Program Assessment

"Assessment of Online Research Co-op Course"

Research Report

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Introduction

Science and innovation is key for economic success. The changing world requires new skills, new ideas, new knowledge, but also new ways of teaching. Education is no longer about rote learning within school walls – it is extending to contexts where land-mass knowledge is deployed, improved and adds value to the people’s lives. What can schools do to increase society’s capacity to advance knowledge? The most promising approach is learning by participation—i.e., learning to create knowledge by actually engaging with others in doing it (Scardamalia, Bransford, Kozma and Quellmalz, 2012).

The present project – the Ontario On-line Research Co-op Program - contributes to the development of the next generation of Canadian scientists who would like to gain early exposure to careers in science and technology. The program goes beyond the traditional teaching practices focusing on rote learning and memorization. Instead, it puts emphasis on dynamic knowledge development by stimulating students’ needs for information, needs for understanding the phenomena and needs for knowledge growth. It follows principles of sustainable development in education by helping students develop attitudes and skills necessary for responsible decision-making in the future career.

The Ontario On-line Research Co-op Program calls for change in the role of the teacher, who gradually evolves from the main source of information into a navigator guiding students in the ocean of the online information. The teacher (or, in this case, rather “mentor”) helps students to understand their own interests so they can pursue them by actively participating in on-line courses, wiki-publications, forums and etc. Thus, students are no longer viewed as passive “consumers” of facts but active players of the learning process.

Program Description

The Ontario On-line Research Co-op course for high-school students has been collaboratively developed by the Canadian Young Scientist Journal, the Ontario Ministry of Education and the federal Science and Technology Cluster. The program matched highly motivated high school students, in Grades 11 and 12, with top researchers in the fields of science and technology. Students had opportunities to work on research projects, interact with like-minded peers, and gain early exposure to careers in science and technology. The online format of the course made it accessible to students across Ontario by eliminating the need for commuting.

The pilot program included students from four Ontario high schools: Earl Haig Secondary School, École secondaire publique De la Salle, Sir Winston Churchill Collegiate & Vocational Institute, and St. Martin Secondary School. During a 4-month semester, students worked for about 90 hours. Students, mentors and co-op teachers interacted through Skype and SharePoint -- the collaboration space allowing for an easy exchange of ideas, information, assigning research topics, and reviewing work submitted over the period of one semester. By the end of the course the student submitted results in a form of case study or research topic review.

This course supported students' transition from high school into postsecondary institutes with a focus on 21st century career development.
RESEARCH GOALS
The goal of this research was to assess outcomes of the Ontario On-line Research Co-op course, by showing whether this course:

1. leads to a conceptual change in the understanding of the nature of science (recognizing the goal of science as the construction of ever-deeper explanations of the natural world)
2. leads to a significant increase in academic student achievement in science;
3. helps students to establish a concept of scientific standards close to that of their mentors, and
4. enables to foster students’ scientific investigation skills.

PARTICIPANTS
In total, four Ontario schools participated in the Ontario On-line Research Co-op Program during the 2013/2014 school year. In this report, we present data collected at Earl Haig Secondary School, where the On-line Research Co-op Program was conducted during the period of October 2013 - January 2014.

Earl Haig Secondary School serves a diverse population and it is recognized for its academic focus, enthusiasm for learning, lively school spirit, and commitment to the arts. The school’s large size (2,200 students) and professional staff ensures a wide variety of curricular and extra-curricular opportunities for students as well as developing leadership skills.

Participants were sixteen and seventeen year-old students from Grade 11 and 12 classes. For comparability, two groups of participants have been created:

- experimental group (participating in the program) consisting of ten boys and three girls; ten students were in Grade 11 and three in Grade 12.
- comparison group (not participating in the program) consisting of 16 boys and five girls; 18 students were in Grade 11 and three in Grade 12.

The two groups were equivalent in terms of the socio-economic level. All students were informed of the goals of the research study and participated voluntarily.

Students from the experimental group were matched with three mentoring scientists in computer science (please see Appendix A for mentors’ biographies and areas of specialization).

Scientists were involved in the course at different degree, with one scientist playing a major role and two others intervening mostly at the end of the course.

With respect to the goals presented earlier, four assessments were conducted targeting:

- student understanding of the nature of science
- student academic achievement
- student concept of scientific standards
- scientific investigation skills

Since the assessments were conducted at different moments of the four-month period, student absences occurred. In the analyses presented below, we report data only for those students who were present at school during the assessment days.

ASSESSMENT 1: UNDERSTANDING THE NATURE OF SCIENCE
Method
In order to evaluate the conceptual change in scientific literacy, an adapted version of the Nature of Science Interview (Smith et al., 2000) was used. This interview consisted of explicit questions about the goals of science, the nature of experiments and change processes (see Appendix B). Previous research shows that this tool proves to be a reliable tool for assessing student scientific literacy levels (Smith and Wenk, 2006; Chuy et al., 2010).

This assessment was administered twice to students: before and after the On-line Research Co-op Program (pre-test in October 2013, and post-test in January 2014). There were 23 questions in total. Each student answer was given a score ranging from 1 to 3 according to three levels of epistemological understanding (as explained in Carey and Smith, 1993):

- Level 1 – Student considers scientific knowledge as a simple collection of facts with no clear differentiation between theories, hypotheses and experimental results.
- Level 2 – Student no longer perceives scientific knowledge as a collection of facts but of tested ideas. Ideas are clearly differentiated from experimentation, and there is an emergent awareness of the role of the explanations in scientific progress. However, there is still no clear understanding of the role of theory in framing research.
• Level 3 – Student recognizes goals of science as the construction of ever-deeper explanations of the natural world. Theories not only explain phenomena but also predict them, guiding various phases of scientific inquiry.

About a quarter of the answers were scored by two raters (the author and her colleague) with 84% of the inter-rater agreement. The remaining three-quarters were individually coded by the author of the report. If the raters hesitated between the two levels, an intermediate level could be allocated (e.g., 1.5 or 2.5). For the mutually coded set of answers (a quarter of the full set), the average of the scores obtained by the two raters was used for further analysis. Finally, for each student, a total of 23 scores (derived from 23 questions) was averaged to obtain a mean score indicating the general scientific literacy level.

Results

A one-way analysis of covariance (ANCOVA) was conducted on the post-test scores, with Group as an independent variable (experimental vs. comparison) and pre-test scores as a covariate. There was a significant effect of the Online Research Co-op Program on the post-test scores after controlling for the effect of the pre-test scores, $F(1,22) = 14.66, p < .01$. Students pursuing the Online Research Co-op Program demonstrated significantly higher scientific literacy levels than those of the comparison class (adjusted means were 1.96 and 1.75 respectively). As assessed by a partial $\eta^2$, the Group factor accounted for 40% percent of the variance in the post-test scores, holding constant the pre-test scores.

In order to identify which areas of the student understanding were affected by the program, a Wilcoxon signed-rank test was conducted for each question, comparing pre- and post-test scores in the experimental group. The Wilcoxon test showed that a four-month program provoked a positive change in student understanding for six out of 23 questions. Two questions showed a significant increase in student scores and four questions a marginal increase:

• Q4: What sorts of questions scientists ask? ($z = -1.73, p = .08$),
• Q6: Can you give an example of a scientist's question and what he or she would do to answer it? ($z = -1.73, p = .08$),
• Q8: How does a scientist decide what experiment to do? ($z = -1.91, p = .06$)
• Q12: What is a theory? ($z = -1.84, p = .07$).
• Q19: What happens to the scientists’ ideas once they have done a test? ($z = -2.53, p = .01$)
• Q21: Do scientists ever change their whole theories? If yes, when and why? ($z = -2.06, p = .04$).

The Online Research Co-op Program improved student understanding in the areas related to the nature of scientific questions, experiment planning, notion of theory, and change processes occurring during the idea and theory development. It helped students exceed Level 1 epistemological views of science (unproblematic accumulation of facts) and exhibit Level 2 conceptions (science as an idea testing).

Below are examples of students’ answers attesting of the Level 2 understanding:

• “Scientists ask questions such as ‘How does this work?’ or ‘Why does it happen?’ Questions that dig deeper into the topic that they are researching”
• “Scientists decide on the experiments to do based on the question posed in their hypothesis. Usually, multiple experiments are done to ensure that a proper answer is achieved and that it is not biased towards what the scientist wants to happen.”
• “Theory is an explanation of facts and events with enough evidence and logic reasoning to back it up.”
• “After scientists have done a test, they either confirm that their idea holds true or not. They can develop new angles on their ideas and extend it to other ideas.”
• “Scientists could change their whole theories if facts and observations prove them wrong”.
However, for the majority of students, there was still no clear understanding of the role of theory in framing research and no awareness of the uncertainty of scientific knowledge (expert Level 3, as defined by Carey and Smith, 1993). Students judged theories as “wrong” or “right” rather than seeing them as “more or less useful” frameworks for explanation of certain phenomena. Therefore, further efforts should be made in order to bring students to a higher level of epistemological views of science.

**ASSESSMENT 2: STUDENT ACADEMIC ACHIEVEMENT**

**Method**

The main focus of the Online Research Co-op Program at Earl Haig Secondary School was on Computer Science (all mentoring scientists involved in the course were experts in this area). Therefore, in order to measure academic progress, student marks from the Computer Science (University) course have been collected. It was expected that participation in the Program would positively affect student academic achievement. In order to test this hypothesis, student marks from two terms were collected: before and after the end of the program.

**Results**

A one-way analysis of covariance (ANCOVA) was conducted on the post-test marks. The independent variable was Group (experimental vs. comparison) and the covariate was pre-test marks. The ANCOVA was significant, $F(1,28) = 6.64, p = .02$. The strength of the relationship between the Program and the post-test marks was moderate, as assessed by $\eta^2$, with factor Group accounting for 19% of the variance in the dependent measure (while controlling for the effect of the pre-test marks). Students pursuing the Online Research Co-op Program demonstrated significantly higher marks in Computer Science course than those of the comparison class (adjusted means were 88% and 84% respectively). Thus, the program had a positive effect on student academic achievement.

**ASSESSMENT 3: SCIENTIFIC STANDARDS**

**Method**

It was expected that student-mentor dialogue would help students establish a concept of scientific standards (possibly close to those held by their mentor). In order to test this hypothesis, “Normative criteria for scientific publication” questionnaire was used (Chase, 1970; see Appendix C). This questionnaire included ten criteria:

- applicability to “practical” or applied problems in the field,
- clarity and conciseness of writing style,
- compatibility with generally accepted disciplinary ethics,
- coverage of significant existing literature,
- logical rigor,
- mathematical precision,
- pertinence to current research in the discipline,
- replicability of research techniques,
- theoretical significance,
- originality.

Participants were asked to judge whether each of the criteria were “essential”, “very important but not essential”, “somewhat important”, or “not very or not at all important” for research and scientific publication. The questionnaire was administered at the end of the Program to both groups of participants, as well as to the main mentor of the experimental group.

**Results**

A one-sample Wilcoxon signed-rank test was used to compare student and mentor ratings for each group (experimental and comparison). Analysis of results show that students from the comparison group underestimated importance of seven out of ten scientific criteria, when compared to the mentor ratings:

- Applicability to “practical” or applied problems in the field ($z = -3.32, p < .01$),
- Clarity and conciseness of writing style ($z = -2.23, p = .03$),
- Compatibility with generally accepted disciplinary ethics ($z = -3.11, p < .01$),
- Coverage of significant existing literature ($z = -3.72, p < .001$),
- Logical rigor ($z = -3.02, p < .01$),
- Replicability of research techniques ($z = -3.28, p < .01$),
- Originality ($z = -3.13, p < .01$).
Unlike the comparison group, students form the experimental group showed rating close to that of their mentor with only three criteria being underestimated:

- Applicability to “practical” or applied problems in the field ($z = -2.27$, $p = .02$),
- Compatibility with generally accepted disciplinary ethics ($z = -2.23$, $p = .03$),
- Coverage of significant existing literature ($z = -2.64$, $p < .01$).

These preliminary results give us an indication that the On-line Research Co-op Program helped reduce the gap between student and mentor standards on research and scientific publication. An additional analysis of pre-test ratings would need to be conducted to validate this statement.

**ASSESSMENT 4: SCIENTIFIC INVESTIGATION SKILLS**

(Tieback connections of student written work to science curricula)

**Method**

The On-line Research Co-op Course allowed students to discuss topics and concepts that often remain out of scope of a traditional classroom. Thus, it was expected that the program would foster students’ scientific investigation skills, as described in the Ontario Science Curriculum for Grade 12, University/College preparation (Ontario Ministry of Education, 2008). In order to see which skills were covered by the program, curriculum content was matched against students’ written work produced as part of the program. This work represented either a study proposal or research topic review in the domain of parallel computing. Based on the Curriculum, four areas of skills were examined: (1) initiating and planning, (2) performing and recording, (3) analyzing and interpreting and (4) communicating (see Appendix D). Matching analysis was performed by the author of the report.

**Results**

Table 1 presents a summary of results for students pursuing the On-line Research Co-op Course. Analysis of student written work shows that:

- In the area of initiating and planning, four out of five sets of investigation skills were covered in student writings,
- In the area of performing and recording, all sets of investigation skills were demonstrated in student writings,
- In the area of analyzing and interpreting, all sets of investigation skills were demonstrated in student writings,
- In the area of communicating, two out of three sets of investigation skills were exhibited in student writings.

In total, 11 out of 13 categories were covered by students, with the percentages ranging from 38% to 100%. The two uncovered sets of skills concerned the application of safe laboratory practices (A 1.4.), and the expression of results (A 1.13; see Appendix D for the full description of skills).

It is important to note that student work was matched against the Grade 12 Science Curriculum (University/College preparation), while three-quarters of students pursuing the program were still in Grade 11. Thus, it can be concluded that the On-line Research Co-op Program allowed students to go beyond their Grade level, allowing them to foster their scientific investigation skills in a new context.

**Conclusion**

The goal of this research was to assess outcomes of the Ontario On-line Research Co-op course. In order to do this, two groups of students were created: experimental class (participating in the program) and comparison group (not participating in the program). Both groups belonged to the same school. The first assessment showed that students from the experimental class demonstrated significantly higher scientific literacy levels than those of the comparison class (after controlling for the effect of the pre-test understanding level). The program improved student understanding in the areas related to the nature of scientific questions, experiment planning, notion of theory, and change processes occurring during the idea and theory development. The second assessment showed a positive relationship between the Program and student marks in the Computer Science (University) course: students from the experimental group obtained significantly higher marks than those of the comparison class (after controlling for the effect of the pre-test achievement level). The third assessment indicated that the program may help closing the gap between student and mentor scientific
standards (although an additional analysis of pre-test results would need to be conducted to confirm this statement). Finally, the fourth assessment showed that the program provided a fairly good coverage of scientific investigation skills, by activating in students 11 out 13 sets of skills, as described in the Ontario Science Curriculum for Grade 12 (University/College preparation).

Before concluding, limitations of this study have to be discussed. First of all, the number of students participating in the program were quite low to allow for accurate statistical analyses. Thus, it is important to take precaution while considering conclusions of this study and increase the number of participants in the future research. Second, there were no pre-test data available for the third assessment (scientific standards). Without this type of data, no definite conclusions can be made on the evolution of scientific standards in the experimental group. Finally, results of the fourth assessment involving curriculum analysis would need to be validated by a second rater (with an acceptable level of inter-rater agreement).

<table>
<thead>
<tr>
<th>Area of Skills</th>
<th>Ontario Curriculum Numbering</th>
<th>Skills Exhibited in Student Written Work</th>
<th>% of Students Demonstrating the Skills</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initiating and planning</td>
<td>A.1.1</td>
<td>formulate relevant scientific questions about relationships, ideas, problems, or issues, make informed predictions and/or formulate educated hypotheses to focus inquiries or research</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>A.1.2</td>
<td>identify appropriate methods, techniques, and/or procedures for inquiry</td>
<td>63%</td>
</tr>
<tr>
<td></td>
<td>A.1.3</td>
<td>identify print and electronic sources that enable to address research topics appropriately</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>no skills exhibited in this category</td>
<td>0%</td>
</tr>
<tr>
<td>Performing and recording</td>
<td>A.1.5</td>
<td>conduct inquiries, controlling relevant variables, adapting or extending procedures as required</td>
<td>75%</td>
</tr>
<tr>
<td></td>
<td>A.1.6</td>
<td>compile accurate data from sources</td>
<td>38%</td>
</tr>
<tr>
<td></td>
<td>A.1.7</td>
<td>select and organize relevant information on research topics from appropriate sources, including electronic, print, and/or human sources, using an accepted form of academic documentation</td>
<td>100%</td>
</tr>
<tr>
<td>Analyzing and interpreting</td>
<td>A.1.8</td>
<td>synthesize, analyse, interpret, and evaluate quantitative data to determine whether the evidence supports or refutes the initial prediction or hypothesis; identify sources of bias and/or error; suggest improvements to the inquiry to reduce the likelihood of error</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td>A.1.9</td>
<td>analyze the information gathered from research sources for logic, accuracy, reliability, adequacy, and bias</td>
<td>88%</td>
</tr>
<tr>
<td></td>
<td>A.1.10</td>
<td>draw conclusions based on research findings, and justify their conclusions with reference to scientific knowledge</td>
<td>88%</td>
</tr>
<tr>
<td>Communicating</td>
<td>A.1.11</td>
<td>communicate ideas, plans, procedures, results in writing, using appropriate language</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>A.1.12</td>
<td>use appropriate numeric modes of representation and appropriate units of measurement</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td>A.1.13</td>
<td>no skills exhibited in this category</td>
<td>0%</td>
</tr>
</tbody>
</table>

**Table 1. Summary of results for scientific investigation skills, as demonstrated by student writings**
Despite the limitations, results of this study are quite encouraging considering the short time-span of the program. Indeed, four-month period is usually too short to produce a significant conceptual change in student understanding. Overall, this research should add to further development of this pilot project.

Acknowledgements
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References

APPENDIX A
MENTORS’ BIOGRAPHIES
Dr. Erik Spence, Applications Analyst
Erik received his doctorate in plasma physics from the University of Wisconsin-Madison. He has held postdoctoral positions at ETH-Zurich, University of Toronto and Princeton University. His research experience in parallel computation focused on fluid dynamics and magnetohydrodynamics, with an emphasis on liquid-metal experiments.

Dr. Jonathan Dursi, Applications Analyst
Jonathan was part of the team that won a Gordon Bell Award, one of supercomputing’s highest accolades, in 2000. He has worked with the US Department of Energy’s Advanced Strategic Computing Initiative, and more recently with the Canadian astronomy community as the co-author of a long-range plan white paper, to design a decadal plan for computing in this data-intensive field. He has taught classes in HPC and technical computing techniques in three countries.

Dr. Daniel Gruner, CTO-Software
Daniel has more than twenty years’ experience working with a variety of programming languages, parallel computing, scientific modeling, software architecture, and administration and architecture of large Beowulf clusters and large shared-memory parallel computers. He has a doctorate in chemical physics from the University of Toronto.
APPENDIX B

"The Nature of Science Interview" (Smith et al., 2000)

Adapted version.

1. What do you think science is all about?

2. What do you think the goal of science is?

3. How do scientists achieve the goals of science?

4. What sorts of questions scientists ask?

5. How do scientists answer their questions?

6. Can you give an example of a scientist's question and what he or she would do to answer it?

7. What is an experiment?

8. How does a scientist decide what experiment to do?

9. What is a hypothesis?

10. Do you think a scientist's ideas influence the experiments he or she does?

11. How do you think scientists come up with their ideas?

12. What is a theory?

13. Why do you think scientists need to create theories? What are theories good for? Why don't scientists just stick to proven facts?

14. Where do theories come from?

15. If you had a theory and then found some facts that didn't agree with it, what would you do?

16. Do you think a scientist's theory influences his or her ideas about specific experiments? How?

17. If a scientist does an experiment and the results are not as he or she expected, would the scientist consider this a bad result? Why or why not?

18. Say a scientist is going to do an experiment to test his or her idea. Would a scientist do an experiment that might prove this idea is wrong? If yes, why?

19. What happens to the scientists' ideas once they have done a test?

20. Do scientists ever change their ideas? If yes, when and why?

21. Do scientists ever change their whole theories? If yes, when and why?

22. Do scientists always achieve their goals? If not, why not?

23. Can scientists make mistakes or be wrong? How?
APPENDIX C
“Normative Criteria for Scientific Publication” Questionnaire (Chase, 1970)

INSTRUCTIONS: Please, take a look at the criteria listed below and indicate whether each of these criteria is: “essential”, “very important but not essential”, “somewhat important”, or “not very or not at all important” for research and scientific publication.

| (a) Applicability to “practical” or applied problems in the field | essential | very important but not essential | somewhat important | not very or not at all important |
| (b) Clarity and conciseness of writing style | | | | |
| (c) Compatibility with generally accepted disciplinary ethics | | | | |
| (d) Coverage of significant existing literature | | | | |
| (e) Logical rigor | | | | |
| (f) Mathematical precision | | | | |
| (g) Pertinence to current research in the discipline | | | | |
| (h) Replicability of research techniques | | | | |
| (i) Theoretical significance | | | | |
| (j) Originality | | | | |
A. SCIENTIFIC INVESTIGATION SKILLS AND CAREER EXPLORATION

OVERALL EXPECTATIONS
Throughout this course, students will:

A1. demonstrate scientific investigation skills (related to both inquiry and research) in the four areas of skills (initiating and planning, performing and recording, analysing and interpreting, and communicating);

A2. identify and describe careers related to the fields of science under study, and describe the contributions of scientists, including Canadians, to those fields.

SPECIFIC EXPECTATIONS

A1. Scientific Investigation Skills
Throughout this course, students will:

Initiating and Planning [IP]*
A1.1 formulate relevant scientific questions about observed relationships, ideas, problems, or issues, make informed predictions, and/or formulate educated hypotheses to focus inquiries or research

A1.2 select appropriate instruments (e.g., respirometer, titration apparatus) and materials (e.g., prepared slides, Petri dishes, food samples), and identify appropriate methods, techniques, and procedures, for each inquiry

A1.3 identify and locate a variety of print and electronic sources that enable them to address research topics fully and appropriately

A1.4 apply knowledge and understanding of safe laboratory practices and procedures when planning investigations by correctly interpreting Workplace Hazardous Materials Information System (WHMIS) symbols; by using appropriate techniques for handling and storing laboratory materials and biological waste (e.g., techniques to prevent contamination of specimens); and by using appropriate personal protection (e.g., wearing gloves when handling biological specimens)

Performing and Recording [PRI]*
A1.5 conduct inquiries, controlling relevant variables, adapting or extending procedures as required, and using appropriate materials and equipment safely, accurately, and effectively; to collect observations and data

A1.6 compile accurate data from laboratory and other sources, and organize and record the data, using appropriate formats, including tables, flow charts, graphs, and/or diagrams

A1.7 select, organize, and record relevant information on research topics from a variety of appropriate sources, including electronic, print, and/or human sources, using suitable formats and an accepted form of academic documentation

A1.10 draw conclusions based on inquiry results and research findings, and justify their conclusions with reference to scientific knowledge

Communicating [C]*
A1.11 communicate ideas, plans, procedures, results, and conclusions orally, in writing, and/or in electronic presentations, using appropriate language and a variety of formats (e.g., data tables, laboratory reports, presentations, debates, simulations, models)

A1.12 use appropriate numeric, symbolic, and graphic modes of representation, and appropriate units of measurement (e.g., SI and imperial units)

A1.13 express the results of any calculations involving data accurately and precisely, to the appropriate number of decimal places or significant figures

A2. Career Exploration
Throughout this course, students will:

A2.1 identify and describe a variety of careers related to the fields of science under study (e.g., nuclear medicine technician, nurse practitioner, hematologist, dietitian, geneticist) and the education and training necessary for these careers

A2.2 describe the contributions of scientists, including Canadians (e.g., Frederick Banting, John A.Hopps, Louis Siminovich, Jean Cuthand Goodwill, Nancy Olivieri), to the field under study