**SCIENTIFIC PRACTICE (SP)**
**September 1, 2015**

## I. Short Description

In Scientific Practice courses, students will learn how scientists use observation, experimentation, data interpretation, and modeling to explain phenomena in the natural world. Through hands-on projects, lab- or field-based activities, and other opportunities to practice science, students will move toward greater scientific literacy. Such literacy provides students with the ability to understand and evaluate culturally available scientific claims as thoughtful Christians and engaged citizens. These practice-based lessons also prepare students to use scientific methods to address problems and make wise decisions in their lives and service to the Church.

## II. Thematic Core Learning Outcomes and Interpretation

### A. Students will be able to….

1. design and conduct scientific investigations
2. evaluate the scientific claims
3. articulate a defensible scientific argument

### B. Expansion and interpretation of the outcomes statement

1. Subject matter and content coverage in Scientific Practice courses

   A course that fulfills these learning outcomes may apply the processes of scientific investigation to a range of subject matter, including content from traditionally defined scientific disciplines or content that spans disciplinary boundaries (e.g., biochemistry or geophysics). Courses that use interdisciplinary topics (e.g., water, energy, or climate change) or explore particular scientific questions or phenomena (e.g., “How can solar energy be collected and used?” or “exploring the body’s immune response”) to engage scientific practice are also encouraged. Regardless of the choice of subject matter, that students will also gain basic competency in the content of the subject being investigated, evaluated, and communicated is implicit in the achievement of these learning outcomes.

2. Preferred pedagogies that include laboratory and/or field work

   To effectively meet the learning outcomes, students are expected to have participated in at least one full “scientific investigation” (see description of this multi-step process below) and evaluated at least one more complete process by the end of the course. A minimum of 25 hours per semester of practical, “hands-on” involvement in laboratory or field work is required. Care needs to be taken to ensure that time allotted to "hands-on" work does not compromise the required content requirements for basic competency in the subject. In many cases the practical component will take the form of an additional lab section. This does not preclude courses that can clearly demonstrate both adequate content and practical components. For instance, a course in which lab groups spend at least 25 hours out of class designing, implementing, collecting data, analyzing data and reasoning about the implications of those results, could meet this requirement, provided there are still robust amounts of material covered in class time assessed separately from performance on the 25 hours of experimental work. Additionally, a "flipped" approach that covers content outside of scheduled class hours can leave sufficient class time for "hands-on" work. Project-based or discovery-driven pedagogies are strongly encouraged because they can effectively involve students in the entire process of scientific investigation. Lastly, involving students in collaborative work by using lab groups or assigning group projects is also encouraged as it most accurately reflects the way scientists themselves work in highly collaborative environments.

3. Approach to the integration of faith and learning

   Faculty members teaching courses in this thematic area are to model being faithful disciples of Christ and practicing scientists. Throughout the course, faculty members will model Christian character and thoughtful engagement between their faith and the content and activities of the course. They will help students develop their own capacities to productively relate Christian thought and practice to scientific investigation and encourage them to develop a robust understanding of the distinctive responsibility of God's people as stewards of creation. This is meant to take seriously the myriad ways that a relationship with Christ impact personhood and how a distinctive Christian personhood then shapes all of life, including learning and intellectual pursuits such as scientific practice. Depending on the subject matter addressed in a Scientific Practice course, this approach to the integration of faith and learning may include discussion of the relationships between specific scientific claims and specific theological claims (e.g., evolution and creation, brain development and the image of God, etc.) or a general discussion of the different forms this relationship can take (e.g., conflict, complementarity, etc.). For classes where the specific scientific claims being studied do not directly or obviously touch on theology, this may alternatively or additionally include exploration of the ways that our Christian character impacts or is impacted by the practices of the discipline (e.g., issues of ethics in scientific practice, Christian considerations that influence project choice or the evaluation of competing explanations, or reflections on how immersion in the scientific process affects how one views the world or other aspects of person formation) or ways in which scientific practice can be involved in the advancement of the kingdom of God.

4. Definitions and explanations of disciplinary terms

   *Scientific Investigations*: In the context of a Scientific Practice course, this term is used to encompass a systemic yet creative form of inquiry that produces data to serve as evidence in support of an answer to a question, solution to a problem or explanation of a phenomenon. The six steps of this process, described below, reflect the essential practices of science and engineering identified by the National Research Council. [1]

   Scientific Investigations include:
   a. *Asking valid scientific questions.* A valid scientific question is one that has some connection to natural phenomena or to accepted scientific principles, theories, or models and can be tested within the scope of the resources available.
   b. *Creating a plan to systematically test the question.* An appropriate plan may include designing experiments, determining what measurements are needed, or may specify what observations would lead to data that can answer the question posed in (a).
   c. *Collecting data in ways that minimize errors and uncertainty.* Minimizing errors and uncertainties includes such considerations as controlling variables, using appropriate tools or instruments for measurement, and collecting sufficient numbers of measurements or observations to allow for reliable statistical analysis.
   d. *Performing accurate data analysis.* Data analysis may be either or both quantitative and

[1] A Framework for K -12 Science Education (National Research Council, 2011).

qualitative, may include the use of models, and may require mathematical or computational tools. Presentation of the data must be done accurately and with attention to the limits of reliability (i.e., error bars and uncertainty).

e. *Interpreting the data.* Data interpretation considers all of the data available and determines how it can be used as evidence to support or refute a particular answer to the question originally posed. Interpretation necessarily includes contextualizing the data within the current body of knowledge (i.e., the accepted scientific principles, theories, and findings) that relates to the question being investigated and will involve some evaluation of the scientific claims of others.

f. *Formulating defensible evidence-based conclusions.* Evidence-based conclusions are the best explanations or best answers to the original question that can be supported by the data obtained.

*Scientific Claims*: At a basic level, scientific claims are the defensible evidence-based conclusions of a scientific investigation and are characterized by being testable, supported by reliable data and/or observations, and are consistent with accepted scientific findings, principles and theories. Students will use their experience and knowledge of the process of scientific investigations to distinguish science from pseudoscience (i.e., claims that fail to meet the criteria below) and begin answering the foundational question "What is science?" For a given scientific claim, this involves a closer look at the process of the investigation that gave rise to the claim:

a. (*Is the claim testable?*) Consider the appropriateness of the initial question and the experimental method used to address it,

b. (*Is the claim supported by reliable data and/or observations?*) Determine the suitability of the data and data analysis methods or models applied and judge the reliability of the empirical results,

c. (*Is the claim consistent with accepted scientific findings, principles, and theories?*) Decide whether or not the claim violates what we already know to be valid scientific information or whether or not the claim raises an appropriate challenge to currently accepted findings.

*Scientific Argument*: A defensible scientific argument attests to the merit of a scientific claim. This often follows a standard format in the sciences (e.g., background information and motivation to set up the scientific question, careful and precise description of the experimental methods used to address that question, presentation and interpretation of the resulting data, and final conclusions where the claim(s) is(are) clearly stated as deriving from the evidence presented). The structure and style of a scientific argument is one that attempts to convince a reader to agree to the validity of the scientific claim (i.e., to agree that the claim represents the best explanation) by carefully framing the question and applying standard forms of inference to the interpreted data (the "evidence") to give the best possible answer to the question.

5. Use of Writing

   Writing assignments within Scientific Practice Courses will require students to become familiar with genre conventions, writing processes, rhetorical situations, and subject matter knowledge common within scientific discourse communities. Students in Scientific Practice classes are expected to write according to the conventions—and become familiar with the writing processes (e.g. group writing, drafting, revision, etc.)—common to one or more of the genres used by scientific discourse communities: informal writing exercises, lab reports, posters, essay responses, or written drafts of spoken comments for an oral presentation. Writing in scientific practice courses serves as a way to both understand the processes of scientific investigation and to respond to the rhetorical situations (purposes and audiences) within the sciences, effectively communicating scientific information developed according to disciplinary subject matter knowledge. In this way, writing serves as both a complementary pedagogy to the practical, hands-on work of scientific practice and as a possible means of assessing student achievement of the outcomes. “Use of writing” also includes the evaluation of written sources (i.e, reading), such as the popular or professional scientific literature or other sources used to motivate the scientific investigation or to interpret and contextualize data.

## III. Guidelines

### A. Expanded Description

Science and technology play a large and expanding role in human endeavors and aspirations. Students’ ability to think and act as thoughtful Christians in service to Christ and the Church in a science-driven, technologically-shaped world requires that they understand what science is, how it is practiced by scientists, and how the claims scientists make can be critically evaluated. Involvement in scientific practice—the way science is performed by scientists themselves—is essential for helping students move beyond misconceptions about the nature of science and science’s relationship to Christian faith. In a Science Practice course, students will learn that the study and exploration of the natural world can be God-honoring and that the practice of science can enhance their faith in Christ, deepen their worship with greater insight into the beauty, order and goodness of his creation, and equip them to be better and wiser stewards of that creation. Students will participate in the full process of scientific investigation, from the articulation of a scientific question to the formulation of a scientific conclusion and along the way learn to evaluate the validity of scientific information. Faculty mentors who are both Christ-followers and experienced scientists will lead them through the process and help them critically reflect both on the practice of science and on the difference faith in Christ can make for our understanding of what science is. The increased scientific literacy and Christian wisdom that comes from this experience will help students be better consumers of science—able to understand and critique scientific findings and arguments that emerge in public discourse and that are used to determine human laws and policies—and better practitioners of their own lay science—knowing when and how to tackle real problems using a structured, scientific approach.

### B. Connection between area outcomes (Part II above) and the 12 overall program goals of Christ at the Core (see p. 8-9 of the Proposal).

Students who take Scientific Practice courses will be learning to engage contemporary society wisely and responsibly, particularly as they encounter science and technology. Such learning will contribute to almost every Christ at the Core program goal, but those that most notably connect with a Scientific Practice course include: Holistic Learning Goals 1, 2 and 3 and Wisdom Learning Goal 4.

1. All three student learning outcomes for Scientific Practice courses promote “Christ at the Core” <u>Holistic Learning Goal #1</u>: “developing strong abilities to discover and evaluate information they need to draw conclusions; practicing analytical, quantitative and scientific reasoning; presenting their thoughts clearly in oral and written forms.”

2. All three student learning outcomes for Scientific Practice promote “Christ at the Core” <u>Holistic Learning Goal #2</u>: “pursuing varied approaches to knowledge with discernment and humility as they map both the rich connections and the conflicts among the disciplines.” Students in Scientific Practice courses will demonstrate that they can pursue the scientific approach to

knowledge, evaluate its claims with discernment, and humbly recognize the benefits and limitations of the types of arguments science can put forward.

3. In order to demonstrate all three Scientific Practice learning outcomes, students will need to develop some understanding of the specific discipline addressed by that particular course, and this supports "Christ at the Core," " Holistic Learning Goal #3: "understanding the contours of theological, cultural, and intellectual traditions." Scientific practice, evaluation of scientific claims, and the construction and presentation of scientific arguments all take place within the context of a particular intellectual tradition having its own history, its own accepted body of knowledge, and its own standards and genres of communication.

4. Because science is almost always done collaboratively, students will cultivate their ability to work with others as they work to demonstrate the learning outcomes in Scientific Practice courses. This connects with "Christ at the Core" Wisdom Learning Goal #4: "cultivating their collaborative abilities, their capacities for independent thought and action, and their imaginative and creative faculties." The process of scientific research also typically requires deriving new hypotheses from existing knowledge, and then testing these hypotheses in novel, yet convincing ways. Students will also learn to evaluate scientific claims for themselves and to draw creative interpretations and conclusions from data as part of the scientific process. All of these activities will cultivate independent thought and students' imaginative and creative faculties.

**C. Examples of Assessment**

A range of rigorous assignments could provide evidence that students have successfully achieved the three Student Outcomes given in section II.A. Depending on the structure of the course, one significant assignment might be relevant for assessing more than one outcome; in other cases a series of assignments will be more appropriate. A few examples and suggested approaches are offered here as *possible inspiration* of disciplinary appropriate and rigorous options, but use of these exact assignments is not required. Faculty are encouraged to go beyond these or substitute other creative assignments as they develop individual courses.

1. Assessment of Outcomes #1 and #3: Near the end of the course, students work in groups to complete a project in which they must use all 6 parts of the scientific process as defined above. They choose a suitable topic, define a question to investigate, develop a strategy for addressing the question, carry out careful data collection and analysis, interpret the results and draw conclusions based on their data. After a few weeks of work, the students present their project in the form of a short oral presentation. The instructor looks for evidence that each group has successfully demonstrated all 6 parts of the scientific process (Outcome #1) and evaluates the clarity and strength of the group's scientific argument leading to their main conclusions (Outcome #3).

2. Assessment of Outcome #2: Students may be given a short article reporting a recent scientific discovery. They write a critique of the claims in the article. The instructor rates the critique as acceptable or unacceptable based on clear evidence that the student examined whether or not the scientific claim was (i) testable, (ii) supported by reliable data, and (iii) consistent with or appropriately challenges accepted scientific findings.

3. Assessment of Outcome #3: Students may be asked to write a lab report on a single lab session where the question, plan of action, etc. were defined primarily by the instructor but

students took their own data. The instructor evaluates the lab report to determine whether or not the student has made a compelling scientific argument in the accepted format for that discipline.

**D. General Advice**

Scientific Practice courses should include elements that move students toward achievement of the learning outcomes as well as elements that assess whether the outcomes have been met. Students may need to practice using the methods of science multiple times and may need to practice evaluating scientific arguments multiple times with constructive feedback along the way before they are finally able to demonstrate the learning outcomes. For example, students could be asked to perform one or more of the 6 parts of a scientific investigation before being asked to perform an entire investigation from beginning to end; in one session students may be given a scientific question along with a set of materials and be asked to come up with a plan to test the question; in another session, students may be given a question and a procedure to address the question and be asked to follow the procedure and collect data. Stepwise practice like this will provide more opportunities for professors to give feedback to students and will assist in students' understanding of how scientific investigations proceed. Multiple drafts or multiple instances of writing assignments may also be necessary to enable students to articulate defensible scientific arguments in formats appropriate to the discipline. Instructors are encouraged to structure their courses with this in mind.