This document contains the student learning goals, student questions, scoring rubrics and a follow up survey with faculty for an assessment instrument developed between 2013 and 2015 by the Ecological Research as Education Network (EREN). Results from and discussion of the EREN assessment instrument appear in:

Anderson, L. J., J. J. Dosch, E. S. Lindquist, T. S., McCay, J. L, Machado, K. Kuers, T. B. Gartner, K. L. Shea, C. Mankiewicz, V. L. Rodgers, P. A. Saunders, R. A. Urban, J. S. Kilgore, A. S. Powell, B. S. Ramage, J. M. Steinweg, J. N. Straub, S. L. Bunnell, M. Witoksky-Eldred. 2020. Assessment of student learning in undergraduate courses with collaborative projects from the Ecological Research as Education Network (EREN). *Scholarship and Practice of Undergraduate Research. 4(1): 15-29.*

You are free to use and modify the assessment instrument and its supporting materials but please cite the publication above to provide credit where appropriate. EREN is interested in improving its assessment practices so we welcome discussion, collaboration and suggestions for changes to the instrument. Please contact erenteam@gmail.com for more conversation.

Table 1. Student Learning Goals for Collaborative Research Projects in the Ecological Research as Education Network (EREN). Goals developed by the EREN Leadership Team in 2013.

Learning goal theme	Students will:	Addressed in Phase 1 Survey	Addressed in Phase 2 Survey
1. Scientific methods in multi-site studies	A. propose appropriate, testable hypotheses for multi-site studies	X	X
	B. propose appropriate experimental designs for multi-site studies	X	X
	C. articulate the importance of uncertainty for experiments across multiple sites	X	--
2. Ecological variation across sites	A. identify factors that vary among sites across geographic or temporal scales	X	X
	B. describe interactions among these factors	X	X
	C. describe how these factors affect ecological processes	X	X
3. Scientific collaboration	A. describe the value of scientific collaboration.	X	--
	B. describe the techniques of scientific collaboration	X	X
4. Data merging and management	A. demonstrate best practices in the accurate collection of multi-site, multi-participant datasets	X	--
	B. demonstrate best practices in the recording of multi-site, multi-participant datasets	X	--
	C. demonstrate best practices in the ethical management of multi-site, multi-participant datasets	X	X
5. Data interpretation and analysis	A. interpret and draw conclusions from data collected in multi-site studies	X	X
	B. analyze data collected in multi-site studies	X	X

Table 2. Survey Questions for EREN's Phase 1 Student-Learning Assessment (Spring 2014)

Learning Goal	Questions
1. Scientific methods for multi-site studies	**Q1.** Imagine a set of 20 x 20 m plots in mature, natural forest sites, with plots distributed all over the eastern United States. List three ecological hypotheses that could be tested with this experimental design.
	Q2. Suppose students measure tree diameters in one 20 x 20 m plot in New Hampshire and one 20 x 20 m plot in Alabama. Trees in Alabama are larger than those in New Hampshire. The students conclude that trees grow larger in Alabama due to the warmer climate in this region. Which of the following statements identify fundamental problems with the design of this experiment? Check all that apply. a. There may be unusual features at either site that make them not representative of ecological processes in the region - multiple plots within the region are needed to determine this. b. You cannot reach this conclusion without doing a manipulative experiment, such as growing trees at warm and cool temperatures in a greenhouse. c. Rainfall is higher in Alabama, and this is the underlying cause of greater tree size. d. No environmental variables were measured at either of the sites, limiting the ability of the students to draw conclusions about the reasons for larger trees in Alabama. e. There are not enough trees in each plot to allow for adequate replication of the study. f. The numbers of trees in each plot should be considered in the data analysis, since tree growth can be affected by local tree density. g. The species of trees may differ across sites; it would be best to compare a common species between the two areas. h. There is no control for this experiment - study plots are needed at a mid-range site like Virginia to serve as a control.
2. Ecological variation across sites	**Q3.** Suppose students continue on to do more in-depth studies of forest sites in Alabama, Texas, and New Hampshire. They discover that trees in Alabama are larger than trees in the other two sites on average. They also discover that soil nitrogen levels are greatest in Alabama compared to New Hampshire and Texas and that trees in Alabama not only have larger trunks, they have more nitrogen in their leaf tissues than trees at the other two sites. The students consult the scientific literature, and find that 80% of nitrogen available for tree growth comes from the process of decomposition, where nitrogen in dead tissues is released by the activities of bacteria and fungi, which are more active under warm, moist conditions. Long term weather records show that summer rainfall is about the same in New Hampshire and Alabama, which are both much wetter than Texas. Summer temperatures are hottest in Texas, next hottest in Alabama, and coolest in New Hampshire. Explain how interactions between climate and decomposition could explain the patterns of tree growth observed in the three sites. Limit your answer to five sentences.
	Q4. A group of students have chosen two study ponds in which to conduct salamander population sampling. One large pond, which is fed by a flowing stream, is located in a prairie habitat in Illinois while the second smaller pond is in a forest in Ohio and is primarily replenished by rainfall. List as many variables as you can that would need to be considered in order to explain differences in salamander populations.

3. Scientific collaboration

Q5. Ecology is the study of interactions among organisms and their environment. Ecologists want to understand how human activities, such as adding greenhouse gases to the atmosphere, changing natural habitats into agricultural fields or urban settings, and introductions of unusual species, affect the physical aspects of the environment, the biology of non-human organisms, and the ability of the environment to support human life. Briefly discuss three reasons why scientific collaboration among ecologists working at multiple sites would be helpful in addressing these kinds of questions. Provide one to three sentences of explanation/discussion for each reason.

Q6. List three to six technological tools, approaches, protocols, or attitudes that are essential to successful scientific collaboration across multiple sites. Provide a one to two sentence description of each one.

4. Data merging and management

Q7. Suppose a group of students wants to compare acorn production across four sites. On October 15th, they count acorns that have fallen into traps that are 0.25 m^2 in size under the canopies of five large white oak trees at Site 1. To calculate the total acorn fall under each tree, the students calculate the total area under the oak canopy, divide this total by the area of the trap under the canopy, and then multiply this result by the number of acorns in the trap. They then call their collaborators at Site 2 to check their results for acorn fall for October 15th. They discover that, due to a miscommunication, the traps at Site 2 are 0.5 m^2 in size. In this case:

a. the data from Site 2 are not comparable with Site 1, because a different trap size was used.
b. the data from Site 2 can be used, but only after new traps of 0.25 m^2 are installed and the acorn counts retaken the next day.
c. acorn production at Site 2 can still be estimated by doubling the acorn production calculations from Site 1.
d. acorn production can still be calculated for Site 2 using the same procedure as Site 1.
e. acorn production cannot be estimated for Site 2 this year, but can after new traps of 0.25 m^2 are installed the following season.

Q8. Here is a list of data collected under oaks at different sites. These data should be put into the same central database. List any problems you see with (1) integrating these data into the same database, and (2) problems scientists who were not involved in collecting the data at that particular site might have in understanding or using it.

Site 1 Acorn Data				Site 2 Acorn Data		
Tree Species	Tree ID	Number of acorns/m^2		Spe	#	Number of acorns/ft^2
Quercus alba	Qa1	31		*Q. alba*	1	28
Quercus alba	Qa2	26		*Q. alba*	2	61
Quercus alba	Qa3	17		*Q. alba*	3	21
Quercus alba	Qa4	40		*Q. alba*	4	32

Quercus alba	Qa5	15		*Q. alba*	5	33

5. Data interpretation and analysis

The data below are from a multi-site study of turtle populations in sites with different amounts of urban development (e.g., paved or impervious surfaces) near the ponds where the turtles live. Two aspects of each population were measured: the proportion of adult male/female animals in each population and the proportion of adult/juvenile animals in each population.

Figure A

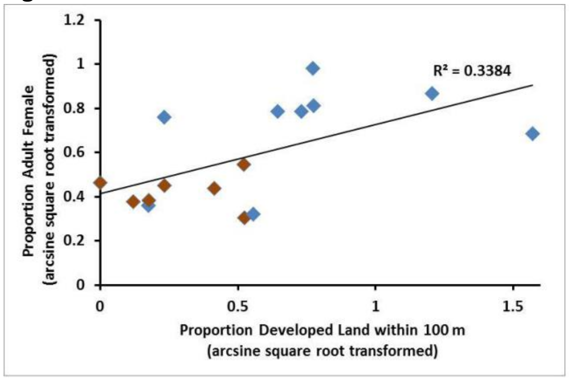
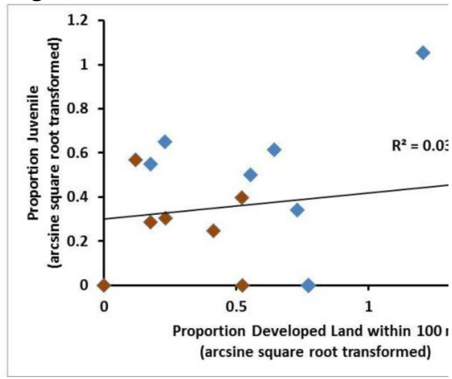


Figure B



Impact of developed land within 100 m of pond on (**Figure A**) proportion of adult females and (**Figure B**) proportion of juvenile *Chrysemys picta*. Points in red represent data from Bridgewater State University in Massachusetts. The relationship in Figure A has a p value of 0.02. The relationship in Figure B has a p value of 0.32.

Answer the following questions about these figures:

Q9. Based on your visual inspection of Figure A and the figure caption, which of the following statements are true? Check all that apply.

a. There is a statistically significant relationship between the proportion of female turtles and development.
b. There is not a statistically significant relationship between the proportion of female turtles and development.
c. The relationship between the proportion of female turtles and development is positive.
d. The relationship between the proportion of female turtles and development is negative.
e. The relationship between the proportion of female turtles and development does not show a strong directional trend.
f. As development near the pond increases, the proportion of female turtles in the population also increases.
g. As development near the pond increases, the proportion of female turtles in the population decreases.
h. As development near the pond increases, the proportion of female turtles in the population does not change dramatically
i. The scatter of points on the graph suggest that other factors, in addition to development, also affect the proportion of female turtles in the population.
j. The scatter of points on the graph suggest that development is the single critical factor affecting the proportion of female turtles in the population.
k. An R^2 value of 1 would suggest that development is a very strong predictor of the proportion of female turtles in the population.
l. The graph shows that development reduces the presence of predators that tend to attack female turtles as they lay eggs, thus leading to more females in the

population.

Q10. Based on your visual inspection of Figure B and the figure caption, which of the following statements is true? Check all that apply.

a. If we were to remove the point with the highest value for the proportion of juvenile turtles, the R^2 value for this graph would get closer to zero.
b. This graph suggests that juvenile turtles are strongly influenced by nearby development in terms of hatching success and survival.
c. This study would have been possible to do with a series of ponds that were all experiencing similar development pressures within 100 m of the pond.
d. More sites with more diverse development patterns would have provided more confidence in our conclusions.
e. The graph shows that juvenile turtles are more affected by local food supply than by nearby development.

Table 3. Survey Questions for EREN's Phase 2 Student-Learning Assessment (Fall 2014, Spring 2015, Fall 2015)

Learning Goal	Question
1. Scientific methods for multi-site studies	
1A	**Q1.** Imagine pairs of 20 x 20 m plots in mature, natural forest sites, with the plot pairs distributed in ten locations all over the eastern United States. Briefly describe a hypothesis that could be investigated using these sites and the experiment you would design to test this hypothesis by filling in the information below: a. Hypothesis (that is, describe the research problem or question of interest): b. Justification for proposing this hypothesis:
1B	c. What kinds of data will you collect and how this will be done? d. What patterns do you predict to find in your data if your hypothesis is supported?
2. Ecological variation across sites	
2B	**Q2.** The table below illustrates summary results (annual or growing season averages) from 20 x 20 m plots located in Alabama, New Hampshire and Texas:

Variable (units)	Alabama	New Hampshire	Texas
Precipitation (mm)	1500	1100	600
Air Temperature (^{o}C)	18.4	7.7	23.5
Rate of nitrogen release from decomposition of organic matter in soil (kg per hectare per year)	180	70	100
Mass of microbial organisms in the soil (ug per g soil)	2560	800	1200
Rate of plant growth per unit area (g C per m^2 per year)	780	450	520

Learning Goal	Question
2A, 2C	a. Explain how interactions between physical variables and ecological processes could explain the patterns in plant growth observed in the three sites. b. Is there anything else you would need to know to explain the differences in plant growth among the sites? List as many items as you can think of.
3. Scientific collaboration	
3B	**Q3.** List as many technological tools, approaches, and attitudes as you can that are essential to successful scientific collaboration across multiple sites. Provide a one sentence description of each one.

4. Data merging and management

4C

Q4. Here is a list of data collected in a survey of acorn counts under oaks at different sites by separate researchers. These data should be put into the same central database. List any problems you see with (a) integrating these data into the same database, and (b) problems scientists who were not involved in collecting the data at that particular site might have in understanding or using it. Be as specific as possible.

Site 1 Acorn Data				Site 2 Acorn Data		
Tree Species	Tree ID	Number of acorns/m^2		Spe	#	Number of acorns/ft^2
Quercus alba	Qa1	31		*Q. alba*	1	28
Quercus alba	Qa2	26		*Q. alba*	2	61
Quercus alba	Qa3	17		*Q. alba*	3	21
Quercus alba	Qa4	40		*Q. alba*	4	32
Quercus alba	Qa5	15		*Q. alba*	5	33

5. Data interpretation and analysis

5A, 5B

Q5. The data below are from a multi-site study of turtle populations in sites with different amounts of urban development (e.g., paved or impervious surfaces) near the ponds where the turtles live. Two aspects of each population were measured: the proportion of adult female to male animals in each population and the proportion of juvenile to adult animals in each population. Based on your visual inspection of Figures A and B and the figure caption, which of the following statements are true? Check all that apply.

Figure A

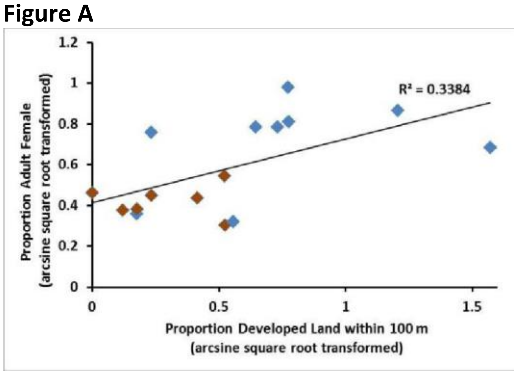
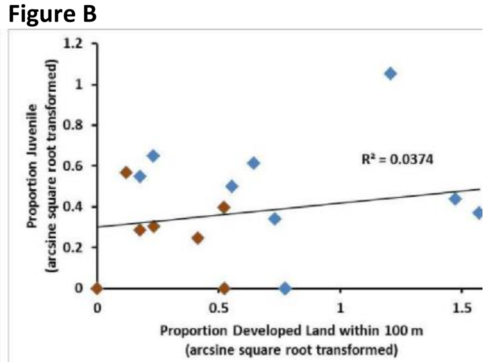


Figure B



Impact of developed land within 100 m of pond on (**Figure A**) proportion of adult females and (**Figure B**) proportion of juvenile *Chrysemys picta*. Points in red represent data from Bridgewater State University in Massachusetts. The relationship in Figure A has a p value of 0.02. The relationship in Figure B has a p value of 0.32.

a. Figure A shows a statistically significant relationship between the proportion of female turtles and development.
b. Figure A shows there is not a statistically significant relationship between the proportion of female turtles and development.
c. The relationship between the proportion of female turtles and development in Figure A is positive.
d. The relationship between the proportion of female turtles and development in Figure A is negative.
e. The relationship between the proportion of female turtles and development in Figure A does not show a strong directional trend.
f. Figure A shows that as development near the pond increases, the proportion of female turtles in the population also increases.
g. Figure A shows that as development near the pond increases, the proportion of female turtles in the population decreases.
h. Figure A shows that as development near the pond increases, the proportion of female turtles in the population does not change significantly.
i. The scatter of points in Figure A suggest that other factors, in addition to development, also affect the proportion of female turtles in the population.
j. The scatter of points in Figure A suggest that development is the single critical factor affecting the proportion of female turtles in the population.
k. An R^2 value of 1 for the data in Figure A would suggest that development is a very strong predictor of the proportion of female turtles in the population.
l. Figure A shows that development reduces the presence of predators that tend to attack female turtles as they lay eggs, thus leading to more females in the population.
m. In Figure B, if we were to remove the point with the highest value for the proportion of juvenile turtles, the R^2 value for this graph would get closer to zero.
n. Figure B suggests that juvenile turtles are strongly influenced by nearby development in terms of hatching success and survival.
o. This study would have been possible to do with a series of ponds that were all experiencing similar development pressures within 100 m of the pond.
p. More sites with more diverse development patterns would have provided more confidence in our conclusions.

Table 4. Survey Questions for Faculty Participating in the EREN Assessment Project

Questions
1. Name 2. Name of institution 3. In how many classes did you administer the EREN Pilot Student Assessment? 4. We must be able to link student responses with the class in which their assessment was taken. Please list the number (e.g., BIO 216) and name (e.g., Forest Ecology) of the class in which you gave the EREN assessment. 5. Is this an upper level (primarily juniors and seniors) or lower level course (primarily freshman and sophomores)? 6. How many students are in this class? 7. What is the format of this class? ● Lecture only ● Lab only ● Lecture and lab 8. Please briefly describe the primary learning goals and focus of this class. 9. Which of the following EREN Learning Goals did your course address by using EREN projects or data in some way? Check all that apply. ● Goal 1 - Students will be able to apply scientific methodology (including hypothesis generation and experimental design) and recognize the importance of uncertainty for experiments at single and multiple sites. ● Goal 2 - Students will be able to identify factors that vary among sites across geographic or temporal scales, describe how these factors interact, and how they may affect ecological processes. ● Goal 3 - Students will be able to describe the value and techniques of scientific collaboration. ● Goal 4 - Students will demonstrate best practices in the accurate collection, recording, and ethical management of multi-site, multi-participant datasets. ● Goal 5 - Students will be able to analyze, interpret, and draw conclusions from data collected in multi-site studies. ● My course addressed one or more of these learning goals, but not through EREN projects. 10. Which EREN projects did you include in this class? What amount of time did you spend on these projects (e.g. approximate number of lectures, approximate number of labs, etc.)? 11. Number of EREN Lectures 12. Number of EREN Labs

13. Number of EREN Lectures plus Labs

14. Explain how the EREN Project(s) was/were incorporated into the class. For example, was the project a lab exercise, part of a lecture, or both? Did it involve the use of data from other campuses? What kinds of assignments were the students given?

15. In this class, when did you administer the EREN assessment? (Check all that apply.)

- Beginning of the semester
- Beginning of an EREN related section
- End of the semester
- End of an EREN related section

16. How were students credited for the assessment?

- The students were asked to voluntarily complete the assessment with no additional credit awarded.
- The students were given a small amount of pass/fail credit for completing the assessment.
- The students were given extra credit for completing the assessment.
- Students did not receive credit, but we threatened to withhold final grade from students who did not take it.

17. Is there any other information you would like to share that will assist with the assessment data interpretation? Do you have any suggestions for improving the assessment survey for students, or this one for faculty?

Table 5. Scoring Rubric for Phase 1 Student-Learning Assessment Survey: 4 = Expert, 3 = Experienced, 2 = Intermediate, 1 = Novice

Question	Rubric
Q1	**4:** All three hypotheses are testable, address scientifically appropriate regional to continental-scale questions, and have a sound ecological basis. **3:** Two of the three hypotheses are testable, address scientifically appropriate regional to continental-scale questions, and have a sound ecological basis. **2:** One of the three hypotheses is testable, addresses a scientifically appropriate regional to continental-scale question, and has a sound ecological basis. **1:** None of the three hypotheses are testable, they do not address scientifically appropriate regional to continental-scale questions, and none have a sound ecological basis.
Q2	**4:** Four correct answers were given and no incorrect answers. The correct answers are: (a) There may be unusual features at either site that make them not representative of ecological processes in the region; multiple plots within the region are needed to determine this. (d) No environmental variables were measured at either of the sites, limiting the ability of the students to draw conclusions about the reasons for larger trees in Alabama. (f) The numbers of trees in each plot should be considered in the data analysis, since tree growth can be affected by local tree density. (g) The species of trees may differ across sites; it would be best to compare a common species between the two areas. **3:** Three or more correct answers were given and no more than one incorrect answer. **2:** Two or more correct answers were given and no more than two incorrect answers. **1:** One or no correct answers were given, and/or more than three incorrect answers were given.
Q3	**4:** The answer correctly discusses the potential interconnections among decomposition, nitrogen availability, temperature, and moisture, and notes the potential link between nitrogen availability and tree growth. **3:** The answer discusses the potential interconnections among some of the variables above, omitting temperature or moisture completely. **2:** The answer demonstrates some understanding of the potential interconnections among the variables, but temperature or moisture is omitted, and other key details are missing or incorrect. **1:** There is limited evidence that the student understands the connections among the variables above.
Q4	**4:** At least 10 relevant variables are listed. **3:** At least 8 relevant variables are listed. **2:** At least 6 relevant variables are listed. **1:** Five or fewer relevant variables are listed.
Q5	**4:** The answer mentions three items: the importance of regional variability in ecological phenomena, the value of different kinds of expertise in explorations of complex ecological problems, and the importance of extensive replication and/or large sample sizes. **3:** The answer mentions two of the above items. **2:** The answer mentions one of the above items. **1:** The answer mentions none of the items above.
Q6	**4:** At least five items relevant to collaborative science are briefly described. **3:** Four relevant items are briefly described. **2:** Three relevant items are briefly described.

1: Two or fewer relevant items are briefly described.

Q7 Only one correct answer possible: Acorn production can still be calculated for Site 2 using the same procedure as Site 1.

Q8 **4:** At least six relevant problems (combining integration and understanding) are mentioned.
3: Five relevant problems (combining integration and understanding) are mentioned.
2: Four relevant problems (combining integration and understanding) are mentioned.
1: Three or fewer relevant problems (combining integration and understanding) are mentioned.

Q9 **4:** Five correct answers are given and no incorrect answers. The correct answers are: (a) There is a statistically significant relationship between the proportion of female turtles and development. (c) The relationship between the proportion of female turtles and development is positive. (f) As development near the pond increases, the proportion of female turtles in the population also increases. (i) The scatter of points on the graph suggest that other factors, in addition to development, also affect the proportion of female turtles in the population. (k) An R^2 value of 1 would suggest that development is a very strong predictor of the proportion of female turtles in the population.
3: Four or more correct answers are given and no more than one incorrect answer.
2: Three or more correct answers are given and no more than two incorrect answers.
1: Two or fewer correct answers and/or three or more incorrect answers are given.

Q10 **4:** Two correct answers are given and no incorrect answers. The correct answers are: (a) If we were to remove the point with the highest value for the proportion of juvenile turtles, the R^2 value for this graph would get closer to zero. (d) More sites with more diverse development patterns would have provided more confidence in our conclusions.
3: Two correct answers are given and no more than one incorrect.
2: One correct answer is given and no more than one incorrect.
1: No correct answers are given and/or two or more incorrect answers are given.

Table 6. Scoring Rubric for Phase 2 Student-Learning Assessment Survey: 4 = Expert, 3 = Experienced, 2 = Intermediate, 1 = Novice

Question	Rubric
Q1a and 1b	**4:** The stated hypothesis is appropriate for a multi-site study and explores an ecologically important idea. Multiple sites are needed to appropriately test the question. There is a strong ecological and intellectual foundation to the hypothesis. The student presents compelling reasoning for investigating this question. **3:** The stated hypothesis is appropriate for a multi-site study and has ecological relevance, but the justification is not detailed and/or well-developed. **2:** The stated hypothesis is not appropriate for a multi-site study, but does have some scientific interest and relevance as shown in the justification statement OR the hypothesis is multi-site focused but has little or no ecological relevance. **1:** The stated hypothesis is not appropriate for a multi-site study and does not have scientific interest or relevance. The student cannot clearly articulate why they are posing this hypothesis. The topic is not something that can be explored with forested plots.
Q1c and 1d	**4:** The experimental design will test the hypothesis and all relevant data needed are accounted for in a reasonably detailed description of the experiment. The student correctly identifies one or more data patterns that would indicate support for their hypothesis. **3:** The experiment will test the hypothesis, relevant data are collected, but some key details are missing. The student correctly identifies one or more data patterns that would indicate support for their hypothesis. **2:** The proposed experiment collects some relevant data, but there are significant gaps in the description and the design is not fully presented. There may be an error in identifying the data patterns that would indicate support for the hypothesis. **1:** The proposed experiment does not collect any data relevant to testing the hypothesis, or contains fundamental flaws. The student does not correctly identify any data patterns that would support the hypothesis.
Q2a and 2b	**4:** The student identifies nitrogen release by microbes as the main predictor of plant growth rate. The student correctly describes possible relationships between temperature, moisture, and nitrogen release by microbes. The student describes the complexities of the patterns across the three sites. **3:** The student identifies nitrogen release by microbes as the main predictor of plant growth rate. They address the relationships between temperature, moisture and nitrogen release, but their answer is less detailed. **2:** The student correctly describes some of the patterns and interactions, but does not discuss the nitrogen release pattern, or only refers to this pattern and does not discuss the other relationships. **1:** The student does not correctly describe the relationships in this example.
Q3	**4:** The student identifies 4 or more other types of relevant data. **3:** The student identifies 3 other types of relevant data. **2:** The student identifies 2 other types of relevant data. **1:** The student identifies 1 or no other types of relevant data.
Q4a	**4:** The student identifies 4 or more relevant items. **3:** The student identifies 3 relevant items. **2:** The student identifies 2 relevant items. **1:** The student identifies 1 or no relevant items.

Q4b

4: The student identifies 7 or more problems.
3: The student identifies 5-6 problems.
2: The student identifies 3-4 problems.
1: The student identifies 0-2 problems.

Q5

4: Students select all 7 correct answers: a, c, f, i, k, m, p, and no incorrect answers.
3: Six or more correct answers are given and no more than two incorrect answers.
2: Five or more correct answers are given and no more than four incorrect answers.
1: Four or fewer correct answers are given and/or five or more incorrect answers are given.