Unit assessment for the Physical Sciences

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Table of Contents

Introduction

The department of Physical Science has had unit level liaisons since Fall 2014. The work up until Fall 2019 has primarily focused on the courses in the chemistry program. The only exception to this work was in Spring 2016 when Anthony Escuadro assumed the role while Allan Wilson was on sabbatical, and concentrated on the physics program. While extensive progress has been made in chemistry assessment, the department wanted to ensure the general education assessment at the course level was also progressing. It was decided that in Fall 2019 the liaison role would be divided between the chemistry program, led by Samar Ayesh (to ensure the robust assessment program persists), and general education led by myself, Phillip Vargas, (to update the general education program assessment).

The timeline I have envisioned for this project has been three years. The first year of this project was primarily focused on the first stage of assessment. As this project incorporates the entirety of the general education courses in the Department of Physical Science, a disproportionate amount of time was allocated to this section. It is my intuition that investing more time on this stage of the assessment program will lead to more significant insight in future years and reduce the potentiality of developing assessments to measure outcomes that are not relevant to the discipline. This part of the project has been largely completed.

Department buy-in and outcome definition

During the Natural Science general education assessment of 2016, the department worked together to design a tool to measure student learning in the natural sciences. This was a herculean task, as all of the general education assessments are, and led to many insights into student learning in the natural sciences. However, one of the most significant aspects we learned was the need to better align the general education outcomes with the curriculum and *then* develop the assessment tool.

This first step in this process was to review the natural science general education outcomes (GEO), and pose the question, “How do we measure these?” These outcomes are somewhat general, and while all of the natural science classes offered at HWC certainly touch upon them, they do not explicitly focus on them. This led to the second major problem. In order to earn an A.A. or A.S. degree at HWC, a student is only required to take one three-credit physical science class. In HWC’s catalog, all of the non-major, physical science courses are survey courses within a particular scientific field. These fall into introductory courses such as geology or astronomy, or topics courses that cover multiple fields such as conceptual physics and chemistry courses or an earth and space science course.

This created a significant challenge, because each of the course learning outcomes (CLO) for these courses were content-based and specific to the content taught in those courses, and HWC’s natural science GEOs were general process-based outcomes. When attempting to then design a tool to measure the GEOs, it became immediately clear that not only a disconnect exists, but that HWC's courses are not well aligned within the larger program.

Assessment research and design

A literature search on student learning outcomes for general education physical science courses unfortunately did not reveal a wealth of information. Many of the physical science professional organisations in higher education such as the American Physical Society and the American Chemical Society focus more on program major assessment rather than general education assessment. It was not until my research shifted toward K-12 education that I found more relevant information, where the Next Generation Science Standards were the *de facto* guidelines.

Next Generation Science Standards (NGSS) Framework and Background

The NGSS was a multi-state, multi-agency project designed to create standards of learning in science and engineering courses for the K-12 grades (NGSS 2013). The main goal of this project was to try and synthesize all of the coursework being taught and to better prepare students to become engineers and scientists (NRC 2012). The results of this project informed the student learning outcomes (SLOs) referred to as performance expectations (PEs) of the common core curriculum.

The NGSS divides its standards along three dimensions: Science and Engineering Practices (SEP), Disciplinary Core Ideas (DCI), and Crosscutting Concepts (CCC). The motivation behind the term "practice" in SEPs is to not only assess what students know, but their understanding of how to investigate the natural world through scientific inquiry (AAAS 1989)(AAAS 1993). To be successful in this practice, students must not only possess the knowledge of the content, but perform as practitioners of this concept (NRC 1996).

Incorporating the SEPs into program level outcomes at HWC would then be a way of integrating scientific processes independent of specific DCIs. The DCIs could become the more content-specific student learning outcomes currently in the scientific disciplines (Physical Science, Earth and Space Sciences, and Life Science), but contain SEP and CCC language. These outcomes would be more refined and focused to a smaller set of concepts. The idea behind this is to provide more depth to fewer concepts to ensure a higher level of mastery which is consistent with national goals (NRC 2012). Assessment can then focus on the SEPs or CCCs, which will be explicitly intersectional concepts across the natural sciences.

Reformulating the Student Learning Outcomes for the Natural Sciences

As the Science and Engineering Practices provide the framework for the core curriculum in K-12 and have been adopted by the CPS, building on these for non-major classes extends this framework into higher education. This language is a minor refinement to our current learning outcomes.

The Next Generation Science Standards:

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

HWC General Education Student Learning Outcomes in the Natural Sciences:

1. Formulate reasonable explanations of natural phenomena based on thorough observations.
2. Interpret and articulate scientific results that are presented in verbal, graphic and/or tabular form.
3. Critically evaluate scientific resources and scientific claims presented in the media.
4. Apply steps of the scientific method to solve problems.

These outcomes can be consolidated to match our institution's format and voice while at the same time preserving the main points. This would allow course level outcomes to mirror the PE DCIs and CCCs to allow assessment across natural science general education courses. An example of these consolidated outcomes (and explanation of the color-coding applied above) is below:

1. (Ask scientific questions)[1] to (plan and carry out scientific investigations)[3]
2. (Develop and use models)[2]
3. (Analyze and interpret data)[4] (using mathematics and computational thinking)[5]
4. (Construct explanations)[6] and (engage in arguments from evidence)[7]
5. (Obtain, evaluate, and communicate scientific information)[8]

Program, Course, and Modular Alignment

After reformulating the general education objectives, the main goal of the first part of this project was to try and synthesize all of the coursework being taught into the performance expectations (PEs) of the common core curriculum. Utilizing this developed framework, the GEOs for the natural sciences could be slightly refined to incorporate the Science and Engineering Practices outlined in the NGSS. Then the SLOs for individual courses can be updated to reflect the performance expectation of that discipline. The master syllabi format lends itself well to this process and is illustrated below with the hierarchal relationship. The language of the GEO of "Develop and use models" would be present in a course SLO for a particular discipline. The discipline-specific concepts could then be in the content section of a unit within that course. Repeating this process for each of the GEOs to all of the courses' SLOs in the physical sciences, would create an explicit mapping of where these outcomes are being taught and allow us to better measure them.

For example the second general education outcome, "Develop and use models" can be found in course learning outcomes in every general education physical science course.

- Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms. [Phy Sci 102, Phy Sci 112]
- Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun's core to release energy that eventually reaches Earth in the form of radiation. [Phy Sci 101, PhySci 111, Astro 201]
- Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features. [Phy Sci 101, Phy Sci 111, Geo 201]

These general education outcomes would be further propogated into more granular outcomes. One of the modular learning outcomes in the Module "Structure and Properties of Matter" in Physics Science 112 would include:

- From the given model, students identify and describe the components of the model that are relevant for their predictions, including:
    - Elements and their arrangement in the periodic table
    - A positively-charged nucleus composed of both protons and neutrons, surrounded by
      negatively-charged electrons
    - Electrons in the outermost energy level of atoms (i.e., valence electrons)
    - The number of protons in each element

The practice of using modeling traversed each of these outcome hierarchies, from Gen Ed to modules within a particular course.

Pilot assessment tools and processes

Existing assessments in science education weren't designed to capture three-dimensional science learning like the kind found in the Next Generation Science Standards. Instead, students' achievement in science is often assessed only every few years with tests that mainly measure students' memorization of facts and definitions (NSTA 2014). The performance expectations in the NGSS were written and incorporated into the Department of Physical Science General Education outcomes to encourage the development of better assessments; but to develop better assessments, we must explore new approaches.

As more institutions and organizations align with the NGSS, an increasing number of assessment tools typically referred to as "tasks" are being developed. One potential candidate to pilot in Fall 2020 is being adopted at Stanford NGSS Assessment Project. Available under the Creative Commons Attribution Licenses and adapted from the "Age of the Earth," a task has been developed to incorporate all three dimensions of the NGSS. (Dalrymple, 1994)

Administer specific assessment

The implementation of the pilot assessment is planned for Fall 2020 in weeks 15 or 16. This assessment will be administered to all general education courses in the department of Physical Science. Pre/post models may be incorporated in future semesters, but the initial semester will focus on changing the culture of instructor-led to department-led assessment. After the assessment is refined, the feasibility of migrating the assessment into the learning management system will be investigated.

Data analysis

The implementation of the pilot assessment is planned for Fall 2020. Since the assessment tool has not yet been administered, the department has not acquired any data yet. However, the data analysis plan going forward is going to focus on validation studies for the first semester.

Supporting evidence-based change

This proposed curriculum restructuring is largely based on the evidence from the Natural Science general education assessment. While the assessment showed statistically significant gains in learning for the students in the physics and chemistry course sequences, it lacked the sensitivity to detect these gains in the general education program. Improving the validity of the assessment tools requires better defining learning outcomes, and the thrust of this project.

Conclusion

As the first year of this project is coming to close. I have completed the development of the program, course, and module learning outcomes for the following courses: Physical Science 101, Physical Science 102,Physical Science 111, Physical Science 112, Geology 201, and Astronomy 201. These outcomes have practices and concepts consistent across disciplines and are aligned with the Next Generation Science Standards. These new curricula are in excellent positions to be assessed with tools and tasks being developed and validated by many organizations and institutions. These outcomes have also been written into a format to be incorporated into the City Colleges of Chicago PACC process.

Unfortunately, while I have been able to keep pretty close pace with my planned timeline, the COVID-19 pandemic has interfered with the PACC process. I had planned to share the master syllabi with the discipline in spring 2020. However, with changes in operations the pandemic has caused, I have delayed this process to ensure all of the disciplines have the time to properly review these changes.

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Appendix

Assessment Tool (Preliminary Concept)

- Students represent, identify and label the oxygen isotope data for chondrites, Mars, Earth and the Moon on the scatterplot.
- Students draw trendlines on the scatterplot that show an increasing linear relationship (with a positive slope) for the chondrite, Mars, Earth and Moon data.
- Students derive an equation that models each trendline (chondrite, Mars, Earth and the Moon) on the scatterplot.
    - Based on observation and interpretation of the scatterplot, students identify and use the following patterns as evidence to support the explanation:
        - The oxygen isotope data for Earth and the Moon would lie approximately along the same trendline.
        - The Earth and Moon trendlines are comparable and have approximately the same slope and y-intercept.
- Students support the explanation by showing their reasoning, including that because the oxygen isotope data for Earth and the Moon would lie on approximately the same trendline (comparable slope and y-intercept), the Moon material and Earth material were likely once part of the same planetary body.

- Students make a claim that the formation of the Moon occurred at a time between approximately 4.4 billion and 4.6 billion years ago.
- Students support the claim by identifying and describing the following patterns in their plots as supporting evidence:
    - Based on observations and interpretation of the scatterplot, the oxygen isotope data for Earth and the Moon would lie approximately along the same trendline.
    - Based on the dot plot, the oldest Earth and Moon samples have approximately the same age.
- Students describe how the evidence supports the claim by reasoning that:
    - Because the oxygen isotope data for Earth and the Moon would lie on approximately the same trendline (comparable slope and y-intercept), the Moon material and Earth material were likely once part of the same planetary body.
    - Because the oldest Earth and Moon samples are approximately the same age, the impact event that formed the Moon likely occurred before the formation of the oldest Earth and Moon samples.
    - The collision that formed the Moon likely occurred after the two colliding planetary bodies accreted but before Earth cooled.
- Students update and label the timeline they began in task component A, now including and labeling the formation of the Moon at a point between approximately 4.4 billion and 4.6 billion years ago, after planetary accretion and before planetary cooling.