Title: Undergraduate Research Driven by the Assessment of Learning Objectives versus the Research Question

Problem: Traditionally research is driven by a central research question. A background search is completed, hypothesis formed, and data collected. The central focus of the project is taking steps towards answering the research question. When undergraduate research is driven solely by the research question, the students often become data collectors without experiencing the research process from start to finish. Pressure to complete the experiment in the specified amount of time generates a further focus on collecting data points and not on learning to troubleshoot independently or to gain a full understanding of the project goals and techniques.

Offering a comprehensive undergraduate research program at a primarily teaching institution presents many challenges. Professors carry a full teaching load, which limits time available for planning and grant writing. Laboratory managers and assistants are often hired to support laboratory courses but not student or faculty research. Research budgets are often limited as a research course does not serve as many students as a lecture/laboratory course. Grant writing assistance is often limited. Despite these hurdles, most teachers would agree that providing students with "hands-on" research is worth the effort.

Undoubtedly, the value of a "hands-on" research experience is acclaimed in the literature. Chickering *et al.* supports active learning by saying, "Learning is not a spectator sport. They [students] must talk about what they are learning, write about it, relate it to past experiences, and apply it to their daily lives. They must make what they learn part of themselves" [1, 2]. Peer teaching has been shown to be extremely effective for students that have different learning styles and personalities [3, 4]. Problem-based learning and discovery has been shown to more effectively accomplish learning goals because it is "simply more engaging, permitting higher ownership and self-regulation of learning" [5]. In developing our undergraduate research program, we focus on two fundamental questions: 1) What are the essential features of a successful undergraduate research experience? and 2) Are they the same if the research is driven by learning objectives rather than a research question?

Design: At Concordia University-St. Paul we are developing a learning objective-based undergraduate research program that includes formal assessment of student learning during and upon completion of the two courses. The purpose of this 9-month (two semester-long) research experience is to guide a group of approximately 10-15 students through the thought process and technical steps of completing a research project from start to finish. After careful consideration, we have established the following learning objectives:

Semester One: Research Proposal (1 credit)
Scientific writing. Scientific writing distinguishes itself from previous student writing experiences in several ways. The writing style is precise, technical, and formal, and it does not lend itself to descriptive and "long-winded" commentary. As the primary objective of semester one, students are required to complete a research proposal according to the National Institutes of Health (NIH) format.

Literature search. Students are introduced to the research topic. A literature search of peer-reviewed and non-peer reviewed material follows.
Hypothesis development. Students are required to summarize the overall research goal (specific aim) as a culmination of the literature search.
Introduction to Materials and Methods. Students are asked to outline the general project plan. Supply lists, beginning protocol development, and solution recipes are included in the research proposal. Techniques are also introduced or reviewed.
Research proposal. The research proposal is written according to the NIH format and includes the following sections: Specific Aims, Background and Significance, Research Design and Methods, and Literature Cited.

Semester Two: Research in Biology (4 credits)
The weekly class meeting. The research class is designed around a weekly class meeting. To complete the research goals, students are divided into groups of 2-4. At the weekly research meeting, each group reports to the class on their accomplishments that week (successes and frustrations). The class is required to troubleshoot for the group. By the end of the meeting, each group is assigned a new set of objectives for the upcoming week.
Introduction to the laboratory setting. Before the start of the semester, most of our students have been exposed to lab activities exclusively in a classroom setting. In these courses, supplies have been set out and protocols handed to them. Semester two begins with a tour of the labs and supply rooms, as well as training on each piece of primary equipment.
Protocol development. Many students have never needed to generate a protocol on their own. Students are asked to refer to the experiment outline of their research proposal and form detailed protocols that can be presented to the class at the weekly class meeting.
Troubleshooting. Research students typically have not been presented with problems that do not come with an answer key. In research, students are faced with problems that have many possible paths to answer the same question. During the weekly meeting, the class contributes ideas to each particular group's research problem. Students must keep limitations such as budget, time, sample availability, and equipment availability in mind when problem solving.
Laboratory Notebook. Students are required to keep a laboratory notebook that contains all ideas, protocols, recipes and procedures attempted in the lab. They also record data and draw conclusions in their notebook.
Research Symposium. Students are required to present their group's research as a scientific poster at our university's Research and Scholarship Symposium in late spring.
Research Paper. Students are required to describe their project in a formal research paper.
Honors Presentation (optional). Students are able to present their research in front of faculty and peers as one requirement for earning Honors in Biology.

Assessment of student learning
Assessment of student learning can be defined as, "the systematic collection of information about student learning, using the time, knowledge, expertise, and resources available, in order to inform decisions about how to improve learning" [6]. Several years ago, Concordia University-St. Paul began the process of implementing university-wide assessment of student learning. Small groups of faculty members met to develop shared descriptive rubrics for both

general education and major program curricula. Software called eLumen was employed to manage and aggregate the data from the university-wide assessment plan. The process of implementing university-wide assessment has already transformed the culture of our institution, making it more learner-centered rather than teaching centered [7].
Since our undergraduate research approach is driven by learning objectives, it is essential to have clear learning outcomes to assess student progress. Faculty members in the biology department collaborated to develop descriptive rubrics that assess student learning during the research process. The rubrics measure four levels of student achievement: beginning, developing, accomplished, and exemplary (See example in Figure 1 below). In addition, descriptive rubrics for specific assignments, such as laboratory notebooks and laboratory reports, were developed to ensure that the faculty members are using common expectations and that those expectations are clearly communicated to the students.

Figure 1: Example of one rubric developed by biology faculty members for our General Achievement (learning outcome) "Acquire and apply skills related to scientific research".

General Achievement: **Acquire and apply skills related to scientific research**.

Specified Achievements	Beginning	Developing	Accomplished	Exemplary
Troubleshooting	The student is not able to identify reasons why an experiment didn't work.	The student is sometimes able to identify reasons why an experiment didn't work.	The student is able to identify why an experiment didn't work and is starting to think about possible reasons for unexpected results.	The student is able to identify why an experiment didn't work, proposes possible reasons for unexpected results, and can take the next step—to design an experiment that addresses the results.

The rubrics used to assess learning by undergraduate student researchers include:

- **Professionalism and ethical behavior**—effective interpersonal skills, self-motivation, completes work ethically, positively contributes to a working group
- **Acquire and apply skills related to scientific research**—following procedures, technical lab skills, knowledge of techniques, troubleshooting (See Figure 1)
- **Demonstrate the ability to reason scientifically**—develops a testable hypothesis and formulates research questions, demonstrates a clear understanding of the "big picture", evaluates experimental approach, analyzes data, synthesizes conclusions
- **Communicate scientifically in writing** (research proposal and final paper)—content, organization, terminology, references
- **Communicate scientifically in an oral presentation**—organization of the presentation, content and terminology, format
- **Laboratory notebook**—organization, objectives of each experiment, materials and methods, data, data analysis, and conclusions

While we have been able to develop clearly defined assessment tools for many of our learning outcomes, assessment of several objectives has proven to be problematic. These include:

- **Selecting research students**—Do we move to a more selective model, and if so, how? Do students apply for the research program or do we accept all students because we feel that the learning process is valuable for everyone?

- **Productivity**—If the course is not assessed based on productivity, how do we ensure that students manage their time and work efficiently in order to make sufficient progress?
- **Attendance**—What are the consequences for not showing up?
- **Accountability**—Since students work in teams, how do we ensure that each student contributes equal time and effort toward the group's project goals?

Findings: While the challenges of offering a comprehensive undergraduate research program at a primarily teaching institution are many, we have found that the benefits of an undergraduate research program far outweigh the hurdles. We have also found that significant learning occurs in the process and is less dependent on the research question than originally thought. The benefits of the research experience can be evaluated through the eyes of the instructor or the student. The benefits of the research experience can be evaluated by the instructor using descriptive assessment tools (rubrics) or from the students' perspective using a course evaluation. These measures of achievement are in contrast to the achievement (or lack of) that is most often measured solely by obtaining a desired result in research that is driven by the research question alone (e.g. a publication or an abstract describing a completed project).

Instructor's perspective:
The benefits of undergraduate research have been well-documented in the literature and include being mentored by the faculty member (academic, career, and personal support); learning how to do science in a non-course setting; gaining technical laboratory skills rather than just reading about them; increasing scientific reasoning skills and the ability to troubleshoot; working in a team and peer-teaching; making connections between classroom knowledge and hands-on research; communicating scientifically in written and oral formats; gaining confidence; and becoming an independent researcher. Our findings will show that, from both the instructor's and student's perspectives, these goals are generally being met.

As stated previously, we use descriptive rubrics developed by our biology faculty members to assess student learning throughout our curriculum (See list of rubrics on Page 3). This data is managed and aggregated using a software program called eLumen. We have been collecting assessment data using eLumen for about three years now, so our data set is very small (n = 16) and is not longitudinal. Even so, we are starting to see some trends that we can address for future research courses. The research students generally meet our expectations for the learning outcomes assessed using descriptive rubrics (achieving the accomplished or exemplary level, See Figure 1). We see lower achievement (developing level) for higher-level thinking activities one might expect would pose a challenge for undergraduate researchers, such as troubleshooting, using proper terminology, analyzing data, and synthesizing conclusions.

Students' perspectives:
Students are asked to evaluate their research experience at the end of the course. Following are some of their responses.

- "There is less of a student/teacher mentality to this class and much more of a research team."

- “I highly recommend this class to my peers because it actively involves you in the learning process. The whole class is hands-on, and I felt very accomplished to…use knowledge from other textbook classes. It is fun to use what you’ve been learning about!”
- “This is hands-on learning…the professor and students have discussions about different aspects of the experiment and work together to solve problems.”
- “The class gives students a chance to experience what people working in the field of research do on a daily basis.”
- “I felt myself getting more confident as time went on. I also noticed a different type of thinking taking place; it opened new thought processes that I hadn’t yet explored.”
- “One of the biggest things I took away from this is beginning to understand the complexity of research.”
- “[I enjoyed] the ability to analyze data and draw conclusions with lab partners and the faculty advisor.”

Undergraduate research is challenging for both faculty mentors and students, but our findings remind us that the benefits outweigh the hurdles.

Contribution: It has historically been difficult to measure the benefits of undergraduate research. With clear learning objectives and formal assessment in place to define the evaluation of those learning objectives, we are able to both provide a valuable research experience and measure the benefits of that experience. In addition, our findings show that experiential/active learning has a distinctly different learning outcome in comparison to textbook/classroom learning. Pipetting is very different than reading how to pipet. Finally, our findings suggest that the benefits of undergraduate research driven by the assessment of learning objectives are as valuable as the benefits gained during research driven by the research question.

General interest: Learning objective-based research can be integrated into any biology curriculum both as a standalone course (as we’ve described) and/or as a mini-project in a major’s course. Our model is also of interest to teachers looking for more formal measures to assess student learning using descriptive rubrics.

References:

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