Natural Sciences

Description and Learning Outcomes

The Mason Core Natural Sciences courses engage students in scientific exploration; foster their curiosity; enhance their enthusiasm for science; and enable them to apply scientific knowledge and reasoning to personal, professional and public decision-making. Lab courses must meet all five learning outcomes. Non-lab courses must meet learning outcomes 1 through 4. Labs and Fieldwork courses must meet learning outcome #5.

To achieve these goals, students will:

1. **Scientific Method:** Understand how scientific inquiry is based on investigation of evidence from the natural world, and that scientific knowledge and understanding:
    a) evolves based on new evidence
    b) differs from personal and cultural beliefs
2. **Scope and Limits of Science:** Recognize the scope and limits of science.
3. **Science and Society:** Recognize and articulate the relationship between the natural sciences and society and the application of science to societal challenges (e.g., health, conservation, sustainability, energy, natural disasters, etc.).
4. **Scientific Literacy:** Evaluate scientific information (e.g., distinguish primary and secondary sources, assess credibility and validity of information).
5. **Labs and Fieldwork:** Participate in scientific inquiry and communicate the elements of the process, including:
    a) Making careful and systematic observations
    b) Developing and testing a hypothesis
    c) Analyzing evidence
    d) Interpreting results

Approved Courses and Enrollment

Students are required to pass two approved science courses, with at least one course that includes a laboratory experience, or transfer in appropriate courses. During the assessment period, 68 courses were approved to meet the Natural Sciences requirement for overview (no lab required) and lab science (see Table 20).

Natural Sciences courses enroll almost 13,000 students each year. Average lecture class sizes vary from 14 in Computational Data Sciences to almost 100 in Biology and Chemistry, though sections can top 300. Labs maintain smaller class sizes for focused, practical instruction—on average, about 20 students, but this also varies by department. Tables 18-19 and figure 36 show enrollment trends over the past five years. Physics and Astronomy is currently the highest enrolled department (31% of AY19 enrollment), followed by Biology (23.7%) and Chemistry (15.2%).

Courses Included in Assessment

The assessment period included 102 sections of Natural Sciences lecture courses taught on all of Mason's campuses and via distance learning in fall 2019. Of the 95 course sections included in the assessment period, 92.6% submitted materials. Of the 289 lab sections taught in fall 2019, 73 (25%) were randomly selected for the assessment; 88% provided materials.

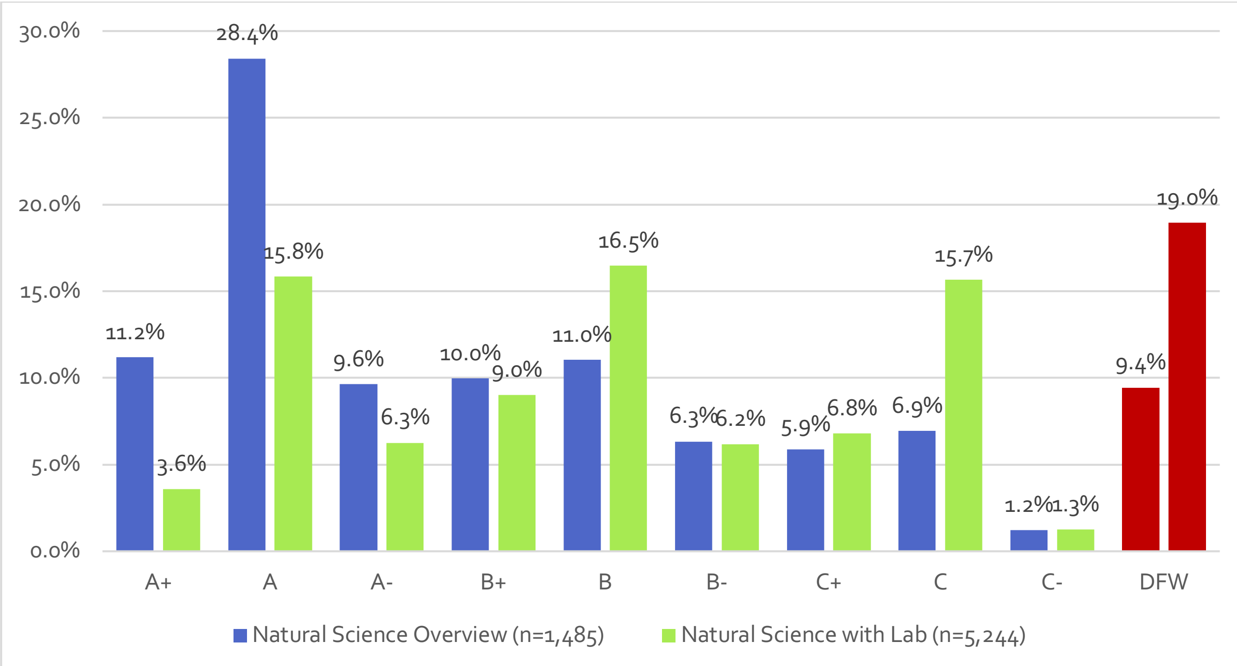
Enrollment and Grades Distribution

A total of 6,758 students enrolled in Natural Sciences lecture courses in the assessment period. The highest enrolled five enrolled courses were BIOL 103 (13.3% of Fall 2019 enrollment), CHEM 211 (12.8%), BIOL 213 (9.1%), GEOL 101 (6.3%), and PHYS 243 (6%). See Tables 18-19.

Of the enrolled students, 89.4% students in Natural Science Overview (NSO) lectures passed their course with a C or above, and 79.8% of students in Natural Science with Lab (NSL) lectures passed their course with a C or above. An independent-samples t-test found that students in NSO courses (m=3.17, $p<.05$) had significantly higher grades overall than students in NSL courses (m=2.70, $p<.05$). Figure 32 displays final grades by course category.

As part of a related project on STEM gateway courses, student enrollment data from AY17-19 were analyzed to understand academic performance in several courses. At interest was performance in introductory STEM courses that were math-heavy (CHEM 211/212, CS 112, PHYS 160/260) versus those that did not require high levels of math (BIOL 213/214, PHYS 243/245). It turns out that courses that the grades in math-based courses (m=2.33) were nearly four-tenths lower, on average, than grades in non-math-based courses (m=2.73). See Figure 37.

Figure 32. Grades Distribution for Mason Core Natural Sciences Courses, Fall 2019



Grades of Audit (AU) and Incomplete (IN) not included in the figure (n=29)

Assessment Methods

Three kinds of work samples were collected for this assessment:

1. Project or homework samples from lecture courses representing any of the learning outcomes #1-4.
2. Exams and scores from lecture courses representing any of the learning outcomes #1-4.
3. Lab report samples from lab courses representing outcome #5.

Faculty were asked to submit samples that represented student submissions completed in the final third part of the semester and that allowed students to demonstrate their learning on one or more of the Natural Sciences learning outcomes. Samples were selected using randomized course enrollment lists to insure the best possible representative sample.

The **Mason Core Rubrics for Natural Science Courses** were used for this assessment. The rubrics were developed by Mason faculty as tools to assess individual student work. The first rubric focuses on outcomes #1-4 and was used for samples from the lecture sections. The second rubric focuses on outcome #5 and was used to assess lab reports. Both rubrics are modeled after the VALUE rubrics and use four performance descriptors: Novice, Developing, Proficient, Advanced, as well as an option for "no evidence." The performance descriptors are developmental, identifying student performance levels in a context of learning and growth.

The rubrics are intended to be used across all of the years of a student's college experience, and is not limited to a single course, assignment, or student class level.

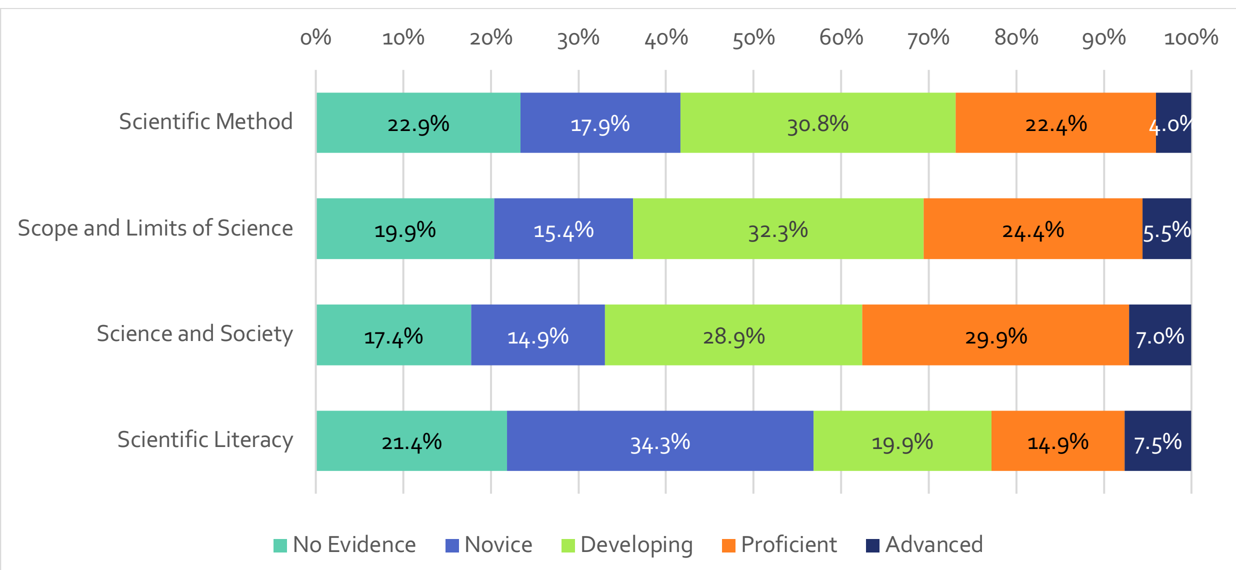
Using a process modeled after the VALUE Institute reviewer calibration, faculty reviewers were trained to use the rubrics to assess student work. Reviews were normed to produce consistent ratings across reviewers. Reviewers met for an in-person, one-day training and review session and completed the reviews of student work by the end of the day. Reviewers were faculty members who have taught Mason Core Natural Sciences courses. Reviewers earned a small stipend for their efforts. Each student work sample was assessed twice.

Learning Outcomes Assessment Results

Lecture Samples – Project Samples

Figure 33 displays results from 201 ratings on the rubric for lecture courses (Outcomes #1-4). Across the outcomes, 20% of samples were rated as "no evidence," meaning that the learning outcome was not identified in the sample. Samples were rated as Novice or Proficient 44-54% across the outcomes, which is to be expected for 100- and 200-level courses. A Pearson's Chi-Square test did not reveal differences between NSO and NSL lecture samples.

Figure 33. Assessment Results for Project Samples from Lecture Courses



N = 201

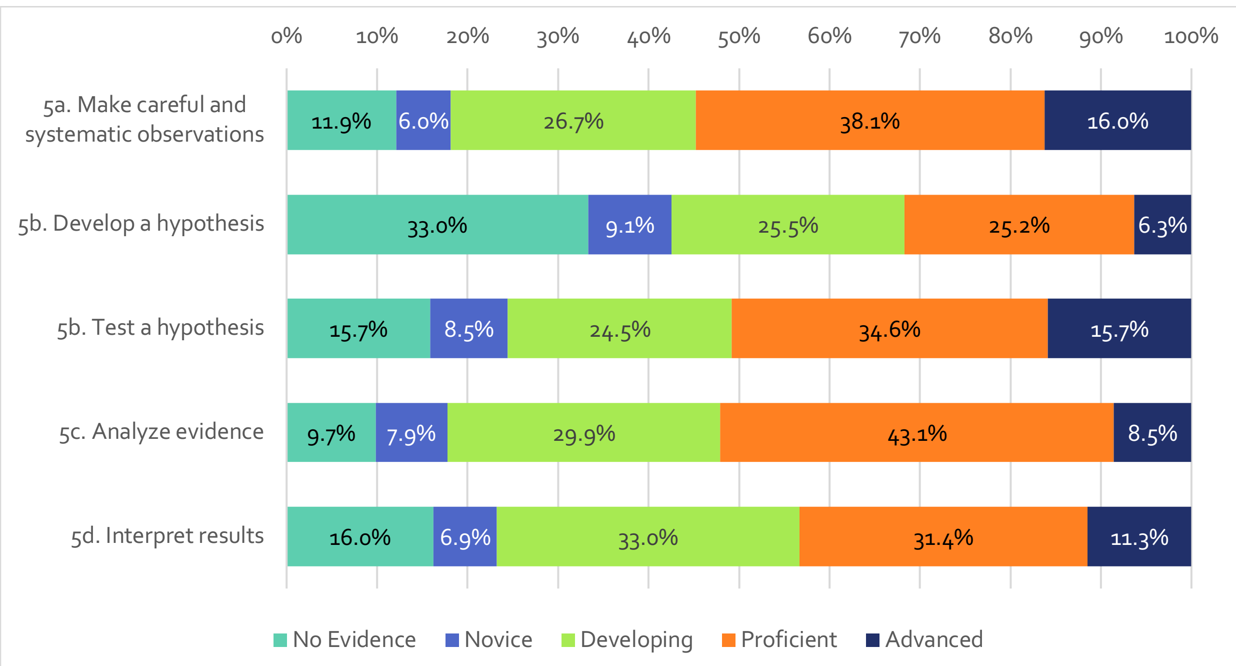
Lecture Samples – Exams

It is common for large lower-division lecture courses in the sciences to use multiple-choice exams as their primary, or only, form of assessment. For courses that use only these kinds of exams, faculty were instructed to submit a document that mapped items from a selected exam to the Mason Core learning outcomes, and then submit student performance data for these items. While most faculty submitting exams did complete this activity, the submissions were inconsistent, and it proved unworkable to compile the results in any meaningful way. Thus, exam data were not included in the assessment results. In future, should this kind of assessment be conducted again, it will be important to solve this challenge.

Lab and Fieldwork Report Samples

Lab and fieldwork reports for general education science courses contain similar elements across disciplines, thus we have reasonable confidence that the rubric used for this assessment was valid. Figure 34 displays results from 318 ratings on the Lab Reports Rubric. A Pearson's Chi-Square test revealed differences between 100- and 200-level courses. Samples from the 200-level courses were rated significantly higher for outcomes 5a and 5c only. It should be noted that in the development of the rubric, faculty claimed that it would be unusual for a lab course at the lower-division to expect students to develop a hypothesis; this is partially seen in the results.

Figure 34. Assessment Results for Lab and Fieldwork Reports Samples from Lab Courses

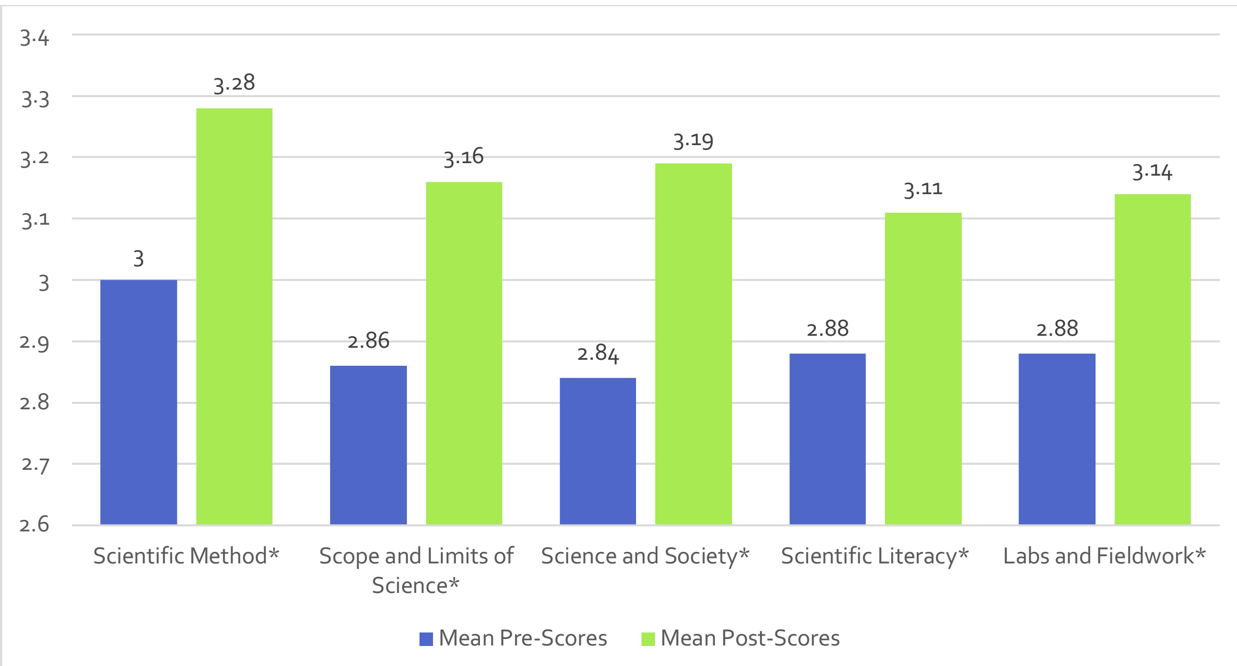


N = 318

Student Self-Assessment

All students who were enrolled in a Mason Core Natural Sciences course during the assessment period received an online self-assessment survey at the end of the semester. The retrospective pre-post self-assessment asked students to rate their knowledge and skills on five learning outcomes at the beginning of the semester (pre), and then again at the end of the semester (post). In total, 343 students completed both the pre and post items, resulting in a 5.1% response rate. A t-test pairwise comparison showed significant perceived learning gains on all five outcomes; no significant differences were found between NSL and NSO courses (see Figure 35).

Figure 35. Mean Scores on Student Learning Self-Assessment



Mean scores, self-reported on a scale of 1-4, n=343, * $p < .05$

How do the Results Meet Expectations?

Because this was the first time that these rubrics were used for the assessment of student work products, and because so much of the student work collected from lecture courses could not be assessed using the rubrics, it seems most appropriate to consider these results as preliminary and descriptive. More work is necessary to understand how well the rubrics can be used to assess general education science outcomes. Natural Sciences faculty should consider these results in terms of the learning outcomes identified for their academic programs.

How are Results Being Used to Improve Students' Educational Experience?

As of this writing, results have not yet been shared with the Mason Core Committee nor the Natural Sciences faculty.

Limitations of this Assessment

As this was the first time that Natural Sciences learning outcomes were assessed using this method, caution should be taken in interpreting the results. The number and nature of the work samples received were insufficient to test the lecture rubric for validity and reliability. The rubric for lecture courses shows promise as a tool for guiding the language and expectations for the Mason Core Natural Sciences, allowing faculty to plan learning experience that support development of these skills from first through senior years. However, it is not clear that the rubric can be used as an effective assessment of student work.

In general, the working group for this category was challenged to locate and select assessment tools for general education learning outcomes. While the faculty working group agreed that the Mason Core learning outcomes were appropriate and valuable for the program overall, they identified multiple challenges for operationalizing the outcomes for teaching and assessment in discipline-based courses. A reconsideration of how the learning outcomes for the sciences are used in the Mason Core is warranted.

Assessment Rubric(s)

The Natural Sciences rubrics were developed by a team of Mason Natural Sciences faculty to evaluate student work for the Mason Core learning outcomes in the Natural Sciences. The rubrics were modeled after the AAC&U VALUE rubrics and were informed by existing rubrics from New Mexico Statewide General Education Steering Committee (2018), University of Nevada Reno (nd), and Delaware State University (2016). The rubrics are designed to evaluate student performance on five learning outcomes, with four increasingly sophisticated performance descriptors for each outcome. The rubrics can be used with student projects or similar work products (not suitable for exams), and with lab or fieldwork reports. Most student work will not show evidence of all outcomes; in this case, an additional category for "no evidence" should be made available.

Table 18. Enrollment in Mason Core Natural Sciences OVERVIEW Courses by Academic Unit, AY2015-19

	2015	2016	2017	2018	2019	TOTAL
Atmospheric, Oceanic, and Earth Sciences	69	55	93	132	131	**480**
Biology		4		205	530	**739**
Chemistry & Biochemistry	72	64	50	63	88	**337**
Environmental Science and Policy	57	123	166	193	218	**757**
Geography and Geoinformation Science	198	238	300	255	309	**1,300**
New Century/Integrative Studies	140	121	24	25	76	**386**
Nutrition	601	552	652	769	783	**3,357**
Physics	327	342	401	523	590	**2,183**
Anthropology		38	124	142	140	**444**
Provost	239	136	209	240	243	**1,067**
TOTAL	**1,703**	**1,673**	**2,019**	**2,547**	**3,108**	**11,050**

Table 19. Enrollment in Mason Core Natural Sciences Lab-Based LECTURE Courses by Academic Unit, AY2015-19

	2015	2016	2017	2018	2019	TOTAL
Atmospheric, Oceanic, and Earth Sciences	1,022	1,025	914	1,040	1,160	**5,161**
Biology	2,784	2,681	2,583	2,466	2,532	**13,046**
Chemistry	1,919	2,030	1,840	1,866	1,881	**9,536**
College of Science	126	78				**204**
Computational & Data Sciences			30	105	136	**271**
Environmental Science and Policy	743	687	663	543	370	**3,006**
Geography and Geoinformation Science	36	61	61	75	49	**282**
Physics & Astronomy			3,698	3,713	3,414	**10,825**
Physics/Astronomy/CompDataSci	3,482	371				**3,853**
Integrative Studies					280	**280**
TOTAL	**10,112**	**6,933**	**9,789**	**9,808**	**9,822**	**46,464**

Figure 36. Five-Year Enrollment Trends in Mason Core Natural Sciences ALL Lecture Courses by Academic Unit, AY2015-19

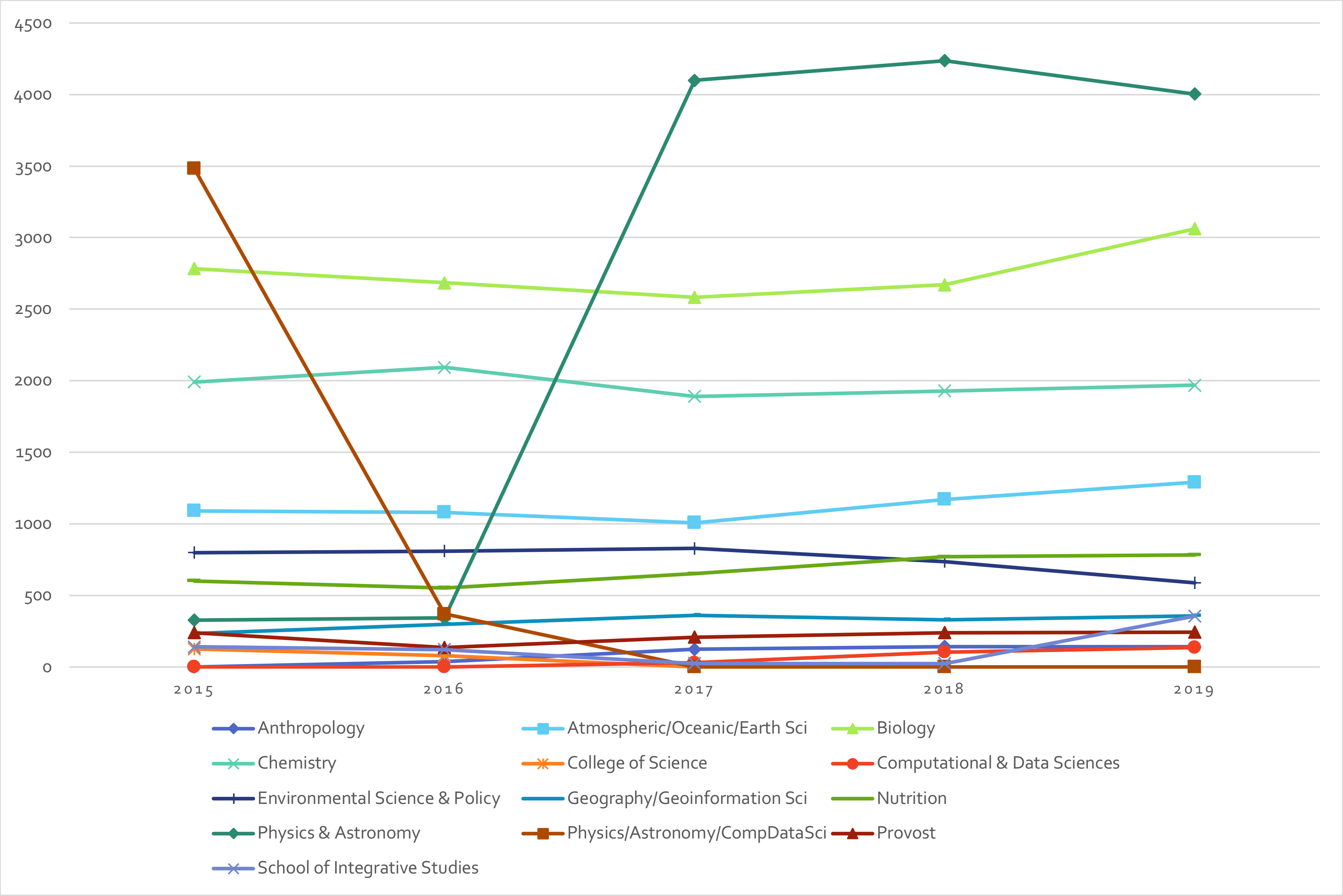


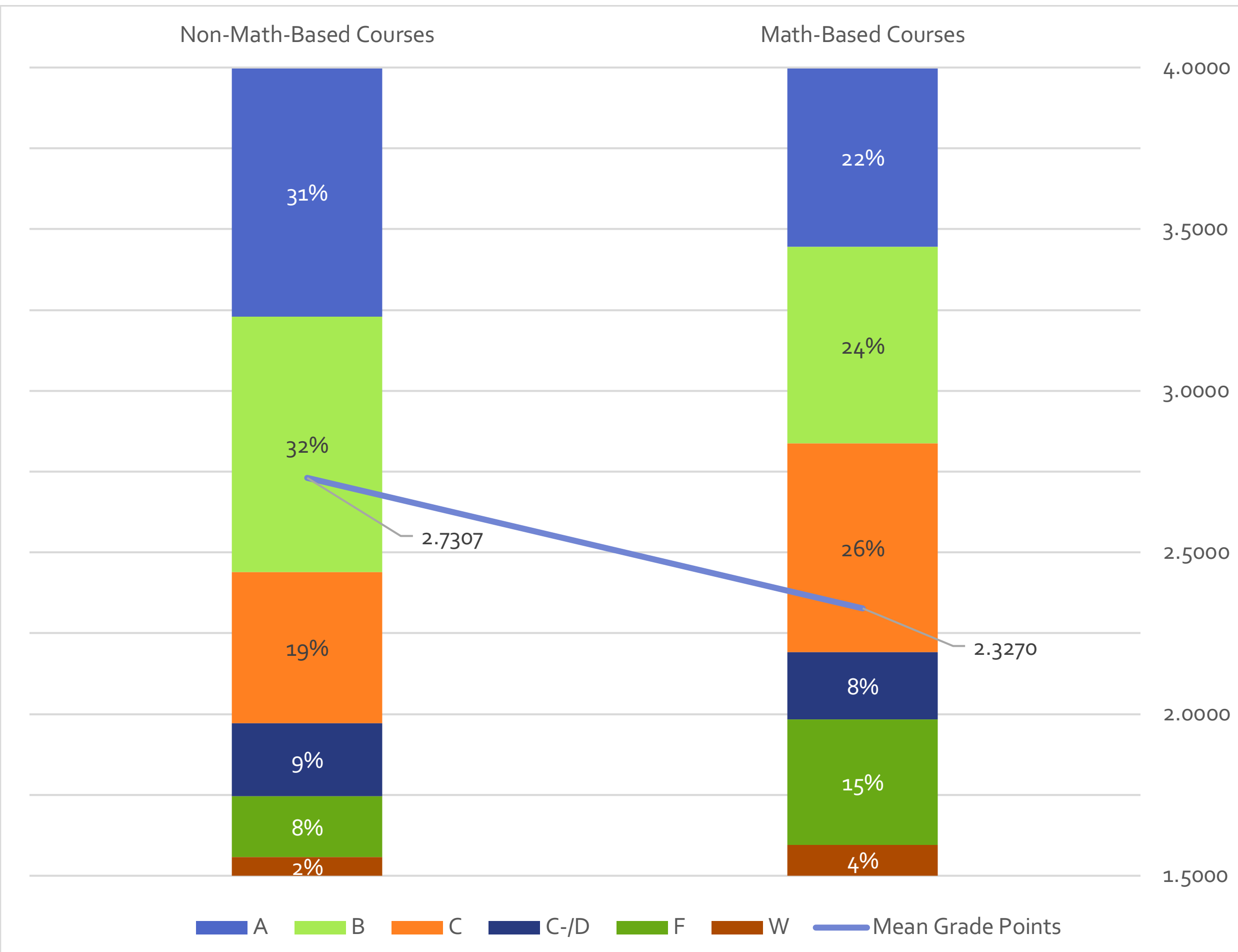
Table 20. Courses Approved for Mason Core Natural Sciences Category

Course	Title	Offered in Fall 2019	Included in the Assessment
Natural Science Overview (Non-Lab)			
ANTH 135	Introduction to Biological Anthropology	X	
ASTR 103	Astronomy	X	
ASTR 302	Foundations of Cosmological Thought	X	
BIOL 107	Intro Biology II Lecture	X	X
BIOL 140	Plants and People		
CHEM 101	Introduction to Modern Chemistry	X	X
CHEM 102	Chemistry for Changing Times		
CLIM 101	Global Warming: Weather, Climate, and Society	X	X
EVPP 201	Environment and You: Issues for the Twenty-First Century	X	X
GEOL 134	Evolution and Extinction		
GGS 102	Physical Geography	X	X
INTS 103	Human Creativity: Science and Art		
INTS 211	Introduction to Conservation Studies		
INTS 301	Science in the News	X	X
NEUR 101	Introduction to Neuroscience	X	X
NUTR 295	Introduction to Nutrition	X	X
PHYS 106	The Quantum World: A Continuous Revolution in What We Know and How We Live		
PROV 301	Great Ideas in Science	X	X
Natural Science with Lab			
ASTR 111	Introductory Astronomy: The Solar System	X	X
ASTR 112	Introductory Astronomy Lab: The Solar System	X	X
ASTR 113	Introductory Astronomy: Stars, Galaxies, and the Universe		
ASTR 114	Introductory Astronomy Lab: Stars, Galaxies, and the Universe		
ASTR 115	Finding New Worlds		
BIOL 103	Introductory Biology I	X	X
BIOL 106	Introductory Biology II Laboratory	X	X
BIOL 213	Cell Structure and Function	X	X
CDS 101	Introduction to Computational and Data Sciences	X	X
CDS 102	Introduction to Computational and Data Sciences Lab	X	X

Course	Title	Offered in Fall 2019	Included in the Assessment
CHEM 103	Chemical Science in a Modern Society	X	X
CHEM 104	Chemistry for Changing Times		
CHEM 155	Introduction to Environmental Chemistry I		
CHEM 156	Introduction to Environmental Chemistry II		
CHEM 211	General Chemistry I	X	X
CHEM 212	General Chemistry II	X	X
CHEM 213	General Chemistry Laboratory I	X	X
CHEM 214	General Chemistry Laboratory II	X	X
CHEM 271	General Chemistry for Engineers Lecture	X	X
CHEM 272	General Chemistry for Engineers Lab	X	X
CLIM 102	Introduction to Global Climate Change Science		
CLIM 111	Introduction to the Fundamentals of Atmospheric Science	X	X
CLIM 112	Introduction to the Fundamentals of Atmospheric Science Lab	X	X
EVPP 108	Ecosphere - Introduction to Environmental Science I-Lecture	X	X
EVPP 109	Ecosphere- Introduction to Environmental Science I- Lab	X	X
EVPP 110	The Ecosphere: An Introduction to Environmental Science I	X	X
EVPP 111	The Ecosphere: An Introduction to Environmental Science II	X	X
EVPP 112	Ecosphere: Introduction to Environmental Science II-Lecture	X	X
EVPP 113	Ecosphere: Introduction to Environmental Science II–Lab	X	X
GEOL 101	Introductory Geology I	X	X
GEOL 102	Introductory Geology II	X	X
GGS 121	Dynamic Atmosphere and Hydrosphere	X	X
INTS 210	Sustainable World	X	X
INTS 311	The Mysteries of Migration: Consequences for Conservation	X	X
INTS 401	Conservation Biology		
INTS 403	Conservation Behavior	X	X
PHYS 103	Physics and Everyday Phenomena I	X	X
PHYS 104	Physics and Everyday Phenomena II		
PHYS 111	Introduction to the Fundamentals of Atmospheric Science	X	X
PHYS 112	Introduction to the Fundamentals of Atmospheric Science Lab	X	X
PHYS 160	University Physics I	X	X
PHYS 161	University Physics I Laboratory	X	

Course	Title	Offered in Fall 2019	Included in the Assessment
PHYS 243	College Physics I	X	X
PHYS 244	College Physics I Lab	X	X
PHYS 245	College Physics II	X	X
PHYS 246	College Physics II Lab	X	X
PHYS 260	University Physics II	X	X
PHYS 261	University Physics II Laboratory	X	X
PHYS 262	University Physics III	X	X
PHYS 263	University Physics III Laboratory	X	X

Figure 37. Grades Distribution by Math-Based Content, AY17-19



Independent-samples t-test found significant differences between math-based and non-math-based courses (N = 18,273; $p < .05$)

Mason Core Rubrics for Natural Science Courses

Student Learning Activities Rubric for Lecture Courses

Learning Outcomes 1-4: METHODS, SCOPE AND LIMITS OF SCIENCE, SCIENCE AND SOCIETY, AND SCIENTIFIC LITERACY

How to use this rubric: This rubric describes the progression in understanding that students should demonstrate as they advance through Mason Core (general education) courses in the Natural Sciences. It is intended to provide guidance to faculty members designing courses and assessment tools and should not be viewed as establishing expectations for a certain level of achievement at the end of a single general education science course. Faculty members are encouraged to use the rubric to establish the level of understanding, for each component of knowledge, they would like to see students achieve in their course. For more information about the learning outcomes and approved courses, https://masoncore.gmu.edu/natural-science-lab-and-non-lab/

Student Learning Outcomes	**Level of Performance**			
	Advanced	**Proficient**	**Developing**	**Novice**
SCIENTIFIC METHOD: Understand how scientific inquiry is based on investigation of evidence from the natural world, and that scientific knowledge and understanding: • evolves based on new evidence • differs from personal and cultural beliefs	Demonstrates understanding of the scientific method by formulating questions about nature; articulates the relationship between evidence and theory, how these are used to build an argument.	Demonstrates understanding of how the scientific method is implemented; describes the relationship between evidence and theory and how the two are used to build an argument.	Articulates the relationship between evidence and theory in a simplistic way; provides limited explanation of how the two are used to build an argument.	Shows minimal understanding of the difference between evidence/data and explanation/theory.
SCOPE AND LIMITS OF SCIENCE: Recognize the scope and limits of science (see notes on page 3)	Clearly articulates the scientific issue/problem, explains how it fits within the discipline's sphere of inquiry, and describes multiple approaches to addressing it.	Clearly identifies and describes the scientific issue/problem; demonstrates general understanding of how it fits within discipline's sphere of inquiry.	Identifies the issue/ problem; offers simplistic explanation of how it fits within discipline's sphere of inquiry.	Unable to identify the issue/problem; demonstrates little or no understanding of discipline's sphere of inquiry.

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Mason Core Rubrics for Natural Science Courses

Student Learning Outcomes	Level of Performance			
	Advanced	**Proficient**	**Developing**	**Novice**
SCIENCE AND SOCIETY: Recognize and articulate the relationship between the natural sciences and society and the application of science to societal challenges	Skillfully evaluates the relationship between scientific and/or technological issues and developments to humans and issues of societal concern and articulates the ramifications of such issues and developments.	Identifies relationships between scientific and/or technological issues and developments to humans and issues of societal concern; discussion of these issues shows increasing sophistication.	Begins to recognize relationships between scientific and/or technological issues and developments to humans and issues of societal concern; discussion of these issues is simplistic.	Offers limited ability to recognize relationships between scientific and/or technological issues and developments to humans and issues of societal concern.
SCIENTIFIC LITERACY: Evaluate scientific information (e.g., distinguish primary and secondary sources, assess credibility and validity of information)	Consistently uses appropriate criteria to evaluate the quality of the scientific information and determine the credibility of the evidence based on its source, relevance to the research question, and methods used to generate it, with a critical eye to authority and bias.	Uses generally appropriate criteria to evaluate the quality of the scientific information and determine the credibility of the evidence based on its source, relevance to the research question, and methods used to generate it.	Recognizes appropriate strategies to evaluate the quality of the scientific information or data. Selects sources using basic criteria, such as relevance to the research question.	Chooses few to no strategies to evaluate the quality of the scientific information or data. Selects sources using limited or unclear criteria.

Mason Core Rubrics for Natural Science Courses

Notes on the Scope and Limits of Science

Defining the Boundaries of Science and Scientific Inquiry

The scope and limits of science define the boundaries of what questions science is equipped to address. Science deals with questions of the physical world. The scientific method addresses questions for which a hypothesis is testable and falsifiable, and experiments and observations are repeatable. Science can address important questions, make predictions, and create useful technologies. Science tells us how the world is.

Modern science can address many questions and solve many problems, but there are limits to its reach. Areas of limitations include questions about value, questions of morality, questions about the supernatural, and questions about "ultimate reality."[1] Science reaches its limits at questions such as: What is beauty? How should a problem be solved? What are ethical solutions? What are moral actions? What is our purpose in the world? Science does not tell us how to use scientific knowledge.

Seven aspects of the Nature of Science that define science as a discipline[2]:

1. Scientific knowledge is subject to change.
2. Knowledge is empirically based.
3. Knowledge is theory laden and subjective.
4. Knowledge is the product of human imagination and creativity.
5. Knowledge involves the combination of observation and inferences.
6. Laws and theories play an important role in developing new ideas.
7. Scientific ideas are validated by repetition and peer review.

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[1] Uko, C. J. (2010). Limitations of modern science. Retrieved from: https://www.researchgate.net/publication/215777806_LIMITATIONS_OF_MODERN_SCIENCE
[2] Schwartz, R. S., Lederman, N. G., and Crawford, B. A. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education, 88*, 610-645.

Mason Core Rubrics for Natural Science Courses

Lab Reports Rubric

Learning Outcome 5: SCIENTIFIC INQUIRY

Laboratory sections in the Mason Core are designed to support students to achieve the following outcome with five sub outcomes listed in column one.

Students will participate in scientific inquiry and communicate the elements of the process, including:

Student Learning Outcomes	Level of Performance			
	Advanced	**Proficient**	**Developing**	**Novice**
5a. Make careful and systematic observations	Data/observations are accurately recorded. All representations of data/observations are clear, complete, and appropriate for the scientific information collected.	Data/observations are recorded with minor errors. Representations of data/observations are mostly clear, complete, and appropriate for the scientific information collected.	Data/observations are recorded with some errors. Representations of data/observations are inconsistently clear, complete, and appropriate for the scientific information collected.	Data/observations are recorded with significant errors. Representations of data/observations are mostly unclear, incomplete, or inappropriate for the scientific information collected.
5b. Develop a hypothesis	Presents multiple relevant, testable hypotheses as appropriate to the questions; connection between hypothesis and the scientific issue is clear and insightfully and fully integrates the appropriate scientific concepts.	Hypothesis is relevant and testable; connection between hypothesis and scientific issue is clear and derives from valid scientific concepts.	Hypothesis is stated; connection between hypothesis and scientific issue is stated and appears to be derived from valid scientific concepts; however, some confusion between hypotheses and predictions.	Hypothesis is missing or unrelated to the scientific question; scientific concepts are not used or are incorporated inaccurately.
5b. Test a hypothesis	Method is well documented, including sufficient detail so that experiment can be easily repeated.	Method is generally well documented, including enough detail to repeat the experiment.	Method is documented but some procedural steps are missing so that not enough details are provided to repeat the experiment.	Method is incomplete, unclear, or not described.

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Mason Core Rubrics for Natural Science Courses

Student Learning Outcomes	Level of Performance			
	Advanced	**Proficient**	**Developing**	**Novice**
5c. Analyze evidence	Analysis is thorough and insightful and goes beyond the obvious connections to demonstrate complete grasp of relevant course concepts.	Analysis is accurate and makes obvious connections to relevant course concepts.	Analysis is general and shows limited or superficial linkage to appropriate course concepts.	Analysis is fundamentally flawed or absent.
5d. Interpret results	Summarizes results correctly. Conclusions are accurate and insightfully link results to both the relevant scientific concepts and the original hypotheses and predictions.	Summarizes results correctly with few errors. Conclusions are accurate and include all aspects of the results. Connections to hypothesis and predictions are clear and accurate, if somewhat simplistic.	Summarizes results correctly with some errors. Conclusions are simplistic but not seriously flawed. Makes connections to the original hypothesis or predictions but misses some obvious relationships.	Summarizes results with errors. Conclusions are overly simplistic, absent, or flawed. Interpretation of findings is limited or missing.

Language for both rubrics was adapted from the following sources:

- Association of American Colleges and Universities. Information Literacy VALUE Rubric. Retrieved from: https://www.aacu.org/value-rubrics
- Delaware State University. General Education – Natural Science Rubric and SLO. Retrieved from: https://www.desu.edu/academics/student-success/services/general-education
- New Mexico Statewide General Education Steering Committee. Draft Rubrics for Assessment of Learning Outcomes for General Education Courses: Content Area: Science. Retrieved from: https://www.nmt.edu/academicaffairs/assessment/Appendix_D_gen_ed_rubrics.pdf
- University of Nevada, Reno. Assessment of Core Curriculum. Retrieved from: https://www.unr.edu/assessment/core

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