Guidelines for Shaping Good Inquiry Projects

Background

In a pedagogical context, **inquiry** refers to an instructional framework based on the idea that the process of discovery inherent to science encourages curiosity and engages a self-directed learner, while the scientific method guides the development of critical thinking skills. The result is often higher scientific literacy both in terms of content and process. Guiding students in inquiry-based learning can be challenging as it requires patterns of group management and pace distinct from that of classroom teaching.

In a 2007 report the National Research Council recommended that four crucial aspects of the scientific process be integrated into inquiry-based programming in K-8 schools:

1. Know, use, and interpret scientific explanations

This thread acknowledges the importance of factual information in using the scientific method, but emphasizes that students be given the opportunity to apply ideas in a predictive framework, observe phenomena, and link different facts.

2. Generate and evaluate scientific evidence and explanations

This is the traditional core of the scientific method as it is practiced. Students should design and conduct their own experiments and interpret results with a focus on the use of evidence in refining hypotheses and methods.

3. Understand the nature and development of scientific knowledge

This component emphasizes the need for students to reflect on the scientific process itself, their own ideas, and the ideas of others.

4. Participate productively in scientific practice and discourse

While the particular subject matter changes with grade level, the intention is that this inquiry process in embedded as a means of delivering content.

Leading Inquiry

In an assessment of inquiry-based education projects at the high school level, Loretta and Orgil (2009) found that "students often gathered evidence and participated in teacher-guided analysis of that evidence, but seldom were they asked to grapple with scientifically oriented questions, create evidence-based explanations, connect explanations to accepted scientific concepts, or justify the results of their investigations to a larger group of peers." It appears more attention is placed on the hands-on aspects of inquiry learning, leaving the self-directed and what have been termed "sense-making" aspects of the process underemphasized. Guiding students in question development and interpretation of findings in a greater scientific context are admittedly difficult tasks. Key to achieving this is establishing of a clear set of goals for the process and behavioral expectations distinct from those of the classroom or recess. While these will be generally analogous across grade levels, goals will be more challenging at higher grade levels and the articulation of behavioral expectations should be tailored to each age group. For example, 3rd and 4th graders will be expected to generate their own question, but may be provided more directed guidance from a leader or may choose a question that is very similar to one presented during rotation activities. A high school student will also need guidance developing a question, but should be encouraged to delve deeper and create a more sophisticated question than those modeled during rotation activities.

The pace and organization of inquiry-driven curricula diverge greatly from traditional classroom teaching. While many teachers already integrate hands-on and student-led activities in their classrooms, taking a class outside and asking that they conform to the same behavior rules as in the classroom can create an unnecessary management problem. Instead, acknowledge that this setting is very different from an indoor classroom and establish a code of conduct unique to the outdoor setting, specifically to a research site. If studies are conducted in a schoolyard students may already very familiar with this area, but they will not be familiar with it as a research site. Students should be instructed to consider the schoolyard their research site and leaders should explain the codes of conduct field scientists use when making discoveries and seeking to answer questions about the natural world in a particular area. General instructions include replacing any objects moved during a process of searching, trying not to step on plants or animals, not handling unfamiliar plants or animals, and not leaving litter or other items. Certain habitats and projects will require more specific instructions on conduct.

Logistics and Preparedness

When studies are conducted in the schoolyard existing facilities (bathrooms, nurse's office, water fountains) will generally be readily available. However, to keep students engaged in their inquiry projects it is useful to ask students to bring a water bottle, a hat or other sun protection, sunscreen, any snacks, and a bag to carry these items. This way, aside from bathroom breaks, students will have everything they need to stay "out in the field" for large chunks of time while collecting data. The large group should also have a first aid kit to handle minor incidents, again so students do not need to break from their inquiry groups for long periods of time (ie: a visit to the nurse's office). If inquiry projects research takes place at a local park or location some distance from the school these items then become mandatory.

Students should stay within eyesight of their group leader at all times. When travelling from one place to another, particularly when crossing roads or parking lots, inquiry groups should stay together. Urban spaces are also often full of people and students should be instructed on how to interact with people who ask them what they are doing. They can say something as simple as, "I am working on a science project with my class." or give a more extensive explanation if someone seems particularly interested. In general, however, students should keep interactions with the public short and explain politely that they need to continue their work. Group leaders should be aware of people from outside the group approaching students and go to the student to assist if needed.

Providing facts and contextual information

In line with helping students learn, use, and interpret scientific explanations, some amount of background information will be crucial for students to develop independent inquiry projects. Often instructors feel the need to provide facts at the outset so students have them as tools to develop questions. But facts are not the real tools. While some facts are crucial, for example a student could not reason her way into knowing the structure of haemoglobin, many more than we might expect can be found through a reasoning process. Knowing facts about oxygen as a requirement for respiration, a student could certainly reason her way into understanding that oxygen is in the blood and carried to tissues, and that the amount of oxygen in the blood may vary based on metabolic needs or abiotic variables. By providing students biological principles, they will be better prepared to intuit the connections between factors or the existence of a particular phenomenon, either form the basis of a very strong scientific question!

Guiding inquiry project development

After students have experienced 2-3 mini inquiry activities, each small group will be expected to come up with a central question to pursue as their inquiry project. Leaders can initiate this process as a guided brainstorming session. This could start as an individual free write where students write down all of the questions that come to mind in a very short span of time (3-5 minutes). At this point there is no directive about a strong question or a good research question; this exercise should just get the students generating questions. Starting this as an individual writing activity helps equalize the contribution from students who may be more shy or hesitant with those who are more willing to offer suggestions. After the free write gather suggestions using a large whiteboard or flip chart. Facilitating this through call-and-response will likely be the quickest way of gathering ideas. If time is limited, ask students to pick their two favorite questions. It also allows the leader to cluster related question in space on the paper, something students can help with. Have a conversation about which questions that would be of high interest to the group. In this kind of conversation it is important that students are treated in the manner a group of adults making this decision would be treated. While they will need some redirection, students will often 'rise to the occasion' and discuss the ideas in a very balanced way. You do not need to attribute ownership to the questions, though students will often remember who contributed what. Instead, talk about the questions as their own entities. This discussion will lead into one about strong questions. You may ask the group such things as, 'what is exciting or interesting about this question?' or 'can you imagine a way you could test this question in the next few days?' These questions lead into outlining the qualities of a strong scientific question. From there you can begin to ask whether each question meets these requirements and eliminate questions that do not meet all of the criteria.

Experimental Design: Handling Data Before and After Experiments

From the very first discussion about their field notebooks, leaders can begin to help students think about collecting data and appropriate experimental design. Define elements of a scientific experiment (control, dependent variable, independent variable) from the beginning and be consistent in using these terms when describing examples or guiding students in setting up tables, charts, diagrams, and graphs. As groups are deciding on a central question and associated hypotheses for their inquiry project, be sure the discussion touches on the following:

- Keep detailed, neat notes

Encourage students to document all their observations during the course of their study and to do so in a neat, organized way. They will likely record their data in a table and can include a column for comments on particular measurements or observations, or may want to note general observations at the top or bottom of the table.

- Consider necessary materials

Prior to starting an experiment, students will need to decide which materials or tools they will need. Write out preliminary methods and associated materials for each step. Make sure they know what units of measurement they plan to record and how many samples or observations are needed for each group or at each time interval. Remind them to take into account the amount of time allotted to complete the experimental portion of the project and make sure the methods align with this timeframe. Leave room in your methods to make notes about unforeseen problems with methods and what you did to solve them.

- Record data in tables and charts

Once students have decided on what they plan to measure (independent and dependent variables) and how they plan to measure it, guide them in drawing a table in their field notebooks for recording this data in an organized way. Generally variables are arranged as columns and observations are arranged as rows. Charts may also be used to record data. Charts may be helpful if the project involves collecting categorical or presence/absence data. Charts are often used in behavioral observations to note whether a particular event happened or not, or when it happened during an observation period.

<u>From the outset it is useful to think about the design of an experiment in terms of how you will test your hypothesis</u>. The basic terminology of experimental design will help. Using

these terms consistently and being clear when using synonyms will help students develop a natural handle on the vocabulary of experimental design.

Variables

- **Independent variable**(s) - These are the modified (or measured) factors of your study that you expect will influence change in the dependent variable. In a **controlled design** the researcher **sets up treatments** of the independent variable to see if or how the dependent variable changes. In an **observational design** the researcher **measures variation** in the independent variable to test if or how variation in the dependent corresponds.
  - Common synonyms included **predictor variable** or **explanatory variable** because these factors are thought to predict or explain changes in the quantity or quality of the dependent variable.
  - **Treatment** refers to the different independent variables the experiment modifies or establishes. If you were interested in whether insect herbivory is higher in sun or shade, you might find individuals of a plant species that grew in both sun and shade and compared herbivory on these "treatments". Even though you did not control the location of the plants, sun versus shade can still be considered the treatments.
  - **Factors** and **levels** are also terms used when referring to independent variables. Factors refer to controlled treatments where the levels, or particular magnitude of different treatments, are determined by the experimenter. If instead of finding plants in sun and shade you decided to provide plants with different amounts of shade, you might provide plants with levels of shade such as 10%, 25%, 50%, 100%. Here the factor is shade and the levels are those percent values.
- **Dependent variable**(s) - These are the variables you measure and have predicted will change when you make or observe changes in the independent variables.
- **Controlled variables** - Students are often confused by the classification of only two kinds of variables because they see many *things* that could influence their dependent variable. It is helpful to talk about keeping all other variables one can imagine (and hopefully those one can't!) exactly the same across treatments of an independent variable. This will enhance confidence that changes in the dependent variable are best associated with pre-determined or observed changes in the independent variable.

Sample size

Statistical testing is based on the idea that sampling methods have produced an accurate approximation of **population data** based on a small subset, or **sample**, of measurements from that population. But you need to make sure you include enough data points in the sample to represent the data of the population. For example, you know that a coin has two sides and thus the probability of getting a head or tail is 50%--you have to get one or the other and there are only two options. However, if you only flip a coin a few times (say 4 or 6 "samples"), you may not get 50%. Instead, you will need to flip the coin many times to see the pattern of probability you know exists based on the options. You can demonstrate this with students by asking them to calculate their frequency of heads and tails after 4, 6, 10, . . . flips. You can ask them after how many flips the frequency reached 50% and stayed there. As the number of options increase, the necessary trials or samples also increases. If you have a 6-sided die, what is the probability that you will roll a "3"?

The answer should be ⅙ = 16.7%. How many roles does it take to see this pattern emerge? And finally, in the real world we are generally dealing with systems where each option does not have an equal probability. If you give a student an opaque bag of marbles with a population of 40 black marbles, 15 green marbles, 15 yellow marbles, 5 white marbles, and 5 blue marbles, what is the probability of drawing each color? Now, if you only draw 10 marbles, what is the result? Because you are far more likely to draw a black marble and moderately more likely to draw a green or yellow marble, you may completely miss the fact that there are white or blue marbles in the bag! You can play this game with students and see how many times they need to draw from the bag to get the appropriate frequencies for each color.

In much of science we are interested in the mean, or average of an effect. You can see from the examples above that as we increase the number of times we sample something, the **average frequency of an event in our sample** converges on the **known frequency based on population** information. Similarly, if you are measuring outcomes from an experiment or the occurrence of something in the natural world, you will need to measure the same treatments or conditions multiple times to get an accurate image of the population from your sample. But why do we want to know about the population? This is covered a bit more in reference to examples, but the idea is that if two things (say individuals exposed to different treatments) are really different from each other, it will look like they come from different populations. We can use sampling to approximate which population an observation belongs to and use population information to determine if two things belong to the same population. This way we can say if two things are different or not, often a key part of hypothesis testing.

Sampling & Bias

Based on the information covered above we now know how sampling allows us to gain an idea of population-level information from a smaller subset of measurements. But this concept only works if we are conducting our sampling in a **random** manner. Here, random refers to the idea that the observer (or person choosing a marble from the bag) is not placing any particular **bias** on a color. In the above example we achieve this by using an opaque bag--the observers cannot see the population of marbles from which they are choosing. It is often helpful to emphasize with students that bias is not inherently bad. Bias is how we can distinguish things from each other and make decisions based on characteristics of things--humans are excellent at these tasks! But as should be evident from the examples above, bias prevents us from gaining an accurate depiction of a population from a sample. If we really want to compare two things and ask if they are from the same population, we need to sample those populations randomly to get accurate information.

Balanced design

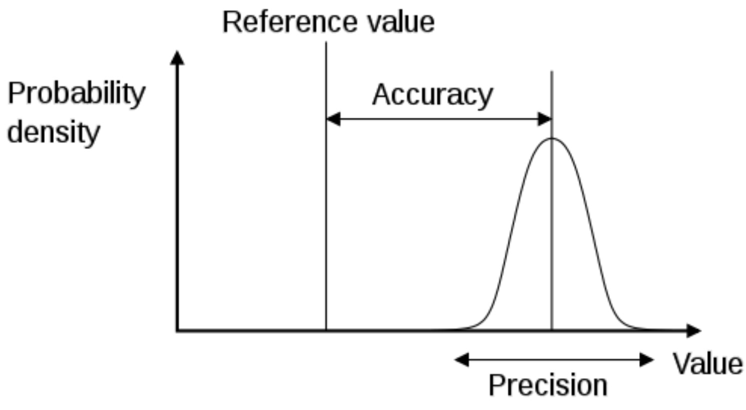
In order to make strong inferences about a treatment or condition, it is useful to have a balanced design wherein treatments or levels of treatments are administered the same number of times to groups of equal size. For example, if you are interested in whether or not water and sunlight affect two species of plants differently, you would set up your experiment so that equal numbers of individuals from each plant species experience all combinations of treatment levels. That would look something like this:

Treatment	Plant species A	Plant species B
Water **high**, sun **high**	25 plants	25 plants
Water *low*, sun *low*	25 plants	25 plants
Water **high**, sun *low*	25 plants	25 plants
Water *low*, sun **high**	25 plants	25 plants

<u>Data Collection</u>

After considering the basic structure of a question, hypothesis, and associated predictions, research scientists begin to think about the kind of data they will need to test their hypothesis(es) and the experimental design necessary to collect the data. Statistical analysis is a key component of this stage in the process. Collecting data without first considering how it will be used to test the hypothesis can become very messy very quickly. This is actually a common pitfall for scientists! This section contains examples of different kinds of data you may collect, the ways to best represent that data, and the appropriate statistical tests to analyze the various kinds of data. First, there are a few common concepts in experimental design that are important to consider at the start of any scientific inquiry:

Types of Data
When measuring aspects of an object or process of interest, you may record discrete or continuous data. **Discrete data are counts that can only take on certain values**. For example, the number of caterpillars on a branch can only be integers because you will not see ½ or ¾ of a caterpillar (unless it is being eaten . . .). **Categorical data also take on discrete values, but instead of being numbers, categorical data are often just that, non-numeric categories**. If you were to identify which species of caterpillar you found, these data would be categorical. **Continuous data are measurements that can take on an infinite or near-infinite number of values**. If you went back and measured the length of all of the caterpillars you counted, you could find that some were 3.4 cm, some were 6.87 cm and some were 9.14 cm. While there may be an upper bound (no caterpillar will be 20 cm), there are is a near-infinite number of possibilities for caterpillar length.



Precision vs. Accuracy

When making measurements it is important to be able to describe how precise and how accurate your measurements are. **Accuracy is a way of describing how close measurements are to the true value**. If a caterpillar is 3.52 cm and your measurement is 3.50, you are very close to the true value. **Precision refers to how close a set of measurements on a particular item are to one another, or the variability in your measurement**. The precision gives you an idea the reproducibility of your measurement. If you measure the caterpillar 5 times and get 3.49, 3.53, 3.51, 3.50, 3.49, your precision and accuracy are fairly high. If you measure the caterpillar 5 times and get 3.32, 3.33, 3.31, 3.32, 3.32, your precision is very high, but your accuracy is low.

General Structure	**Question**	**Hypothesis** *Explanation of phenomenon based on an observation*	**Predictions** *Clear statement of expected outcome under the given premise, falsifiable*	**Type of experiment**	**Type of data**
How does X affect Y?	Does soil moisture affect leaf temperature?	Soil moisture influences plant leaf temperature.	Increasing soil moisture will result in decreasing leaf temperature.	Experimental, multiple treatments, correlative, abiotic-biotic	Independent variable *Discrete or Categorical* Dependent variable *Continuous*
			Plants growing in wetter areas will have lower leaf temperatures in the sun than those growing in dry areas.	Observational, correlative, multiple measurements, abiotic-biotic	Independent variable *Continuous* Dependent variable *Continuous*
	Does the presence of insect predators influence pollinator behavior?	Predator presence affects pollinator visitation to flowers.	Flowers with an insect predator shape placed nearby will receive less visits from pollinators than those without a predator.	Experimental, single treatment, comparative, biotic-biotic	Independent variable *Categorical* Dependent variable *Continuous*
Is A different than B?	Are there different communities of insects on the soccer field and the playground?	Different habitats with different amounts of moisture will support different communities of insects.	There will be more moisture and a greater diversity and abundance of insects on the soccer field than on the playground.	Observational, comparative, two-factor, abiotic-biotic	Independent variable *Continuous* Dependent variable *Continuous*
	Do different species of birds visit palo verde trees, mesquite trees, and cacti?	Palo verde and mesquite trees support different bird species.	Bird species visiting paloverde and mesquite trees will be the same, but those that visit cacti will be different.	Observational, comparative, biotic-biotic	

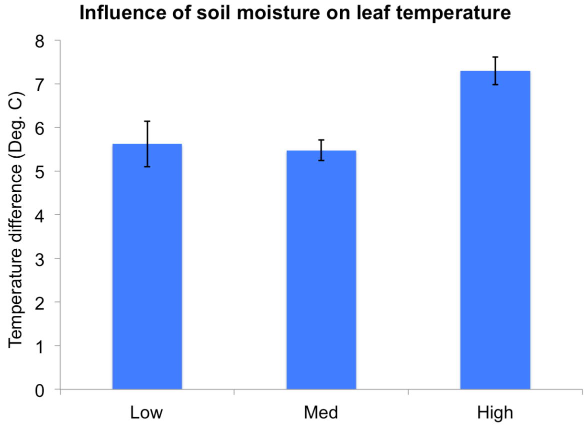
Example 1: Soil moisture & leaf temperature

General Structure	**Question**	**Hypothesis** *Explanation of phenomenon based on an observation*	**Predictions** *Clear statement of expected outcome under the given premise, falsifiable*	**Type of experiment**	**Type of data**
How does X affect Y?	Does soil moisture affect leaf temperature?	Soil moisture influences plant leaf temperature.	More soil moisture will result in lower leaf temperature.	Experimental, multiple treatments, correlative, abiotic-biotic	Independent variable Discrete or Categorical Dependent variable Continuous

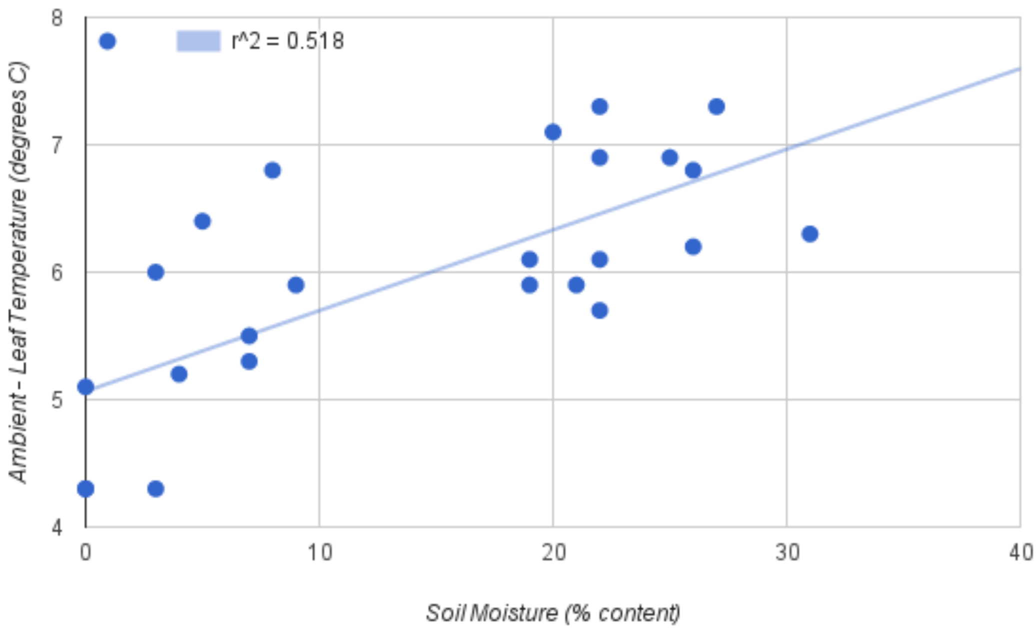
For this kind of experiment students may provide different amounts of water to plants and measure leaf temperature as the dependent or response variable. Using a **balanced design** with **replicates** might look something like the following table. Since soil moisture is something the experimenter would control, it is the independent variable and will likely be a categorical (i.e.: treatments of volumes of water).

lant	Treatment	mbient - Leaf Temp (°C)			Descriptive Statistics		
		ay 1	ay 2	ay 3	lant verage	reatment verage	tandard eviation
	ow water	.1	.3	.7	.7		
	ow water	.8	.6	.9	.1		
	ow water	.2	.9	.1	.1	.6	.52
	ledium water	.3	.1	.7	.7		
	ledium water	.1	.5	.9	.5		
	ledium water	.1	.1	.5	.2	.5	.23
	ligh water	.3	.9	.1	.1		
	ligh water	.1	.3	.6	.7		
	ligh water	.9	.0	.5	.1	.3	.32

When the **independent variable is discrete** (including categorical) and **the dependent variable is continuous**, you can use a **bar chart or boxplot** to represent the data. A bar chart can be constructed by calculating the average and standard deviation of the dependent variable (difference between leaf temperature and ambient temperature) per day over all plants. Because this is a balanced design with the same number of replicates per treatment, you can average by plant and then over treatment, or simply average all of the values taken for each treatment at once.



General Structure	Question	Hypothesis *Explanation of phenomenon based on an observation*	Predictions *Clear statement of expected outcome under the given premise, falsifiable*	Type of experiment	Type of data
How does X affect Y?	Does soil moisture affect leaf temperature?	Soil moisture influences plant leaf temperature.	Plants growing in wetter areas will have lower leaf temperatures in the sun than those growing in dry areas.	Observational, correlative, multiple measurements, abiotic-biotic	Independent variable Continuous Dependent variable Continuous



In this example the independent variable is not set by the experimenter, instead it involves measuring natural variation (in this case in soil moisture) and asking whether that ***correlates*** with plant thermoregulation. In instances where **data from both variables can be treated as continuous** and it is predicted that **a change in the independent variable will result in an increase or decrease in the dependent variable**, you can represent that data using a **scatterplot**. You can test your hypothesis about the relationship by drawing a **line of best fit through the data**.

DEVELOPING A STRONG QUESTION

While there are differences in the delivery of inquiry-centered programming to different grade levels, the core components of a strong question and testable hypothesis do not change. The basic requirements of a strong scientific question are:

- It is has a real answer. Even something as simple as "yes" or "no".
- It is testable within the time available.
- It has a hypothesis that is falsifiable.
- It is connected with a greater body of scientific literature, often offering an answer to an as-yet-unknown question.

Using these criteria we can determine good questions and tweak weak questions to be strong ones. As a leader, it is not sufficient to simply point out the characteristics that make a weak or strong question, you should guide students through the process of turning a weak question into a stronger one.

Weak Question	Problems	Stronger Question
Broad factual questions How many different ant species are in the parking lot?	This question has a *real answer* and is *testable*, but a falsifiable hypothesis cannot be formulated	Are there more ant species in the area of the parking lot near the dumpsters or the area near the baseball field? Problem solved! Falsifiable hypothesis: There are more ant species near the dumpster than the baseball field.
Narrow factual questions What is the tallest plant in the school yard?	One could certainly find the answer to this question and potentially even create a hypothesis about which plant is the tallest, the relevance of such a question is not clear. It is not couched within a larger scientific context.	To improve this question we might want to ask why knowing the tallest plant might be interesting. Is it a question about habitat quality, such as where in the school yard plants get the tallest? Or is it a question about what organisms live in and around a taller plant versus a smaller one? Either way, the question will need to be more specific (which species of plant(s)?) and relate plant size to another aspect of biology aimed at the relevance of size.
Phenomenological questions Why do bees like yellow flowers?	Like many broadly phrased "why" questions, this does not have a real answer. Additionally, even if is is possible to determine a physiological mechanism underlying bees' preference for yellow flowers, this is not achievable in the course of our program.	If the premise of the "why" question has not been established, it is often sufficient to remove the why and ask, 'do bees prefer yellow flowers?' *Prefer* is stronger than *like* because it inherently implies a comparison, and many strong questions are comparative. If we already know this to be the case, we might ask 'What is it about yellow flowers that make them more attractive to bees?' Students can brainstorm variables (color, size, nectar content) and these can become hypotheses.

Basic structure of questions

General Structure	**Question**	**Premise** *Facts or observations upon which the hypothesis is based*	**Hypothesis** *Clear statement of expected outcome under the given premise, falsifiable*	**Type of experiment**
How does X affect Y?	Does soil moisture affect leaf temperature?	More moisture in the soil allows plants to maintain cooler leaf temperatures in the sun.	Increasing soil moisture will result in decreasing leaf temperature. Plants growing in wetter areas will have lower leaf temperatures in the sun than those growing in dry areas.	Experimental, multiple treatments, correlative, abiotic-biotic Observational, correlative, multiple measurements, abiotic-biotic
	Does the presence of insect predators influence pollinator behavior?	Flying pollinators have very good vision and will detect predator shapes near flowers and avoid those flowers.	Flowers with an insect predator shape placed nearby will receive less visits from pollinators than those without a predator.	Experimental, single treatment, comparative, biotic-biotic
Is A different than B?	Are there different communities of insects on the soccer field and the playground?	DIfferent insects rely on different habitat variables, but all insects need water, so areas with more water will have more insects. The soccer field has higher soil moisture.	There will be more insects on the soccer field than on the playground.	Observational, comparative, abiotic-biotic
	Do different species of birds visit palo verde trees than mesquite trees or cacti?	While palo verde trees and mesquite tree are very similar in structure, cacti are very different and have many defenses. Therefore, there will be generalist birds that can visit many trees and specialists that only visit cacti.	Bird species visiting paloverde and mesquite trees will be the same, but those that visit cacti will be different.	Observational, comparative, biotic-biotic

LEADERSHIP STYLES

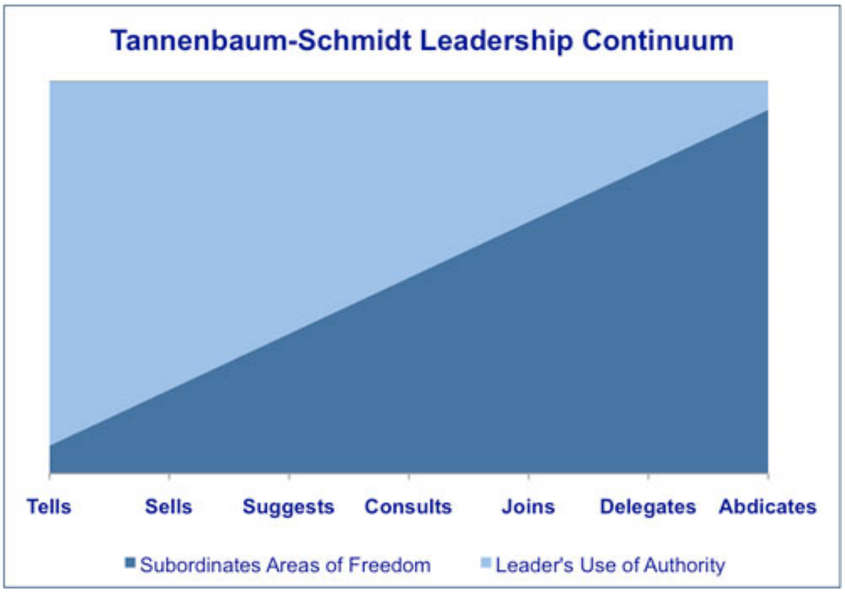
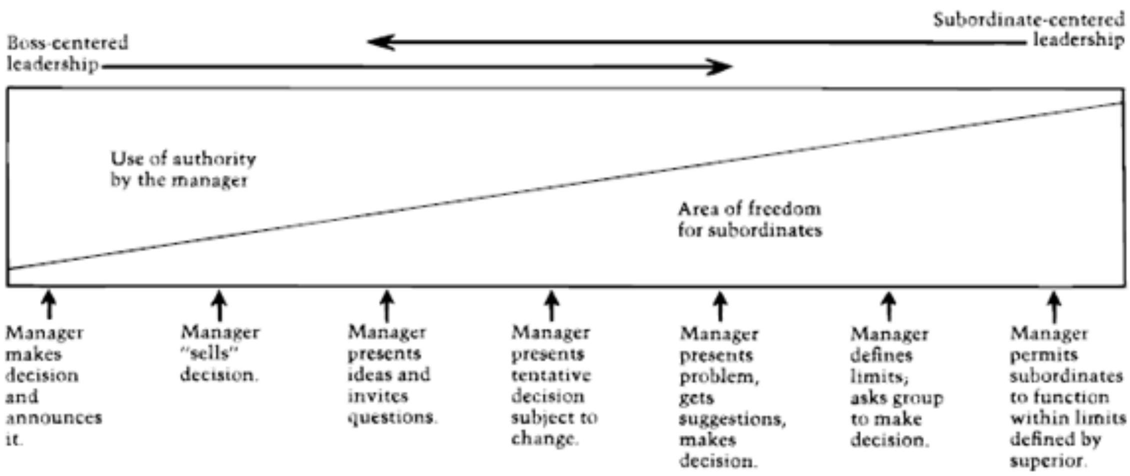


EXHIBIT I Continuum of Leadership Behavior



- “I put most problems into my group’s hands and leave it to them to carry the ball from there. I serve merely as a catalyst, mirroring back the people’s thoughts and feelings so that they can better understand them.”

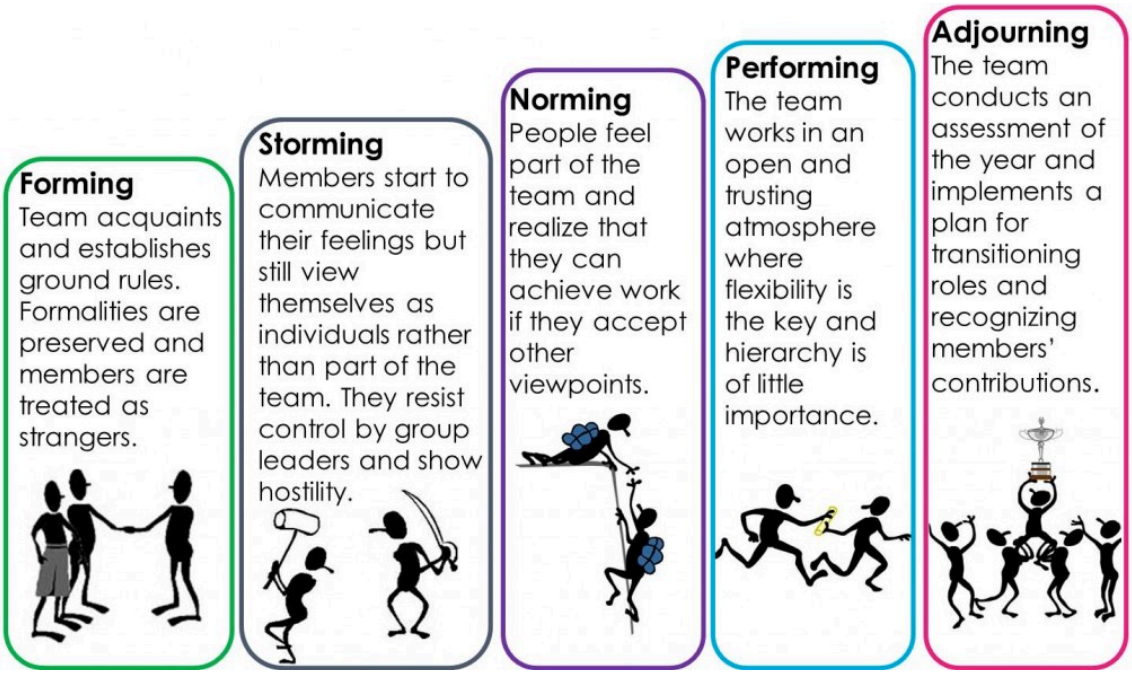
- “It’s foolish to make decisions oneself on matters that affect people. I always talk things over with my subordinates, but I make it clear to them that I’m the one who has to have the final say.”

- “Once I have decided on a course of action, I do my best to sell my ideas to my employees.”

- “I’m being paid to lead. If I let a lot of other people make the decisions I should be making, then I’m not worth my salt.”

- “I believe in getting things done. I can’t waste time calling meetings. Someone has to call the shots around here, and I think it should be me.”

SMALL GROUP DYNAMICS



Stage 1: Forming - In the Forming stage, personal relations are characterized by dependence. Group members rely on safe, patterned behavior and look to the group leader for guidance and direction. Group members have a desire for acceptance by the group and a need to know that the group is safe. They set about gathering impressions and data about the similarities and differences among them and forming preferences for future subgrouping. Rules of behavior seem to be to keep things simple and to avoid controversy. Serious topics and feelings are avoided. The major task functions also concern orientation. Members attempt to become oriented to the tasks as well as to one another. Discussion centers around defining the scope of the task, how to approach it, and similar concerns. To grow from this stage to the next, each member must relinquish the comfort of non-threatening topics and risk the possibility of conflict.

Stage 2: Storming - The next stage, which Tuckman calls Storming, is characterized by competition and conflict in the personalrelations dimension an organization in the task-functions dimension. As the group members attempt to organize for the task, conflict inevitably results in their personal relations. Individuals have to bend and mold their feelings, ideas, attitudes, and beliefs to suit the group organization. Because of "fear of exposure" or "fear of failure," there will be an increased desire for structural clarification and commitment. Although conflicts may or may not surface as group issues, they do exist. Questions will arise about who is going to be responsible for what, what the rules are, what the reward system is, and what criteria for evaluation are. These reflect conflicts over leadership, structure, power, and authority. There may be wide swings in members' behavior based on emerging issues of competition and hostilities. Because of the discomfort generated during this stage, some members may remain completely silent while others attempt to dominate. In order to progress to the next stage, group members must move from a "testing and proving" mentality to a problem-solving mentality. The most important trait in helping groups to move on to the next stage seems to be the ability to listen.

Stage 3: Norming - In Tuckman's Norming stage, interpersonal relations are characterized by cohesion. Group members are engaged in active acknowledgment of all members' contributions, community building and maintenance, and solving of group issues. Members are willing to change their preconceived ideas or opinions on the basis of facts presented by other members, and they actively ask questions of one another. Leadership is shared, and cliques dissolve. When members begin to know-and identify with-one another, the level of trust in their personal relations contributes to the development of group cohesion. It is during this stage of development (assuming the group gets this far) that people begin to experience a sense of group belonging and a feeling of relief as a result of resolving interpersonal conflicts. The major task function of stage three is the data flow between group members: They share feelings and ideas, solicit and give feedback to one another, and explore actions related to the task. Creativity is high. If this stage of data flow and cohesion is attained by the group members, their interactions are characterized by openness and sharing of information on both a personal and task level. They feel good about being part of an effective group. The major drawback of the norming stage is that members may begin to fear the inevitable future breakup of the group; they may resist change of any sort.

Stage 4: Performing - The Performing stage is not reached by all groups. If group members are able to evolve to stage four, their capacity, range, and depth of personal relations expand to true interdependence. In this stage, people can work independently, in subgroups, or as a total unit with equal facility. Their roles and authorities dynamically adjust to the changing needs of the group and individuals. Stage four is marked by interdependence in personal relations and problem solving in the realm of task functions. By now, the group should be most productive. Individual members have become self-assuring, and the need for group approval is past. Members are both highly task oriented and highly people oriented. There is unity: group identity is complete, group morale is high, and group loyalty is intense. The task function becomes genuine problem solving, leading toward optimal solutions and optimum group development. There is support for experimentation in solving problems and an emphasis on achievement. The overall goal is productivity through problem solving and work.

Stage 5: Adjourning - Tuckman's final stage, Adjourning, involves the termination of task behaviors and disengagement from relationships. A planned conclusion usually includes recognition for participation and achievement and an opportunity for members to say personal goodbyes. Concluding a group can create some apprehension - in effect, a minor crisis. The termination of the group is a regressive movement from giving up control to giving up inclusion in the group. The most effective interventions in this stage are those that facilitate task termination and the disengagement process.

LESSON PLANNING WITH THE 5E MODEL

Stage	Function	Description
Engage	Establish a Question	Pose a question that will drive the overall inquiry and provide a sense of purpose. The question should be comprehensible, relevant, & motivating.
	Capture the Students' Attention	Actively hook the students in to get them interested in the lesson and stimulates their thinking. Some ideas include: • Set up an interesting situation in the classroom (or observe one outdoors) and allow students to observe and discuss the situation • Sorting items into predetermined categories (e.g. various items sorted into magnetic or non-magnetic groups)
	Elicit Students' Initial Ideas	Invite students to share initial ideas about possible answers to the question. Help students connect previous knowledge to the new concepts introduced in the unit. Probe students' ideas to find out how they understand the question and what misconceptions they may have.
Explore & Investigate	Explore Phenomena for Patterns	Provide opportunities for students to explore scientific phenomena related to the question to find & understand patterns. This includes: • Conducting their own investigations or designing a prototype to test ideas • Time to think, plan, investigate, and organize information collected • Making & recording observations first hand (collecting evidence in order to back up any claims made) • Looking for patterns in observations Instructors observe and listen to students as they interact with each other and the information provided. Probing questions help students clarify their understanding and redirect their investigations when necessary.
	Explore Ideas About Patterns	Provide opportunities for students to share their ideas about patterns observed. This includes: • Sharing and supporting their ideas about patterns • Comparing/coming to agreement about observed patterns
Explain	Students Explain Patterns	Provide opportunities for students to express their ideas. Facilitate student discourse and help them focus on the goal of the lesson. They can: • Create graphs, charts, reports, diagrams, or sketches • Share their own explanations for the patterns (analyze & interpret data) • Provide evidence (from their own investigations and prior knowledge) supporting their claims • Share ideas of how their explanations answer the question. • Support or refute the claims of other students, using their own evidence
	Introduce Scientific Ideas	Provide accurate & comprehensible representations of the scientific idea(s). This is a grade level appropriate scientific explanation for the patterns students observed.
	Compare Student & Scientific Ideas	Help students compare their own explanations with the scientific explanation provided by the teacher. Students can compare, test & revise their own explanations. Students use the scientific explanation to answer the question.

Extend / Elaborate	Apply To Near & Distant Contexts with Support	Provide opportunities for students to apply the scientific explanation in new contexts to challenge their thinking. Initially, provide support through modeling & coaching. Students can answer questions about new experiences involving the same patterns & explanation. New questions can be similar to or different from the original question. Instructors remind students there are multiple solutions to real world problems. Encourage perseverance when challenges occur. Have students draw connections between STEM careers and their project work.
	Apply With Fading Support	Provide opportunities for students to apply the scientific explanation in new contexts with diminishing support from the teacher.
Evaluate	Demonstrate New Knowledge & Understanding	Encourage students to assess their understanding and abilities, as well as identify future directions for learning in relation to the topic. Assessment should be embedded throughout the lesson, as well as at the end of the lesson. More structured evaluation may include: • self-evaluation—reflecting on their own progress or knowledge, as well as the ethical, environmental, and social impacts of their new knowledge or solution to the complex question presented • peer reviews • journals • drawings • models • concept maps • performance-based tasks

5 E Lesson Checklist

Engagement
Did you design an activity that… ☐ captures students' attention? ☐ activates students' prior knowledge? ☐ connects to a complex question, global issue, challenge, or real world problem?
Exploration
Did you design an activity that allows students to… ☐ analyze the science, technology, engineering, mathematics, or other disciplines as appropriate in a complex question, global issue, challenge, or real world problem? ☐ apply a systematic approach (utilizing engineering design process or the scientific and engineering practices) to address the real world connection? ☐ select and employ technological tools that are relevant to answering a complex question, investigating a global issue, or developing solutions to a challenge or real world problem?
Explanation
Did you design an activity that allows students to… ☐ analyze data/information and draw conclusions? ☐ communicate understandings and possible solutions? ☐ use technology appropriately for analysis and communication?
Extension / Elaboration
Did you design an activity that allows students to… ☐ modify/refine procedures, prototypes, models, solutions, arguments, essays, etc.? ☐ analyze STEM careers that relate to the learning activity?
Evaluation
Did you design an activity that allows students to… ☐ demonstrate understanding of concepts through performance-based tasks? ☐ participate in peer reviews? ☐ reflect on answers or solutions to the complex question, global issue, challenge, or real world problem?

Sense of place activities

Silence - quiet thinking alone. Send students off to find a spot that they feel at home in. Have them sit alone, no talking, for 5-10 minutes. When they come back, ask them to share one thing they noticed or thought of in that place.

Meet a tree. In pairs. Student 1 walks Student 2 (blindfolded, and disorientated via spinning around) to a nearby tree. Student 2 can touch/smell/taste that tree. Student 1 then walks Student 2 to another location and then removes blindfold. Student 2 must use their senses to discover which tree they 'met'. Can be paired with dichotomous key / identification activities after the tree is identified. Close with group circle with all student pairs to talk about what aspects of sense made it possible to find their tree.

Sound map. Each student takes a sheet of paper and sits somewhere silently for five minutes. Any sound they hear in front, draw on the top of the page; to the left, on the left of the page, etc. Sounds can be drawn as cartoons or words, with distances from page center proportional to distance in the field. After some time, bring students back together and discuss unexpected sounds, unique sounds that only one student heard, etc.

Close observation drawing. Choose a small scene the size of your hand. Have each student draw it as carefully as possible for 5 minutes. Swap drawings with other student and see if they each noticed something different.

Guided poem. Write a word in capital letters down the left side of the page (e.g. student's name). For each letter, write a line of a poem starting with that letter about the field site. Share poems from volunteers.

Paired drawing. Students in pairs stand back to back. One student describes what they see in as much detail possible to the other, who then draws it. Then exchange and repeat in the other direction. At the end, both students exchange drawings and see how accurate they were.

Time drawings. Take a sheet of paper and divide it into three horizontal sections. In the top, ask students to draw the landscape as it looks today. In the middle, draw it (in winter / in summer / 500 years ago / 1000 years ago) using their imagination. In the bottom, draw it (1 million / 10 million / 100 million years ago). Share drawings and use to scaffold further lessons on landscape change.

"I am like…" poem. Ask students to choose an object, then write a sentence, I am like [my object] because…. Repeat for 10 objects. Share the final poems.

Differences from home. Write or draw differences between this landscape and the student's neighborhood at home.

Free write. Start writing about the first thing that comes into your mind and don't stop, not even for punctuation or if the mind blanks. Requires good setup for students to feel comfortable.

How to keep a field notebook. Choose an item to draw/diagram. Talk about the importance of keeping notes, i.e. arrows to label sections, date/time/name, species ID, descriptive notes, and so on. Practice on an object, then have students choose a scene of their own.

Natural art. Have students collect materials such as twigs, leaves, pointed rocks. Challenge them to build a sculpture / make a painting / design an animal's home using the objects. Share the final pieces with other small groups of students.
See: http://www.youtube.com/watch?v=kGFOLChNOak (Andy Goldsworthy)

Draw-a-comic. Have students tell the story their day in the landscape or an adventure they are having (or what an animal is doing). Have a small group draw the story in cartoon-panel form.

RESOURCES

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5E LESSON PLANS
http://moodle.oakland.k12.mi.us/os/pluginfile.php/75151/mod_page/content/5/Documents/Inquiry_Application_5_E_Model.pdf
Enhancing Education—the 5 E's: http://enhancinged.wgbh.org/research/eeeee.html
Maryland State Dept. of Ed., STEM Centric Unit and Lesson Template:
http://mdk12.msde.maryland.gov/instruction/curriculum/stem/pdf/stemcentricunittemplate.pdf
STEM Lesson Planning Template Using the 5-E Model:
http://www.usd383.org/home/showdocument?id=2054
5E Model Science Lesson:
http://www.virginia.edu/blandy/blandy_web/education/Bay/5ELessonExamples.pdf

SENSE OF PLACE
https://skyschool.arizona.edu/skyschoolwiki/index.php?title=Sense_of_place_activities
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