2017 Exploring Physical and Life Sciences GE Assessment

In the fall of 2017 and spring of 2018, the GE committee at Westmont College assessed the Exploring Physical Science and the Life Sciences outcome: "Students will generalize how the scientific method can be used to investigate the physical and living world."

DESIGN AND METHODS

Direct Assessment

Students in five courses fulfilling the GE criteria for either Exploring the Physical Sciences or Exploring the Life Sciences completed a questionnaire (see Appendix 1) based on a National Science Foundation Quiz. This tool was selected in consultation with the department chairs of Biology, Chemistry, Kinesiology, and Psychology (the department chair for Physics elected not to participate). Portions of it were also used in the 2007-2008 Exploring the Physical Science GE Assessment. The first five items were designed to assess students' basic understanding of the nature of science. Items 6 and 7 were intended to assay students' ability to interpret graphical data, and the last set of items (8-10) assessed students' ability to read and interpret general science articles. The first five items are also knowledge-based assessment, allowing for a determination of how well students understand the scientific method, whereas the last five are skills/applied assessments that examine how well students can generalize the scientific method to investigate the physical and living world.

In the fall of 2017, this questionnaire was administered in Introduction to Life Science and the lab section of General Chemistry I. In the spring of 2018, it was administered in two sections of General Psychology and one section of Introduction to Life Sciences. General Chemistry I is a course that fulfills the GE criteria for Exploring the Physical Sciences, whereas General Psychology and Introduction to Life Sciences are courses that fulfill GE criteria for Exploring the Life Sciences.

Participants

A total of 377 students completed the questionnaire. Of these, 191 were women, and 120 were men (the gender for 66 were not provided). The majority (47%) were freshman, followed by sophomores (16%), juniors (6%), and seniors (5%), with remainder not having information about class rank available.

RESULTS AND DISCUSSION

Understanding the Nature of Science

Descriptive statistics for items 1-5, which assess students' basic understanding of the nature of science and how well students understand the scientific method, are presented in Tables 1 and 2.

Table 1: Items 1 and 2

	True	False	Missing
1. The scientific method *does not* require experimental results to support a theory	33 (8.75%)	**343 (91%)**	1 (.27%)
2. An experiment that does not produce the predicted results is flawed and the results always should be discarded.	6 (1.59%)	**370 (98.14%)**	1 (.27%)

Note. Correct responses are highlighted in bold.

Table 2: Items 3-5

	a	b	c	d
3. Which of the following statements best describes a scientific theory?	A theory is a highly tentative form of scientific knowledge and has little evidence to support it. 21 (5.57%)	**A theory is one of the highest forms of scientific knowledge and an established theory has a great deal of evidence to support it. 259 (68.70%)**	A theory is an initial guess that a scientist makes in order to understand a particular phenomenon. 96 (25.46%)	Science is concerned only with facts, and theories have no place in science. 0 (0%)
4. Which of the following statements most closely characterizes scientific work?	Science is deductive (it proceeds in a logical manner from initial statements or facts to final conclusions). 53 (14.05%)	Science can address all kinds of questions (including questions concerning ultimate meaning, beauty, and morality). 23 (6.10%)	Science relies *primarily* on the intuition of scientists. 4 (1.06%)	**Science is empirical (it relies on observation and experiment to support ideas). 296 (78.51%)**
5. Which of the following best describes a scientific law (such as the law of conservation of energy)?	Scientific laws represent absolute truth and once established can never be falsified. 57 (15.12%)	**Scientific laws are generalizations made from observations and have great predictive power. 80 (21.22 %)**	Scientific laws provide fundamental reasons and explanatory underlying mechanisms for observations. 240 (63.66%)	

Note. Correct responses are highlighted in bold.

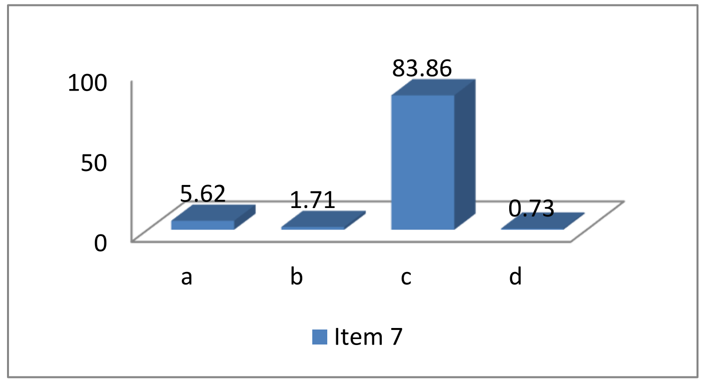
As delineated in Tables 1 and 2, the vast majority of students provided correct responses on items 1-4. The only item on which the majority of students endorsed the wrong response was item 5. The Life and Physical Science faculty conjectured that this might be because students are confused about the differences between a theory and a law, or between a hypothesis and law.

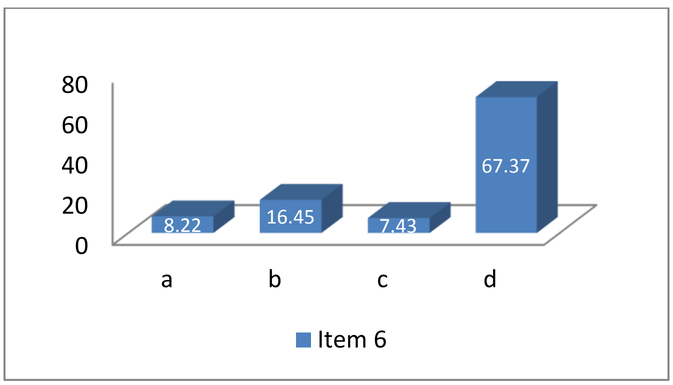
Overall, however, students in Exploring Physical and Life Science courses seem to well understand the nature of science.

Interpreting Graphical Data

Descriptive statistics for items 6-7, which assess students' ability to interpret graphical data, are presented in Figures 1 and 2. The majority of students selected the correct response to both items (items d and c, respectively).

Figure 1

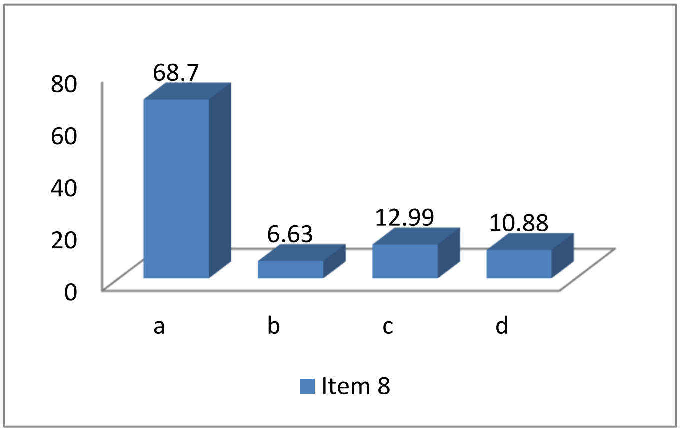


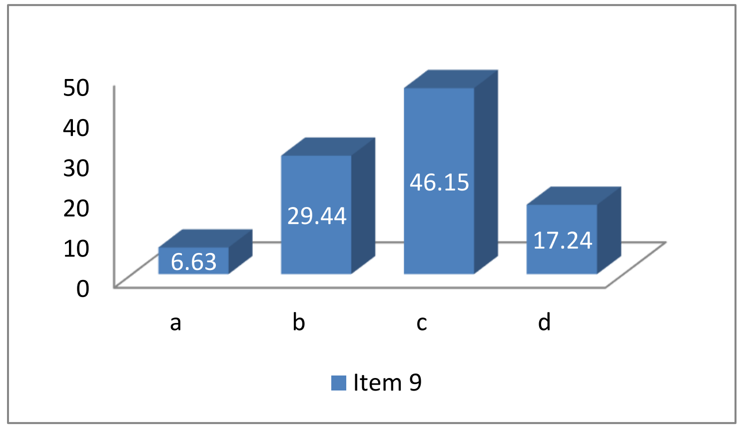


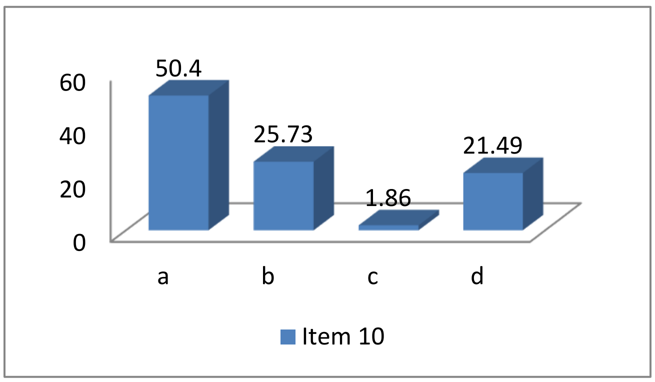
Students in the Exploring the Life and Physical Sciences seem capable of interpreting scientific data presented in graphic form.

Reading and Interpreting General Science Articles

Descriptive statistics for items 8-10, which assess students' ability to read and interpret general science articles, are presented in Figures 3-5.







The majority of students provided correct responses to items 8 and 9 (responses a and c, respectively, were correct), but not item 10 (response b was correct). The Life and Physical Science faculty conjectured that this this might be because students did not carefully read the article, got confused with the concepts, did not have an example of an exemplary response, or struggled to critically extrapolate implications from the article findings. Based on responses to items 8 and 9, however, students in Exploring Physical and Life Science courses seem to be somewhat adept at reading and interpreting information in scientific articles.

Additional Inferential Statistics

T-test analyses did not show any significant differences between men and women in their responses to any items on the questionnaire, $p > .05$. The results from an ANOVA did not show any significant differences between students in the various classes (Chemistry I, General Psychology, etc.) of the Life and Physical Sciences that were assessed, $p > .05$. This suggests equal competence between male and female students, as well as between the various courses the Life and Physical Sciences.

CONCLUSIONS

Based on these findings, the Life and Physical Sciences faculty are comfortable saying that students in Exploring Physical and Life Science courses “generalize how the scientific method can be used to investigate the physical and living world.” Students in these courses seem to well understand the nature of science and the scientific method. They can effectively interpret scientific data presented in graphic form, and they are somewhat adept at reading and interpreting information in scientific articles. In general, students in the courses assessed seem more competent in interpreting visual or graphical data than reading and interpreting scientific writing. There were no statistical differences in responses between men and women, or between those in the various courses of the Life and Physical Sciences, suggesting equivalent competency in knowledge about the scientific method and its application and generalization toward investigating the physical and living world. Considering these findings, instructors who teach courses that fulfill the GE criteria for Exploring the Physical and/or Life Sciences should be encouraged that their courses are fulfilling the Student Learning Outcomes.

The two areas for student improvement are (a) understanding the difference between a theory and a law, or between a hypothesis and a law, and (b) extrapolating implications and conclusions from scientific articles or writing. To address these areas of weakness, instructors for courses that fulfill the GE criteria for Physical and/or Life Sciences can devote greater time to delineating differences between theories, hypotheses, and laws, both in conceptual understanding and application. It is also recommended that instructors help students more critically extrapolate implications and conclusions from scientific articles (e.g., reviewing studies in class, requiring assignments that require careful reading and extrapolation of scientific conclusions and implications).

At this time, the department chairs of Biology, Chemistry, Kinesiology, and Psychology are not recommending any changes to the GE Student Learning outcome.

Appendix 1: Student Learning Outcomes Assessment Questions

Academic Major: ________________________ **Gender**: M F

Academic Year: Freshman Sophomore Junior Senior

Ethnicity: _____________________________

Transfer student: Y N

Student ID#: ______________________

Please circle the response that you think is most accurate. Since we are also interested in the level of your understanding, feel free to supply a brief explanation if you suspect your answer might be atypical.

1) **True or False:** The scientific method *does not* require experimental results to support a theory.

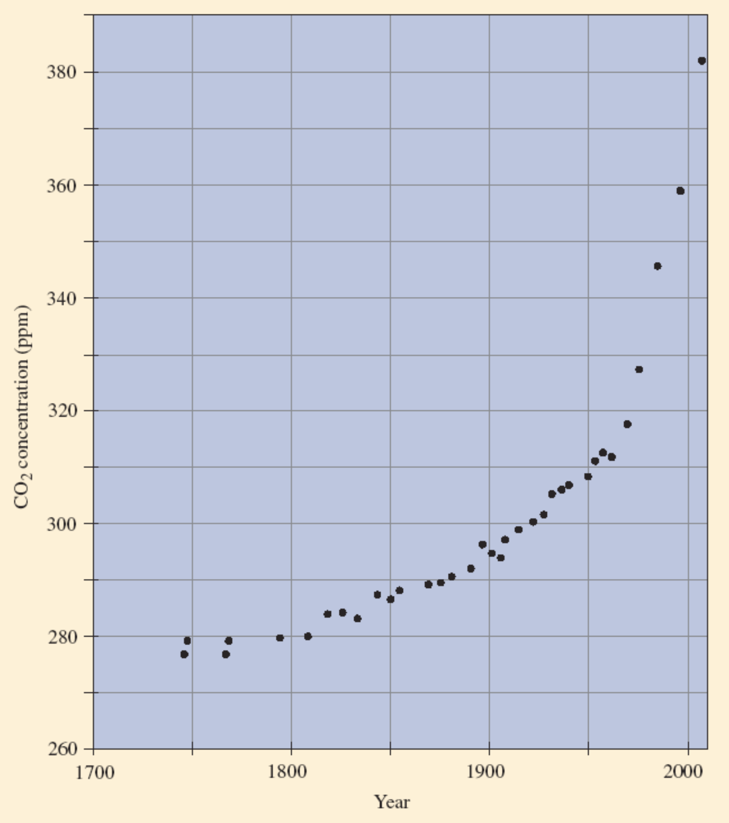
2) **True or False**: An experiment that does not produce the predicted results is flawed and the results always should be discarded.

3) **Which of the following statements best describes a scientific theory?**
   a. A theory is a highly tentative form of scientific knowledge and has little evidence to support it.
   b. A theory is one of the highest forms of scientific knowledge and an established theory has a great deal of evidence to support it.
   c. A theory is an initial guess that a scientist makes in order to understand a particular phenomenon.
   d. Science is concerned only with facts, and theories have no place in science.

4) **Which of the following statements most closely characterizes scientific work?**
   a. Science is deductive (it proceeds in a logical manner from initial statements or facts to final conclusions).
   b. Science can address all kinds of questions (including questions concerning ultimate meaning, beauty, and morality).
   c. Science relies *primarily* on the intuition of scientists.
   d. Science is empirical (it relies on observation and experiment to support ideas).

5) **Which of the following best describes a scientific law (such as the law of conservation of energy)?**
   a. Scientific laws represent absolute truth and once established can never be falsified.
   b. Scientific laws are generalizations made from observations and have great predictive power.
   c. Scientific laws provide fundamental reasons and explanatory underlying mechanisms for observations.

Consider the following graph, which shows the levels of carbon dioxide (an important greenhouse gas) in our atmosphere.



Atmospheric carbon dioxide derived from Siple Station ice core measurements and from levels measured at the South Pole, Antarctica

6) Which of the following statements best describes the increase in atmospheric carbon dioxide between 1750 and the present?

a. The amount of carbon dioxide has doubled.
b. The amount of carbon dioxide has increased by a factor of five.
c. The amount of carbon dioxide has increased by 5%.
d. The amount of carbon dioxide has increased by 35%.

7) Which of the following statements best describes the rate of change in atmospheric carbon dioxide between 1750 and the present?

a. The amount of carbon dioxide is increasing at a constant rate.
b. The amount of carbon dioxide is decreasing at an increasing rate.
c. The amount of carbon dioxide is increasing at an increasing rate.
d. The amount of carbon dioxide is increasing at a decreasing rate.

Read the following article from the New York Times Science pages.

New Ways to Store Solar Energy for Nighttime and Cloudy Days

MATTHEW L. WALD

Published: April 15, 2008

Solar power, the holy grail of renewable energy, has always faced the problem of how to store the energy captured from the sun's rays so that demand for electricity can be met at night or whenever the sun is not shining.

The difficulty is that electricity is hard to store. Batteries are not up to efficiently storing energy on a large scale. A different approach being tried by the solar power industry could eliminate the problem.

The idea is to capture the sun's heat. Heat, unlike electric current, is something that industry knows how to store cost-effectively. For example, a coffee thermos and a laptop computer's battery store about the same amount of energy, said John S. O'Donnell, executive vice president of a company in the solar thermal business, Ausra. The thermos costs about $5 and the laptop battery $150, he said, and "that's why solar thermal is going to be the dominant form."

Solar thermal systems are built to gather heat from the sun, boil water into steam, spin a turbine and make power, as existing solar thermal power plants do — but not immediately. The heat would be stored for hours or even days, like water behind a dam.

A plant that could store its output could pick the time to sell the production based on expected price, as wheat farmers and cattle ranchers do. Ausra, of Palo Alto, Calif., is making components for plants to which thermal storage could be added, if the cost were justified by higher prices after sunset or for production that could be realistically promised even if the weather forecast was iffy. Ausra uses Fresnel lenses, which have a short focal length but focus light intensely, to heat miles of black-painted pipe with a fluid inside.

A competitor a step behind in signing contracts, but with major corporate backing, plans a slightly different technique in which adding storage seems almost trivial. It is a "power tower," a little bit like a water tank on stilts surrounded by hundreds of mirrors that tilt on two axes, one to follow the sun across the sky in the course of the day and the other in the course of the year. In the tower and in a tank below are tens of thousands of gallons of molten salt that can be heated to very high temperatures and not reach high pressure.

"You take the energy the sun is putting into the earth that day, store it and capture it, put it into the reservoir, and use it on demand," said Terry Murphy, president and chief executive of SolarReserve, a company backed in part by United Technologies, the Hartford conglomerate.

Power plants are typically designed with a heat production system matched to their electric generators. Mr. Murphy sees no reason why his should. His design is for a power tower that can supply 540 megawatts of heat. At the high temperatures it could achieve, that would produce 250 megawatts of electricity, enough to run a fair-size city.

It might make more sense to produce a smaller quantity and run well into the evening or around the clock or for several days when it is cloudy, he said.

At Black & Veatch, a builder of power plants, Larry Stoddard, the manager of renewable energy consulting, said that with a molten salt design, "your turbine is totally buffered from the vagaries of the sun." By contrast, "if I've got a 50 megawatt photovoltaic plant, covering 300 acres or so, and a large cloud comes over, I lose 50 megawatts in something like 100 to 120 seconds," he said, adding, "That strikes fear into the hearts of utility dispatchers."

Thermal storage using molten salt can work in a system like Ausra's, with miles of piping, but if the salt is spread out through a serpentine pipe, rather than held in a heavily insulated tank, it has to be kept warm at night so it does not solidify, among other complications.

A tower design could also allow for operation at higher latitudes or places with less sun. Designers could simply put in bigger fields of mirrors, proponents say. A small start-up, eSolar, is pursuing that design, backed by Google, which has announced a program to try to make renewable electricity for less than the price of coal-fired power.

Mr. Murphy helped build a power tower at a plant in Barstow, Calif., sponsored by the Energy Department in the late '90s. It ran well, he said, but natural gas, a competing fuel, collapsed in price, and the state had few requirements for renewable power.

"There were not renewable portfolio standards," Mr. Murphy said. "Nobody cared about global warming, and we weren't killing people in Iraq."

8) **According to this article, which of the following is the cheaper way to store energy?**
    a. as heat in a insulated container
    b. as energy in a battery
    c. as kinetic energy in a turbine
    d. none of the above

9) **According to this article, an important obstacle to overcome in utilizing solar energy is:**
    a. the lack of solar energy
    b. the expense of solar energy
    c. the intermittence of solar energy
    d. the inability to harness solar energy to make electricity

10) **According to this article, one important reason for storing solar energy as heat and later converting it to electricity is:**
    a. It is easier to convert heat to electricity (in comparison to converting light into electricity).
    b. It can make electricity production more uniform.
    c. It keeps more people employed.
    d. None of the above.