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Investigating the Alignment of Intended, Enacted, and Perceived Learning Outcomes in an Authentic Research-Based Science Program

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Abstract

This study investigates the intended, enacted, and perceived curriculum in an authentic research-based science program using curriculum mapping as a tool for analysis. The main research inquiry guiding this study is: How do the students' perceptions on their achieved learning outcomes in an authentic research-based learning environment align with the intended and enacted outcomes? A mixed method approach was adopted, where the program and its core-courses were mapped from different perspectives. Data on the learning outcomes and perceptions of students learning were collected through questionnaires, focus groups, and interviews from multiple perspectives. Results of the curriculum mapping showed consistency and cogency of program and course-level learning outcomes. Students' perceptions of their authentic research experiences were well-aligned with the intended and enacted learning outcomes. The results of this study could be used to help other programs implement similar curriculum review approaches in their context.

Cette étude examine le programme d'études visé, adopté et perçu dans un programme de sciences authentiquement basé sur la recherche en utilisant la cartographie de programme comme outil d'analyse. L'objet principal de la recherche qui a guidé cette étude était le suivant : comment les perceptions des étudiants concernant leurs résultats d'apprentissage dans un environnement d'apprentissage authentiquement basé sur la recherche s'alignent-elles avec les résultats visés et adoptés? Une approche à méthodes mixtes a été adoptée, dans laquelle le programme et ses cours de base ont été cartographiés à partir de diverses perspectives. Les données relatives aux résultats d'apprentissage et aux perceptions de l'apprentissage des étudiants ont été recueillies par le biais de questionnaires, de groupes de discussion et d'entrevues à partir de diverses perspectives. Les résultats de la cartographie du programme ont indiqué une uniformité et une force du programme et des résultats d'apprentissage au niveau des cours. Les perceptions des étudiants concernant leurs expériences de recherche authentiques étaient parfaitement alignées avec les résultats d'apprentissage visés et adoptés. Les résultats de cette étude pourraient être utilisés pour aider d'autres programmes à mettre en oeuvre des approches pour la révision de programme d'études dans leur propre contexte.

Keywords

undergraduate research, authentic science research, learning science by doing science, student-centered curriculum mapping, curriculum review; recherche au niveau du premier cycle, recherche scientifique authentique, apprendre les sciences en faisant des sciences, cartographie de programmes d'études centrée sur l'étudiant, révision de programmes d'études

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Theoretical Framework and Study Focus

There is often a gap between what instructors think students are learning and what the students perceive they are learning in post-secondary education (Bath, Smith, Stein, & Swann, 2004; Kuh, 2007). Research has shown differences in instructors' and students' perceptions regarding the extent of development of some skills and attributes through degree programs (Leckey & McGuigan, 1997) such as a different emphasis on critical thinking skills. Curriculum mapping provides a tool to align the learning perceptions of the different stakeholders in an undergraduate program. Curriculum mapping involves associating course outcomes with program-level learning outcomes and aligning elements of courses (e.g., teaching and learning activities, assessment strategies) within a program to ensure that it is structured in a strategic, thoughtful way that enhances student learning (Dyjur & Kalu, 2016; Harden, 2001).

The scholarship of curriculum practice in higher education is in the emergent stages (Oliver, Ferns, Whelan, & Lilly, 2010). Increased attention has been recently paid to curriculum mapping processes at several post-secondary institutions, often for quality assurance and accreditation purposes (e.g.; Oliver et al., 2010; Perlin, 2011; Veltri, Webb, Matveev, & Zapatero, 2011; Willett, 2008). This has drawn attention to the complexity of issues associated with curriculum mapping and has become a topic of rising interest in higher education literature (Arafeh, 2016; Sumsion & Goodfellow, 2004; Wang, 2015; Wolf, 2007).

The overarching goal of the study was to investigate the alignment of students' lived experiences and perceptions of learning outcomes in an authentic research-based science program as compared to the perspectives of other stakeholders using curriculum mapping as an evaluation tool. Our approach in curriculum review supported a reflective practice involving multiple perspectives including students, teaching assistants, instructors, and the program director, provided a visual presentation (heat maps) of the degree of alignment of intended, enacted, and perceived learning outcomes and perceptions and provided indicators of where curriculum redesign should centre (Spencer, Riddle, & Knewstubb, 2012). The research question that guided our study was: How do the students' perceptions of their learning gains and the quality of the learning experiences in an authentic research-based learning environment align with the intended (by the program director) and enacted (by the instructors and teaching assistants) outcomes?

Context: Undergraduate Nanoscience Program

The Nanoscience program is an undergraduate minor program at the Faculty of Science in a research-intensive university in a North American city; it started in fall 2008. The program created opportunities for students from diverse science disciplines and at different semester levels to work in teams to undertake authentic research experiences (Labouta et al., 2018). The Nanoscience courses embody the scientific method and put the learner in the position of "a scientist" (i.e., experience of science as a method of generating and validating scientific knowledge or "learning to do authentic science") (Ciccone, 2012; Crippen & Archambault, 2012; Gurung, Chick, & Haynie, 2009; Handelsman et al., 2004; Hodson, 1992; National Research Council 1999; Shulman, 2005). The program-level learning outcomes were written collaboratively by the program director, instructors, and teaching assistants, and are listed in Table 1. The minor consists of five courses. The learning philosophy of the program is reflected in the three core courses, which became the main focus of the research project: NANS 301 (acquiring fundamental understanding of key concepts in nanoscience), NANS 401 (building testable hypotheses), and NANS 502 (executing self-directed nanoscience research projects).

Table 1.
Learning Outcomes (Skills and Knowledge) of the Nanoscience Program

Attribute	Description
Interdisciplinary Skills	Ability to explain, interpret and analyze issues across the spectrum of different disciplines and integrate knowledge from different fields of study.
Experiential and Problem-Solving Skills	Ability to plan, design and execute experiments. Ability to use scientific knowledge to identify, define and permit analysis of problems, and arrive at solution.
Creativity and Curiosity	Ability to adapt to new situations. Use or modify materials or equipment at hand to obtain results. Develop divergent ways of thinking. Ability to pick out unusual associations of ideas. Thirst for knowledge.
Research	Ability to find information, collect data and assess its relevance and reliability. Ability to formulate or articulate scientific problems and partake research projects to solve them.
Technical Skills	Acquire skills specific to the Nanoscience field. This includes electron microscopy, atomic force microscopy, thin film characterization, nanoparticle sizing and charge density measurements, and optical techniques.
Deep Thinking	Ability to assess scientifically-based arguments and/or information and critically evaluate the basis of the included ideas. Ability to distill salient points from assimilated information.
Communication and Collaboration Skills	Ability to explain and present scientific ideas effectively to different groups of people in multiple formats (written and oral). Ability to work effectively as member of inter- and intra-disciplinary teams.
Knowledge	Ability to explain the theories of self-assembly and quantum confinement and apply this knowledge to construct nanoparticles.

Methodology

A mixed method design was adopted for the case study and summarized in Table 2. This form of inquiry has philosophical assumptions – often based on pragmatism – that focus attention on the research problem and use pluralistic approaches to drive knowledge (Andrew & Halcomb, 2009; Morgan, 2007; Patton, 1990; Tashakkori & Teddlie, 2010). This form of research is popular in evaluation or program implementation fields (Creswell, 2014). In this study, quantitative (core component) and qualitative (supplemental component) methods built on each other to answer the research question. Questionnaires were first conducted providing quantitative (close-ended, Likert-scale questions) and qualitative data (open-ended questions). This was followed by a qualitative explanatory phase (focus groups and interviews) that sought to assist in explaining both the quantitative and qualitative findings in prior stages (Andrew & Halcomb, 2009). Instruments used for data collection and data analysis approaches are explained in the next few sections.

Table 2
Summary of the Multiphase Mixed-Method Study Design

Phase	Purpose	Data Collection Methods	Participants
Curriculum Mapping	• Determining the degree of alignment between intended, enacted, and perceived learning outcomes.	Questionnaires	*n*=81
Collaborative Analysis and Sense Making	• Triangulation to seek complementary information and explanations of the data from the questionnaires (Bergman, 2008; Erzberger & Kelle, 2003). • Identifying action-oriented and research-based future plans for further improvement of student learning.	Focus groups and interviews	*n*=19

Curriculum Mapping: Questionnaires

Four similar questionnaires were developed to collect data from the students (in-class questionnaires), alumni (online questionnaires), instructors and teaching assistants, and the program director (email questionnaires). Questions mainly focused on the course learning outcomes. Responses were either close-ended or open-ended answers. Initial drafts of the questionnaires underwent an expert review process to identify problems related to data analysis and question comprehension (Presser & Blair, 1994; Rothgeb, Willis, & Forsyth, 2007) by five researchers, two pedagogical experts with previous experience in developing and running questionnaires, one expert in the field of nanoscience and two graduate students in nanoscience.

Quantitative analysis of close-ended responses. A total of 24 questionnaire items were coded on the perceptions of the participants on the learning outcomes. Ordinal measurement levels of the quantitative questions were coded as follows: "To a great extent"=3, "To a moderate extent"=2, "To a small extent"=1 and "Not at all"=0. The measurement level "I don't know" and unanswered questions were not coded. Comparisons of responses based on opinions from students, alumni, instructors, teaching assistants and the program director on three courses (NANS 301, NANS 401 and NANS 502) and the whole program (only by the alumni and the program director) were made using their modes and was presented as a heat map to facilitate curriculum mapping and alignment evaluation between perceptions of the different stakeholders.

Qualitative analysis of open-ended responses. Open-ended questionnaire responses were analyzed using qualitative content analysis using NVivo 10 (QSR International Inc.). Content analysis is a categorizing approach that was initially described as "objective, systematic and quantitative description of the manifest content of communication" (Berelson, 1952, p.18). With time, it has expanded to include interpretation of the latent content of the communication. In contrast to traditional quantitative content analysis, qualitative content analysis allows for the subjective interpretation of the content while maintaining the systematic process of coding and identifying themes or patterns (Graneheim & Lundman, 2004; Kaefer, Roper, & Sinha, 2015;

Schreier, 2012; Vaismoradi, Turunen, & Bondas, 2013). Qualitative comments were coded, categories were created, and comments were themed. An inter-rater reliability of 94% was achieved using the Kappa statistic.

Collaboration and Sense Making: Focus Groups and Interviews

Semi-structured open-ended focus groups and interviews lasting about 2 hours each were conducted with the participants (Table 2) and were transcribed verbatim. Transcripts and activity sheets were similarly characterized by qualitative content analysis (Graneheim & Lundman, 2004). An inter-rater reliability of 95% or more was obtained.

Results and Discussion

Curriculum mapping was used as a tool to investigate the potential of an authentic research-based science program. The current study depicts the alignment of the different perceptions of the learning outcomes using curriculum mapping. In order to develop an objective quantitative measure of assessment of the authentic science program within the Nanoscience program, we mapped the program from the perspective of all stakeholders (i.e., the program director, instructors, teaching assistants, students, and alumni) using questionnaires.

Using a heat map approach for the visual depiction of alignment of program and course outcomes is a common practice in curriculum mapping (Botwright Acuna, McDonald, Kelder, & Able, 2016; Letassy, Medina, Britton, Dennis, & Draugalis, 2015; Spencer et al., 2012). Similarly, we compiled our quantitative alignment results in a colour-coded heat map format (Table 3). To facilitate comparison of perceptions, intended outcomes by the director were used as a standard (coloured as yellow in the heat map format). Perceptions by the students and the teaching staff for each of the three courses as well as alumni perceptions of the whole program were compared to the standard (the director's perceptions). Equally-, over-, and underestimated enacted and perceived outcomes are presented in yellow, light to dark green, and orange to red, respectively. Students' and alumni perceptions were, in most cases, well-aligned with intended outcomes, as indicated by the scarcity of red cells in the heat map.

Table 3
*Alignment of Planned, Enacted, and Perceived Learning Outcomes**

Atrribute	NANS 301				NANS 401				NANS 502				Program	
	S	TA	I	D	S	TA	I	D	S	TA	I	D	A	D
Interdisciplinary skills	2	3	2	2	3	3	3	3	3	3	3	3	3	3
Experiential skills	1	2	1	1	3	2	3	2	2	3	3	3	3	3
Research skills	2	1	3	2	2	1	2	2	2	3	3	3	3	3
Problem-solving skills	2	3	3	3	3	3	3	3	3	3	3	3	3	3
Collaboration skills	2	3	3	2	2	3	3	2	3	3	3	3	3	3
Communication skills - written format	2	3	3	1	3	2	3	2	2	2	3	3	2	3
Communication skills - oral format	1	NA	1	1	3	1	2	2	3	3	3	3	3	3
Creativity	2.3	2.3	2	1.8	2.3	1.3	2.3	2	1.5	2.5	3	3	2.75	2.5
Curiosity	3	3	3	2	3	2	2	2	2	3	3	3	3	3
Deep thinking	2.2	2.6	2.8	1.2	2.2	2	2.6	2	2	3	3	3	3	3
Knowledge on the phenomenon of self assembly	3	3	3	2	3	3	2	2	3	2	NA	2	3	2
Knowledge on quantum confinement theory	3	3	3	2	3	1	0	2	3	2	NA	2	3	2
Electron microscopy	3	3	1	1	3	3	3	3	2	3	3	3	3	3
Atomic force microscopy	2	3	0	0	3	2	3	2	3	2	3	3	3	3
Thin film characterization	2	NA	2	0	2	NA	2	2	2	2	NA	2	3	2
Nanoparticle sizing and charge density measurements	1	3	0	1	2	2	3	2	3	3	3	3	3	3
Optical techniques	2	3	2	1	2	2	3	2	3	3	3	3	3	3

To a great extent	3
To a moderate extent	2
To a small extent	1
Not at all	0

Director

mode < director — *mode* > director

S	Students
TA	Teaching assistants
I	Instructors
D	Director
A	Alumni

**Planned* (by the director, denoted as "D"), *enacted* (by the instructors "I" and teaching assistants "TA") and perceived learning outcomes (by the students "S" and program alumni "A") for the Nanoscience courses (NAS 301, 401 and 502). Alignment is based on comparison of the modes developed from quantitative questionnaire data to and presented as a heat map relative to the perceptions of the director (yellow). "NA" indicates no mode due to different opinions by the respondents.

As shown in Table 3, in comparing planned and perceived learning outcomes in the entry course of the program (NANS 301), one could conclude that entry-level students had the tendency to overestimate their abilities on several learning outcomes. Novices have been known to overestimate their knowledge and skills and have greater difficulty recognizing their own strengths and weaknesses relative to experts or more advanced learners (Ambrose, Bridges, DiPietro, Lovett, & Norman, 2010; Dunning, 2005a; Hacker, Bol, Horgan, & Rakow, 2000). This was sometimes obvious in the NANS 301 students' quotes (better estimating the development of some learning outcomes), as compared to the instructors and program director's tendency to highlight the challenges that students face throughout this process. Below are some exemplary quotes on how NANS 301 students describe their knowledge acquisition and development of their deep thinking skills versus the opinions of the program director and a NANS 301 instructor. Students noted, "Quantum aspects were very interesting" (NANS 301 student, questionnaire data), "self assembly phenomenon is among the topics to keep in the program" (NANS 301 student, questionnaire data), and "[NANS 301] makes you think critically about the problems given to you" (NANS 301 student, questionnaire data). Other stakeholders noted,

> Since our approach encourages students to learn deeply and not through memorization, other courses, which do not follow this approach encourage students to go back to memorization of content. This makes learning science by doing science challenging across a student's entire degree program. (Program director, questionnaire data)

> Some students are ill-prepared for this course – not having done any chemistry for example, or no physics at all. As such, I feel students have an uneven experience through the course – some sections are trivial to them, some quite challenging, depending on their background. (NANS 301 instructor, questionnaire data on challenges faced teaching the course)

Further, teaching staff in NANS 301 overestimated some of the learning outcomes (such as development of collaboration skills) by NANS 301 students. This could be justified by considering the model of mastery offered by Sprague and Stuart (2000). According to this model, novice students are in a state of unconscious incompetence, but with time they become more aware of what they know (i.e., becoming consciously incompetent). As their mastery develops, they attain a higher degree of competence within particular areas and advance to being consciously competent. Teaching staff are however at the end of the spectrum in a state of "unconscious competence" in which they exercise the skills and knowledge in their disciplinary domain instinctively. This can be an obstacle for effective teaching, where teachers organize and apply their knowledge differently. Teachers can recognize meaningful patterns and configurations based on their prior experience and can take shortcuts and skip steps without conscious awareness (Blessing & Anderson, 1996). This can cause them to overestimate students' ability to do the same (Ambrose et al., 2010). This finding was evident in the qualitative data where students and instructors in NANS 301 described mastery at collaborative work in different ways. For the instructors of NANS 301, group work activities worked well. On the other hand, the students in their classes felt challenged by these activities despite recognizing their merits. One instructor noted, "The group and class discussions work very well. They are an integral part of the class" (NANS 301 instructor, questionnaire data). Students noted, "The heavy focus on team effort and interdisciplinary exchange [is among the strengths of NANS 301]" (NANS 301 student, questionnaire data) and

> In Nanoscience 301 we had to do a paper done with a group which allowed us to choose and research the topic. I found it challenged me because it requires the collaboration of people with different views as well as how the topic had to be revised many times. (NANS 301 student, questionnaire data)

In contrast, results presented on the other side of Table 3 show that students at the end of the program – NANS 502/the capstone research project – had a tendency to underestimate the development of some learning outcomes such as creativity and deep thinking skills relative to what is intended and enacted. Similar observations were made earlier by Laursen et al. (2010) where students and alumni were not able to observe as many gains in skills as by their research advisors. As full credentialed members of the profession, research advisors could readily recognize some developing behaviours and attitudes related to thinking and working as a scientist, as novice versions of their own professional practice. These specific learning outcomes were accurately estimated by alumni whose perceptions were well-aligned with intended outcomes by the program director. It should be noted here that 55 % of alumni respondents were attending graduate school when completing the questionnaire. These roles could have allowed them to actively observe some gains in skills and knowledge from the Nanoscience program that were not observed by alumni working in other fields. A program alumnus and current graduate student noted,

> I definitely think the Nanoscience program positively contributed to the skills that I developed as a scientist such as critical thinking because on a traditional labs, they would get you to follow procedure. You don't think anything about it. You don't have to evaluate but in nanoscience, you had to come up with your own steps and really reason why it was useful. I think in that sense, nanoscience is highly instrumental. (Program alumnus and current graduate student, interview)

Another noted,

> I think the Nanoscience program definitely affected my preparation for graduate school. I guess the biggest thing would be the NANS 502 project because I think if you compare it to other independent research projects the university has, they don't give you nearly the same amount of freedom in your project as the NANS 502 project does. So I think in that sense, it's really a good preparation for a researcher at a graduate level. For example, we used to have a budget, we had to look at the budget and figure out if we can do certain things, maybe figure out cheaper ways of doing it if we want to do something. (Program alumnus and current graduate student, interview)

In a few cases, respondents had a wide discrepancy on the answers provided (i.e., all responses \were different), and thus no mode was calculated, which is indicated as “NA” in Table 3. For instance, instructors did not agree on the outcomes regarding knowledge in NANS 502. In the follow-up focus group, the instructors explained that NANS502 students acquire different knowledge bases as they all work on different research projects. The instructors also agreed that NANS 502 (capstone research project) is not about quantifiable knowledge as much as the process of developing scientific research skills such as careful experimentation, taking good notes, and data interpretation. All in all, aggregate results of the curriculum mapping (Table 3) showed consistency and cogency of program and course-level learning outcomes. In most cases, intended program-level learning outcomes were enacted by the instructors and perceived by the students.

Study Limitations

Several psychology research studies, reviewed by Dunning (2005b) suggest that people’s impressions of their skills and knowledge are not perfect indicators of their actual proficiency. While not objective assessment, student self-evaluations are argued by some to have great potential for demonstrating skills development, which is often difficult to assess with other measures and assessment tools (Bath et al., 2004; Moore & Hunter, 1993). It is, however, difficult to segregate direct evidence of each individual skill from students’ work. Nevertheless, this work is part of a bigger project, in which we plan to track an individual’s perceptions throughout the program and tie this to actual proficiency levels. The current study, however, emphasizes a constructivist view of the curriculum review process which locates knowledge, attributes, and capabilities in students’ minds (Driver & Oldham, 1986).

Conclusion and Recommendations

This study demonstrated how a mixed-method approach, including curriculum mapping, focus groups, questionnaires, and interviews could provide a tool to systematically investigate program alignment and perceptions of the intended, enacted, and perceived curriculum from multiple points of view. It clarifies cogency of program-level and course-level learning outcomes. In this study, questionnaire, interview and focus group data suggest that students' perceptions of their authentic research experiences in a Nanoscience program were well-aligned with the desired learning outcomes.

The data collection, analysis, and interpretation process outlined in this project could thus be used to help other programs implement similar curriculum review approaches in their context. Specifically, different stakeholders (e.g., students, alumni, instructors, program directors, teaching assistants) should be included in evaluating the intended, enacted, and perceived curriculum. Many curriculum review processes do not involve teaching assistants, and we found that bringing teaching assistants into curriculum conversations provided them with the opportunity to better understand curriculum goals and teaching approaches. Importantly, students often experience the curriculum differently from instructors. Understanding the student and alumni perceptions provide a critical component to improving the student learning experience.

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