methodological Framework for Assessing the Effects of Direct Access to Notebook Computers. In *Proceedings of World Conference on Educational Multimedia, Hypermedia and Telecommunications 2006* (pp. 3084-3089). Chesapeake, VA: AACE.

Freiman, V. and Lirette-Pitre, N. (2007), PISA2000 Case Study: New Brunswick. In: Arbeitsgruppe Internationale Vergleichstudie (HRSG) *Schullleistungen und Steurung des Schulsystems in Bundesstaat: Kanada und Deutschland im Vergleich* (pp. 336-362). Waxmann, Muenster, New-York, Muenchen, Berlin.

Hayes, J. R. (1996). A new framework for understanding cognition and affect in writing. In C.M. Levy et S. Ransdell (Eds.), *The science of writing* (pp. 1-27). Mahwah (NJ): Erlbaum.

Holcomb, L. B. (2009). Results & Lessons Learned from 1 :1 Laptop Initiatives : A Collective Review. *TechTrends*, Vol. 53, Number 6, 49-54. .

McClure, J. R., Sonak, B., & Suen, H. K. (1999). Concept map assessment of classroom learning: Reliability, validity & logistical practicality. *Journal of Research in Science Teaching*, 36 (4), 475-492.

Ministère de l'éducation du Nouveau-Brunswick (2002). *Quality Learning Agenda*, Fredericton: Nouveau-Brunswick.

Ministère de l'éducation du Nouveau-Brunswick (2009). *Programme de français au primaire de la maternelle à la 8e année*. Direction des services pédagogiques, Fredericton: Nouveau-Brunswick.

NCTM (2000). *Principles and Standards for School Mathematics*. Reston, VA : NCTM.

OECD (2009), "*21st Century Skills and Competences for New Millennium Learners in OECD Countries*", OECD Education Working Papers, No. 41, OECD Publishing,© OECD.doi:10.1787/218525261154

Ormrod, J. E. (2004). *Human learning* (4th ed.). Upper Saddle River, NJ, USA: Pearson.

Poirier, L. (1997). Rôle accordé aux interactions entre pairs dans l'enseignement des mathématiques - une illustration en classe d'accueil, Éducation et francophonie, 25(1), retrieved 01.01.2009 at http://www.acelf.ca/c/revue/revuehtml/25-1/rxxv1-06.html

Wandersee, J. (2000). Using concept mapping as a knowledge mapping tool. In K. Fisher, J. Wandersee , & D. Moody (Eds.), *Mapping biological knowledge* (pp. 127 – 142). Dordrecht: Kluwer.

Yin, Y., Vanides, J., Ruiz-Primo, M. A., Ayala, C. C., & Shavelson, R. J. (2005). Comparison of two concept mapping techniques: Implications for scoring, interpretation, and use. *Journal of Research in Science Teaching*, 42(2), 166-184.