Teaching Critical Thinking Skills in Science with sInvestigator

NSF 1611742 Project Outcomes Report

The main outcomes of this project are:

- An inquiry-based approach to helping students learn critical thinking skills for solving scientific problems.
- A computational theory of evidence-based reasoning in science that forms the basis of this approach.
- An intelligent computer system, called sInvestigator (science Investigator), that implements the computational theory, greatly facilitates the development of inquiry-based exercises by instructors, and provides a hands-on learning experience to students.
- Sample exercises for students from middle school through university.

The developed inquiry-based approach engages the students in understanding, extending, creating, critiquing, and debating evidence-based scientific argumentations in real-life scientific investigations. It involves using science cross-cutting concepts and disciplinary core ideas, giving the students numerous opportunities to exercise imagination and creativity, and develop critical scientific practices, particularly: (1) Asking questions; (2) Constructing explanations; (3) Engaging in argument from evidence; and (4) Obtaining, evaluating, and communicating explanations.

Figure 1 presents the developed model of scientific inquiry as discovery of evidence, hypotheses, and arguments which is implemented in sInvestigator. For simplicity, Figure 1 shows only two hypothesized answers but the actual number depends on the specific scientific inquiry considered.

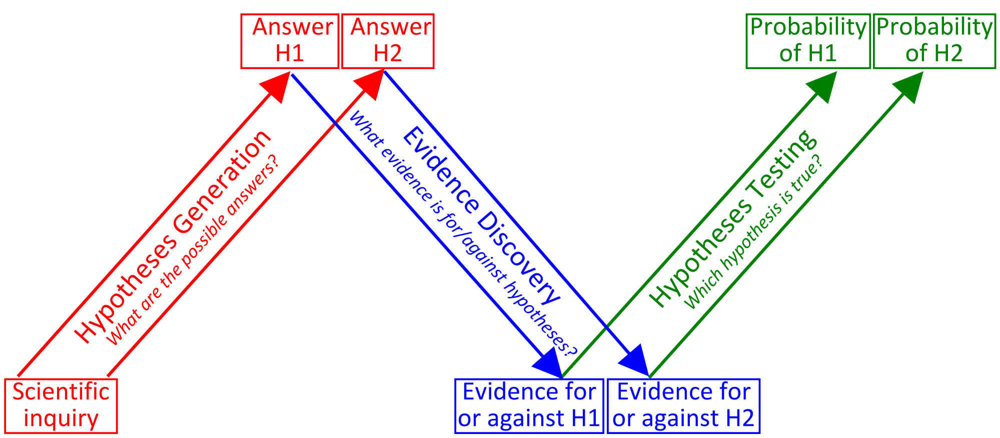

Figure 1. Scientific inquiry as discovery of evidence, hypotheses, and arguments.

A classical textbook example of using inquiry in a science class is presented in "Inquiry and the National Science Education Standards: A Guide for Teaching and Learning," pp.5-11, National

Research Council, 2000, Washington, DC: The National Academies Press. https://doi.org/10.17226/9596. Figure 2 illustrates an adaptation of this example to show how sInvestigator can naturally support inquiry-based teaching and learning.

The process started with the instructor formulating the scientific inquiry (Why are these three trees different? They used to be the same.), and challenging the students to imagine possible answers, leading to the following hypotheses:

- It must be too much water that causes a tree to die.
- Insects are eating two of the trees.
- The trees have different ages.

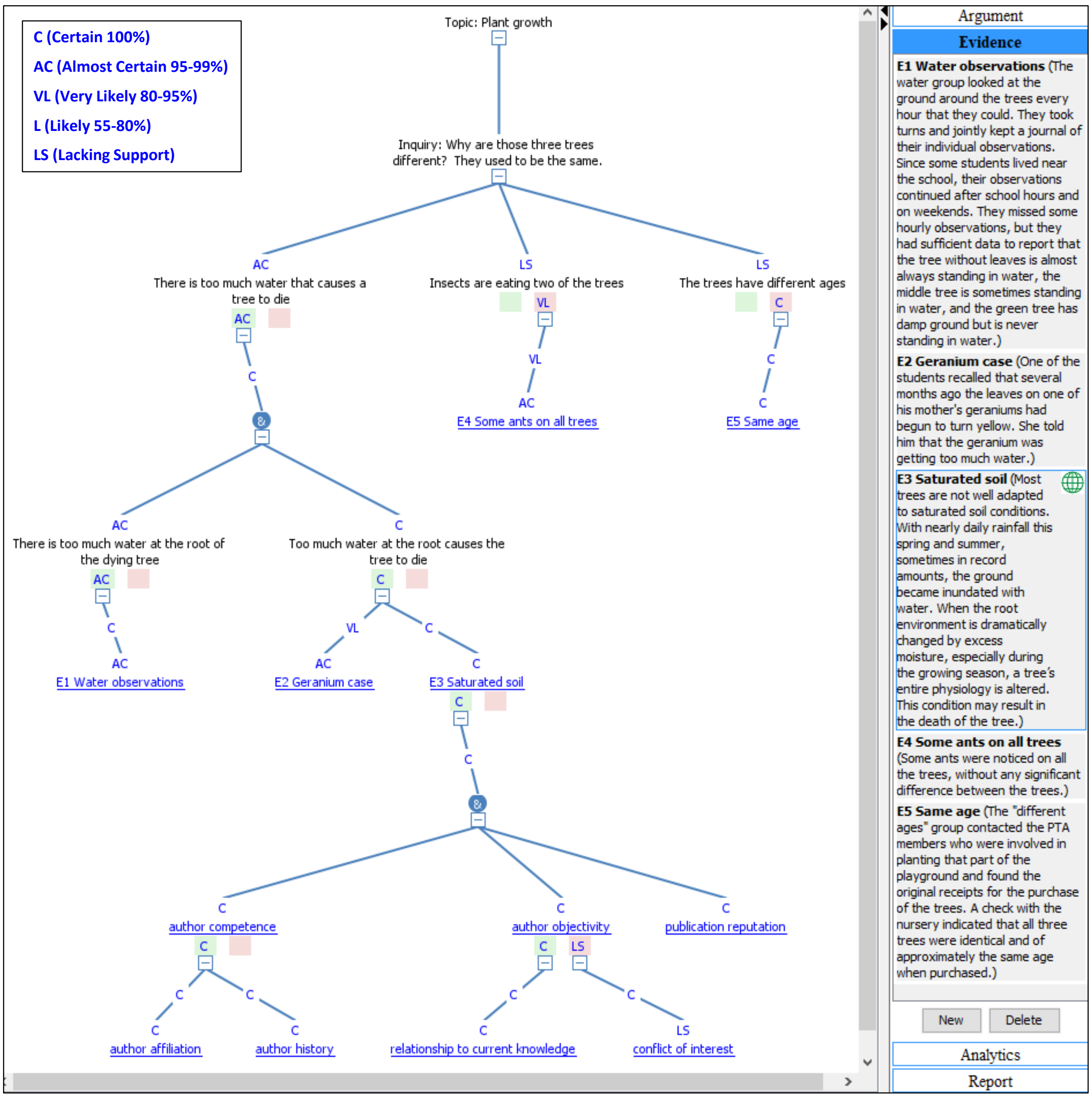

Figure 2. Inquiry representation in the interface of sInvestigator.

The students were then invited to pick a hypothesis which led to three groups, a “water” group, an “illness” group, and an “age” group. Each group carried out its investigation, discovering a variety of sources with information about characteristics of trees, their life cycles, and their environments. The “water” group that investigated the first hypothesis decomposed it into two simpler sub-hypotheses that showed more clearly what evidence may be used to test them:

- There is too much water at the root of the dying tree.
- Too much water at the root causes the tree to die.

To discover evidence for the first sub-hypothesis, the group decided to look at the ground around the trees every hour that they could, taking turns on making individual observations, until they had sufficient data indicating that there is too much water at the root of the dying tree. An evidence item for the second hypothesis was found on the Internet.

The team then assessed and justified the credibility and relevance of the discovered evidence. They also conducted a deeper credibility analyses of the Internet article by assessing author’s competence (affiliation and history), objectivity (relationship to current knowledge and conflict of interest), and publication’s reputation. Then sInvestigator computed the probabilities of all the hypotheses and generated a draft report. The team finalized the report and debated it in class.

sInvestigator was experimentally used in the following undergraduate honors science courses for non-science majors at George Mason University: HNRS 353 Modern Scientific Revolutions, HNRS 353 Science of Cities, and HNRS 240 History of Science. Case studies for middle school and high school science classes have also been developed.

The sInvestigator website (http://lac.gmu.edu/sInvestigator/index.html) is maintained as the most complete and up to date repository of information on our research on teaching critical thinking in science, including instructions to download the most recent version of the system for both PC and Mac. It contains a wide variety of exercises for representative inquiry-based experiences, such as: Analysis of competing scientific theories; Predicting, observing and explaining the result of an experiment; Explaining a physical phenomenon; Classifying an entity (e.g., organism or a rock); Arguing about a socio-scientific issue; Exploring a mystery. The report “Inquiry-based Teaching of Critical Thinking Skills in Science with sInvestigator” (http://lac.gmu.edu/publications/2021/sInvestigator-Report.pdf) presents several of these exercises.

While we researched the teaching and learning of critical thinking skills in science, the developed approach and sInvestigator support the teaching and learning of the general theory of evidence-based reasoning which is at the core of many problem solving and decision making tasks in a wide variety of domains, such as cybersecurity, law, intelligence analysis, forensics, medicine, history, archaeology, and many others. This is a core competency which is important for any person, in any area of activity.