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Science Galls Me: What is a Niche Anyway?

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INQUIRY & INVESTIGATION

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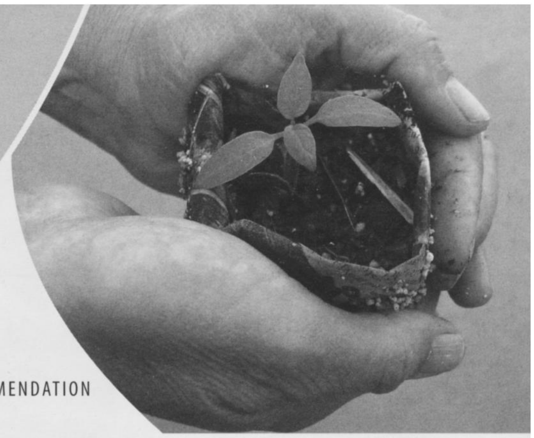

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NABT BioClub RECOMMENDATION

During many backyard barbecues, nature walks, and other outdoor activities, we are often approached by people fascinated by an odd bulb-like structure they have found on a nearby plant. They ask, "What is this?" These "bulbs" are actually specialized growths, galls, that have been caused by insects. Since so much natural curiosity surrounds these phenomena, why not use them to educate students about plant insect interactions? We've developed a lesson to investigate basic principles of ecology, more specifically niche partitioning, while using a jigsaw activity that explores galling insects' interactions with goldenrods. Not only does this lesson capture secondary students' interest and keeps them engaged in hands-on activities, the content addresses two Content Standards (of the *National Science Education Standards*) for 9-12 life sciences: (1) Organisms both cooperate and compete in ecosystems. The interrelationships and interdependencies of these organisms may generate ecosystems that are stable for hundreds or thousands of years (NRC, 1996, p. 186). (2) Living organisms have the capacity to produce populations of infinite size, but environments and resources are finite. This fundamental tension has profound effects on the interactions between organisms (NRC, 1996, p. 186).

Organisms often must compete for food and resources access in natural communities in order to survive. This is true especially for insects that live on the tall goldenrod (*Solidago altissima*). Hundreds of insects have overcome resource limitations by out-competing other herbivores and making use of the same plant in various ways. These ecological interactions take place at the level of the individual, the population, the community, and the ecosystem. We offer an introduction to principles of ecology, plant insect interactions, and provide a classroom activity that highlights niche partitioning by galling insects to help provide secondary science educators with a way to share and explore these interactions with their students.

Investigating trophic relationships among goldenrod plants and gall inducing insects offers rich learning opportunities for high school life science classes (Heinrich et al., 2001; Sandro & Lee, 2006). Our investigation focuses on gall collection, gall identification, measurement skills, and observation. These skills support the development of content knowledge as well as scientific process skills such as prediction, developing and testing hypotheses, gathering empirical data, and inference. Understanding variation in resource use is directly related to resource partitioning. Using wildlife in classroom experiments improves content retention, problem solving, and decision making (Millenbah & Millspaugh, 2003). Because a single goldenrod plant often has multiple insects associated with it, and is common within most of the United States, goldenrods are an optimal choice for investigating niche partitioning.

One way multiple species are able to interact in a single environment and limit competition is a strategy called niche partitioning (Albrecht & Gotelli, 2001). Ecologists approach the problem of quantifying niches by focusing on one or more aspects of competition between species. For example, there may be many different food sources, growth resources, or habitat regions available in the environment; yet, a particular species may only use a narrow range of the environmental resources available.

There are two different descriptions of a species' niche, the fundamental and the realized. These can be thought of as the "potential" and "realistic" niches. The fundamental niche of a species includes all of the conditions in which it could live, all of the geographic regions it could occupy, and all of the potential food sources it could consume. This type of niche is typically very broad, because many species are capable of being generalists. More specifically, a fundamental niche is determined by the morphological and physiological capacity to deal with variation in the environment, in the absence of antagonists. For instance, some species are adapted to consume fibrous, leafy materials while others are adapted to consume vascular tissues. Fundamental niche can be measured by examining the range of resources or range of environments a species is capable of exploiting.

Organisms share the environment with other species, resulting in an overlap of fundamental niches indicating intense competition for a specific resource. The competitive exclusion principle illustrates the outcome when two species utilize the same limited resource within a stable community; one species will consistently out-compete the other. Thus, when two or more fundamental niches overlap, a phenomenon called niche partitioning occurs. This means that species will interact and compete until each species has reduced its niche size to reduce competition. The result is that each species only uses a portion of its fundamental niche. This portion of the fundamental niche is called a realized niche. It may be much

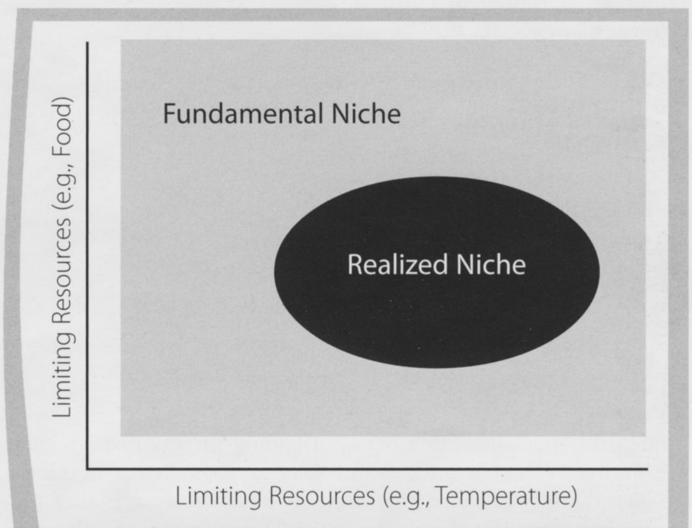

Figure 1. A comparison of the fundamental versus realized niche.

smaller than the fundamental niche (see Figure 1). A significant characteristic of realized niches is that populations of the same species may have very different realized niches. Realized niche limitations depend upon the precise commodities of the ecosystem and the nature of the other species involved in the resource partitioning.

Figure 2. Tall goldenrods in bloom.

○ Study System

Host Plant

Solidago L. (Asteraceae; tribe Goldenrod) is a North American genus of 75 species. *Solidago altissima* (tall goldenrod) is a native flowering plant that regrows each spring from underground rhizomes (Maddox et al., 1989; Abrahamson & Weis, 1997). This species is widely distributed over most of temperate North America, primarily in disturbed habitats, such as abandoned fields, roadsides, and other areas of secondary succession. These plants are also commonly encountered in undisturbed or reconstructed prairies. *Solidago altissima* display tiny, yellow rayed blossoms massed in a showy, plume-like cluster from September to late October (see Figure 2). These plants can be identified by their hairy, grayish stem and rough texture of the leaves, which are toothed and have triplicate parallel venation (Abrahamson & Weis, 1997). In the midwestern region of the United States, these plants can grow alongside the similar smooth goldenrod (*Solidago gigantea*). The major morphological distinction between these species is the presence of hairs on the leaves and stem of the tall goldenrod and absence of hairs on the smooth goldenrod. For a more detailed comparison, see Abrahamson's (n.d.) online guide. Either or both of these plant species may be used for this activity.

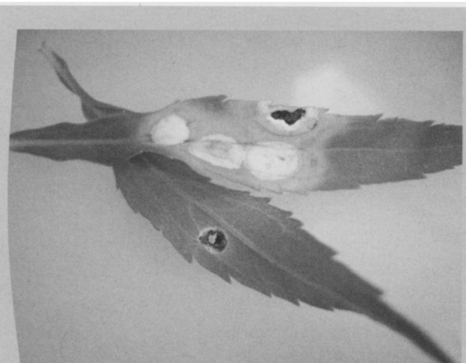

Figure 3. *Asteromyia carbonifera* associated blister gall.

Figure 4. *Epiblema scudderiana* associated woody gall. Photo: Stephen B. Heard (University of New Brunswick)

Galling Insect Herbivores

A diverse community of insect herbivores (>100 species) uses *S. altissima* as a host plant (Maddox & Root, 1990; Root & Cappuccino, 1992; Fontes et al., 1994). These insects represent a diversity of feeding guilds and many are goldenrod specialists. Remnants of galling insects in particular are easily collectible and identifiable, as each insect develops its own distinct gall type that remains observable even after the insect has abandoned the structure. Descriptions and illustrations of some common gall-making species on *S. altissima* follow (see Figures 3 through 9).

Asteromyia carbonifera Sacken (Diptera: Cecidomyiidae) (Figure 3). This is a gall-making fly that creates multiple, small, blister-like galls on the leaves of goldenrods with the aid of a mutualistic fungus (Weis, 1982). These galls first appear on the plants between May and June and are observable through late October. Tip: Have students look on both sides of the leaf; these galls will be visible on each side.

Figure 5. *Eurosta solidaginis* associated ball gall.

Epiblema scudderiana Clemens (Lepidoptera: Tortricidae) (Figure 4). This gall-making moth creates rough, elliptical, woody appearing galls high on goldenrod stems. While these galls begin to appear in May/June, the moths over-winter in the galls so they can be found late in the year. Tip: The galls are often overlooked since they look very much like the stem. Have students who are willing to be careful observers search for these.

Eurosta solidaginis Fitch (Diptera: Tephritidae) (Figure 5). This fly and its gall are most commonly associated with goldenrods (see Heinrich et al., 2001; Waring et al., 1990). Ball-shaped galls are created by the fly and appear midway down on goldenrod stems beginning in late June to early July. Generally only one larval gall forms on each plant. Tip: These galls will probably be the easiest to find and they can also be used for additional lab activities (see Sandro & Lee, 2006; Yahnke, 2006).

Gnorimoschema gallaesolidaginis Riley (Lepidoptera: Gelechiidae) (Figure 6). These moths lay their eggs in the fall near patches of goldenrod. The eggs over-winter and hatch in the spring, leaving the larvae to find new goldenrod shoots. Larvae bore their way into the young terminal meristem where they induce elliptical galls beginning to appear in early summer. Tip: Since these galls form early in the summer, they tend to be found low on the goldenrod stem and can also be identified by a small circular patch near the top end of the gall.

Procecidochares atra Loew (Diptera: Tephritidae) (Figure 7). This fly creates a bunch gall at the terminal and lateral meristems (buds) of a developing goldenrod shoot during midsummer. Tip: You will most likely find these galls within a cluster or bunch formation with multiple galls at each meristem.

Rhopalomyia solidaginis Loew (Diptera: Cecidomyiidae) (Figure 8). This midge attacks the terminal meristem of a developing shoot, producing an apical bunch or rosette gall that provides protection for the developing midges and a habitat for a community of other insects. These galls appear in midsummer with adults emerging around September. Tip: If you carefully dissect this gall, you will find a "tent-like" housing surrounding the insect.

○ Outdoor Gall Activity

The activity includes guidelines for gall collection, classroom use, and assessment questions. We suggest that this unit only be implemented in the fall semester of the academic year. Most of these galls will remain observable until October; after this time, plants tend to lose their leaves, making it difficult to identify the plants and insect galls. In the spring, the majority of the gall inducing insects will not have begun laying their eggs, thus, galls will not yet be formed.

Figure 6. *Gnorimoschema gallaesolidaginis* associated elliptical gall.

Figure 7. *Procecidochares atra* associated rosette gall.

Background Knowledge

- Galls are caused by many organisms living on plants, including insects, mites, mistletoe, fungi, and bacteria.
- Most gall-forming insects are herbivores, but do not significantly damage the host plant, and the larvae inside are often eaten by a variety of birds and rodents.
- Typically, galls grow into a specific size, shape, and color that is characteristic of the particular insect species.
- The plant's defensive reaction to the galling insect herbivore attacks is to isolate the toxins or activities of the invader in a tough, tumorous mass of tissue called a gall. However, in doing so, the plant provides food and shelter for the developing larvae inside.

The selected insects and galls discussed earlier are easy to come by if you visit a field prior to your lesson and gather the galls you will be searching for that day. This will also provide an opportunity to survey the common insect galls that students will be able to identify in your particular region. The portion of the plant that supports the gall can be a clue as to how a particular insect uses its host as a food resource. Most insect herbivores are selective: They specialize as leaf chewers, sap suckers, stem borers, root pruners, gall makers, leaf miners, collectors of pollen or nectar, etc. Each of these feeding strategies represents a separate ecological niche and all of the species that feed on the same plant in the same way are known as members of a feeding guild. Within a feeding guild, all species compete directly with each other for exactly the same resource. Between members of different guilds, competition is usually less direct and less severe. As a result, there is strong selective pressure limiting the number of species within each guild. However, there can also be resource separation among different galling insects; an example would be the gall-forming insects which produce galls on different regions of the goldenrod plant (see Figure 9). This leads to the development of different realized niches for each species. If an insect herbivore typically consumes leaf tissue, such as *Asteromyia carbonifera,* it is more likely to develop galls on goldenrod leaves; while *Epiblema scudderiana*, an insect that consumes the core of the goldenrod stem, is more likely to develop galls on the primary stem of the goldenrod.

It is important to remember that each insect makes a specific gall, therefore, you can identify insect species by identifying the gall. It is reasonable to expect each group to collect between 10 to 30 galls dependent upon the insect selected for investigation (up to 30 galls for *Eurosta, Rhopalomyia,* and *Asteromyia*, as these galls tend to be common in most goldenrod fields, and 10 to 15 galls for *P. atra*, *Gnorimoschema*, and *Epiblema* since these insects tend to be patchy and may or may not be present in the field you are investigating). See the materials list and guidelines for gall collection (Appendix A).

Lesson Goals

This lesson is designed to create a cooperative and challenging learning environment in which students will have the opportunity to gain an understanding of field biology. We focus on developing content knowledge and process skills including collection,

Figure 8. *Rhopalomyia solidaginis* associated rosette gall.

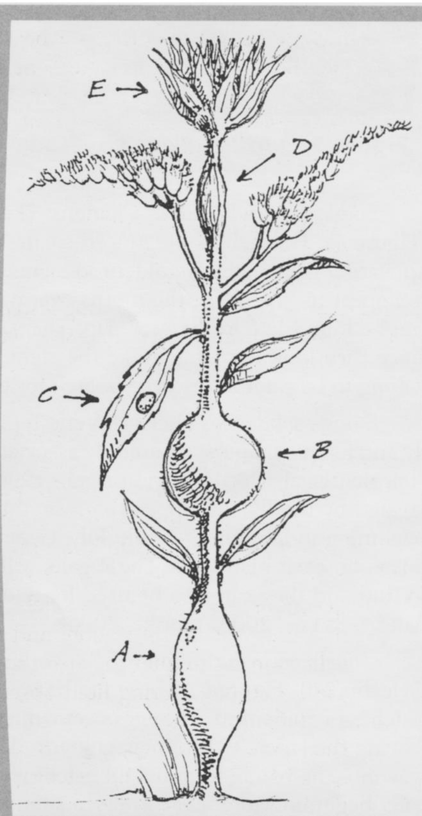

Figure 9. Primary locations of galls on *Solidago altissima.* Artwork by John O. Stireman III, Wright State University.

observation, and identification techniques. This is accomplished by organizing and analyzing evidence collected in the field and utilizing empirical data to generate supporting evidence for student claims. Students can also gain valuable experience by collaborating with peers to solve real-world problems.

Lesson Format

We propose engaging high school students with a collaborative jigsaw investigation focused on gall related plant-insect interactions. The jigsaw approach to investigations is an instructional strategy that encourages the formation of a community of learners (Michaelsen et al., 1997). In our lesson, students work as teams to conduct investigations into plant insect interactions and the resulting gall formation.

These are the six steps we suggest for setting up a jigsaw investigation of niche partitioning in your classroom.

- **First.** Divide students into teams of three to four students each. We found that, for the full effect of this activity, it is optimal to have the same number of groups as insects available to investigate, but this is not necessary. At this point, the teacher should carefully consider how the teams are grouped with respect to students who may need extra assistance during the field investigation portion of the activity. It may be advantageous to group individuals needing the most help with advanced students.
- **Second.** Assign or have each group select a specific galling insect and develop guiding questions encompassing four areas of focus: the gall itself (individuals), the galling insect (populations), the plant (individuals or populations), and organismal interactions (at the level of the community and ecosystem). As the instructor, you must be sure that the questions selected will help guide students toward investigating niche-based topics. These questions can be generated by student teams or assigned by the teacher, depending upon the desired level of inquiry. Each student should have one question to investigate. These are some examples of questions students have investigated:

  Do galls damage or kill the plant? What is the primary purpose of a gall? Are galls caused by a specific species always found on the same part of the plant? Are galls or the contents of galls used as a resource for other organisms? What is the defensive action of plants toward gall-inducing insects? What is the full scope of resources available for our insect to utilize (e.g., the fundamental niche)?
- **Third.** Once the guiding questions have been established, each student team is responsible for collecting galls and pertinent field data (see Appendix A for a sample gall collection protocol; See Appendix B for sample field data collected). During this portion of the investigation, students should take note of the location of the galls on the plant and gather evidence to help them answer their guiding questions. You may need to help students with plant identification, gall identification, and demonstrate appropriate collection techniques to gather some galls for dissection in the classroom. During field observations, it is appropriate to challenge student teams to apply their knowledge of galls and gall forming insects or ask additional investigation questions. If a student cannot participate in the outdoor field portion, he/she can still investigate the collected galls back in the classroom. Once back in the classroom, it is often fun and appropriate to have students dissect some of the galls collected to see the internal anatomy and how many insects or species are present. For example, we found that the *Eurosta* galls are often attacked by birds in search of food and the *Rhopalomyia* galls are often hosts to several different insect species.
- **Fourth.** Student teams should use the evidence from their field investigation and resources gathered upon returning to the classroom to answer their assigned questions. At this point, we challenged students to find articles focusing on ecological relationships that exist between plants and insects, in particular, resources about niche partitioning.
- **Fifth.** Students incorporated information from their readings with their field data to develop answers to their questions and shared these with their group. Then the group developed a presentation to share with the class summarizing all of its findings regarding its assigned insect. The ultimate goal for these presentations is for students to understand that the gall forming insects utilize different plant resources, allowing them to use the same plant as a resource while eliminating competition. For example, we found that *Gnorimoschema* utilizes goldenrods very early in the season, followed by *Eurosta* and finally *Epiblemba*. Thus, these species employ temporal niche partitioning. We also found that *Rhopalomyia* and *P. atra* tend to compete by attempting to occupy the same niche space (apical meristem) at the same time. Thus we could assume that the least successful species would eventually adapt to a different niche or die out.
- **Sixth.** Assessing student learning is a major part of all lessons. In this activity, both students and teacher are responsible for assessment. The students assess peers on their contributions to the investigation. The instructor assesses student performance throughout the tasks as well as the quality and accuracy of content given during the group presentations. We designed a rubric to assist with students' peer evaluations (Appendix C). We also designed a scoring guide to assist with the instructor's summative assessment (Appendix D). This scoring guide emphasizes the use of evidence to support claims and relate explanations to key concepts associated with niche (e.g., fundamental niche, realized niche, and niche partitioning). We also encourage conducting formative assessment throughout the activity. This is implemented when challenging the students in the field, asking questions as students are interpreting data, probing students to think beyond superficial responses to questions, and encouraging communication about the project among groups.

○ Conclusion

Utilizing jigsaw activities in high school classrooms offers flexibility for teachers to control their level of involvement within an investigation. For example, this approach is open to both student-developed questions or teacher-assigned investigations. Teachers have multiple opportunities within the jigsaw approach to provide or withhold scaffolded instruction based upon the level of student skill. This lesson provides students opportunities to develop both content knowledge and build process skills needed for conducting science. Students partake in fieldwork interacting with an ecosystem in which there are multiple examples of niches. Such investigations of niches using goldenrods have not previously been conducted at the high school level. In particular, using goldenrods as a study system allows students access to content knowledge not found within traditional textbooks. Additionally, students are given the opportunity to experience an investigation similar to what scientists might experience and to approach it as scientists might.●

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APPENDIX A. Gall collection

Gall Collection Protocol

1. Search for galls of insect assigned – this will be a haphazard sampling technique.
2. Record location of gall on plant and number of this type of gall on plant.
3. Note any additional galls found on plant.
4. Record any additional data deemed necessary for guiding question i.e., light intensity, flowering density, plant height, distance of plant from others, etc.
5. Clip goldenrod stem directly above and below gall (as applicable) for collection.
6. As collecting galls, consider whether or not you are noticing any trends in plant usage or location by your insect.
7. Bring galls and recorded observations back to class.

Necessary Collection Materials

- cutting utensil
- bag to carry galls
- pencil and paper
- measuring tape
- class-developed matrix - one copy per student
- photometer – optional

Note: It is important to try to make collections from plants that are at least 5 meters apart to help prevent multiple collections from clones. While this technique is not fail-safe, it will help students get a better diversity of gall collections from unique goldenrod host plants. This approach of selecting plants is considered haphazard since students will happen upon plants with galls in a quasi-random manner.

BIO

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APPENDIX B. Team 3: Gnorimoschema

Guiding Question: Are galls caused by specific species always found on the same part of a plant?

Team questions: Do galls damage or kill the plant? What is the primary purpose of a gall? Are galls or the contents of galls used as a resource for other organisms?

PLANT	LOCATION OF GALL	PLANT HEIGHT/DIAMETER	OTHER INFORMATION
1	One Gnorimoschema gall 22 cm from ground on main stem	111 cm/0.55 cm	One Asteromyia on one leaf (78 cm from ground) Gnor. gall looks eaten – bird?
2	One Gnorimoschema gall 37 cm from ground on main stem	93.5 cm/0.5 cm	
3	One Gnorimoschema gall 74.5 cm from ground on main stem	108 cm/0.55 cm	Two Asteromyia on one leaf (67.5 cm from ground)
4	One Gnorimoschema gall 39 cm from ground on main stem	95 cm/0.4 cm	
5	One Gnorimoschema gall 32 cm from ground on main stem	112 cm/0.7 cm	Two Asteromyia on two leaves (105 cm from ground) (74.5 cm from ground)
6	One Gnorimoschema gall 29.5 cm from ground on main stem	77.5 cm/0.4 cm	One Asteromyia on one leaf (58 cm from ground)
7	One Gnorimoschema gall 27 cm from ground on main stem	72 cm/0.45 cm	
8	One Gnorimoschema gall 31.5 cm from ground on main stem	70 cm/0.5 cm	1 Rhopalomyia on apical meristem (70 cm)
9	One Gnorimoschema gall 61 cm from ground on main stem	97.5 cm/0.35 cm	
10	One Gnorimoschema gall 36.5 cm from ground on main stem	106 cm/0.5 cm	
11	One Gnorimoschema gall 59.5 cm from ground on main stem	109 cm/0.6 cm	
12	One Gnorimoschema gall 59 cm from ground on main stem	110 cm/0.7 cm	
13	One Gnorimoschema gall 34 cm from ground on main stem	89 cm/0.4 cm	
14	One Gnorimoschema gall 61 cm from ground on main stem	93 cm/0.4 cm	One Eurosta on main stem (69 cm from ground)

DISSECTION DATA

1 Empty
2 One larva inside
3 One larva inside
4 Empty – webs inside (spider?)
5 Empty
6 One larva inside
7 One larva inside
8 One larva inside
9 Looks like sesame seeds – parasitic wasp?
10 Looks like sesame seeds – parasitic wasp?
11 One larva inside
12 One larva inside
13 Empty – small beetle shell
14 One larva inside

APPENDIX C. Peer Evaluation Rubric

Peer Evaluation Rubric – Science Galls Me

Student: ______________________ Date: __________ Evaluator: ______________________

Criteria	Poor	Good	Exemplary	Comments
Gathering Data	Very little material evidence was collected in the field. Did not complete field notes.	Considerable material evidence was collected in the field. Field notes were of good quality and provided information for classification.	Evidence collection was significant and guidance was provided. Field notes were of high quality and very useful for the team.	
Sharing Information	Did not readily share information with teammates.	Shared information with the team on a regular basis.	Readily shared information with the team.	
Accepting Responsibility	Did not accept responsibility for researching or answering assigned questions.	Accepted responsibility for researching and answering questions. Most of the information provided was useful for the team.	Consistently accepted responsibility for researching and answering questions. The information provided was useful for the team.	
Collaboration	Difficult to work with and unreliable when collecting evidence in the field – did not collaborate or show support for others.	Worked well with teammates when collecting evidence in the field – limited cooperation and support for others was shown.	Worked well with teammates when collecting evidence in the field – was cooperative and supportive of others.	
Presentation Preparation	Limited involvement in preparation for presentation.	Provided limited ideas, information, and evidence for presentation.	Consistently contributed ideas, information, and evidence for presentation.	
Overall Assessment	This individual was not a good collaborator. He/she was often unreliable and unwilling to work with teammates.	This individual was a good collaborator. He/she often worked effectively with teammates.	This individual was easy to work with and an excellent collaborator. He/she was always reliable and willing to work with teammates.	

APPENDIX D. Summative Scoring Guides for Instructor

INDIVIDUAL ASSESSMENT OF STUDENT PRESENTATION
Science Galls Me Scoring Guide

Student: ______________________________

Criteria	Expectations	Point Values
Accuracy	The information presented by the student during the team presentation is accurate.	
Preparation	The student is confident, well prepared, and organized during his/her portion of the presentation. He/she is able to discuss the topic without reading from a prepared text.	
Knowledge	The student was knowledgeable and was able to provide complete and in-depth explanations.	
Evidence	The student supported all claims with evidence gathered during the field collection, observed on the plants, observed within the galls, or noted in the field notes.	
Clarity	The student spoke clearly and was easy to understand.	
Appearance	The student was dressed appropriately.	
Answers to Questions	The student was able to answer questions from other teams about the galling insect his/her team chose to investigate.	

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APPENDIX D. *continued from the previous page*

TEAM ASSESSMENT OF STUDENT PRESENTATION
Science Galls Me Scoring Guide

Student:______________________________

Criteria	Expectations	Point Values
Preparation	The team was well prepared for the presentation. • Student participants worked together to present their work to the class. • The team was well prepared: ◦ All necessary PowerPoints, overheads, handouts, etc., were prepared ahead of time.	
Knowledge and Accuracy	The team was able to accurately explain: • all of the questions addressed by the research group. • explanations addressed fundamental niche, realized niche, and niche partitioning.	
Evidence	The team supported all claims with evidence: • gathered during field collection. • observed during gall dissections, if appropriate. • additional resources used.	
Organization and Clarity	The presentation was well organized and easy to follow. Explanations provided by the team were clear and easy to understand.	
Answers to Questions	The team was able to accurately address questions from the teacher and other teams.	