# Scientific Reasoning for Pre-service Elementary Teachers

Homeyra R. Sadaghiani

*Department of Physics, California State Polytechnic University, Pomona, CA 91768*

**Abstract.** The objectives of K-12 teacher education science courses often focus on conceptual learning and improving students overall attitude towards science. It is often assumed that with the use of research-based curriculum material and more hands on inquiry approaches, without any explicit instruction, student scientific and critical thinking skills would also be enhanced. In the last three years, we have been investigating student scientific and evidence-based reasoning abilities in a K-8 pre-service science course at Cal Poly Pomona. After recognizing student difficulties understanding the elements of scientific reasoning, we have provided explicit feedback using a rubric to assist students to become more rigorous and reflective thinkers; to use appropriate and accurate vocabulary; exercise evidence-base reasoning; and develop skepticism with respect to their own views. We will share the rubric and report on the preliminary results.

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## INTRODUCTION

In current education, an essential approach to learning science is concerned less with accumulating raw facts and scientific definitions and procedures, than with learning to think scientifically. It is imperative to think critically, organize knowledge and facts, learn appropriate terminologies, assess relevant scientific data, and clearly interpret them to reach a robust scientific conclusion. It is also important to recognize the assumptions as well as the implications and communicate them effectively with others.

In teaching physics, it is generally assumed that over the course of learning the content and problem solving, students also acquire adequate thinking and reasoning skills. Nevertheless, research shows that learning the content knowledge does not necessarily impact student scientific reasoning ability.[1] Although many instructors recognize the crucial role of scientific thinking skills and implement rigorous hands on activities that follow the cycle of scientific reasoning (observation, prediction, hypotheses, etc.), in practice however, the emphasis often has been on teaching content of a specific discipline.[2] The implicit teaching of thinking skills has rarely been effective in promoting students scientific reasoning ability.[3] According to the literature it is possible to instruct students to develop transferable thinking skills through a series of well-planned exercises that require students to practice critical thinking and simultaneously demonstrate their progress in achieving these complex skills explicitly.[4-6]

The philosophical traditions of Socrates, Plato, and Aristotle gave rise to the scientific thinking characterization we use today. In scientific thinking, a huge emphasis is on the use of evidence and what matters the most is the reason for ones belief and its implications.[7] In the process, the thinker improves the quality of his or her thinking by skillfully taking charge of the structures inherent in thinking and imposing intellectual standards upon them.[8] Thus, by evaluating self-thought process, identifying the different elements of scientific reasoning, and weighing the evidence, one could improve his or her thinking skills. This attribute infers that the development of one's critical thinking ability is through metacognition, thinking about one's thinking and consciously trying to improve it by reevaluating the thought processes. We applied this framework to improve student scientific thinking skills in the context of a pre-service physical science course.

In this study, we first explicitly introduced the basic elements of the scientific reasoning and analyzed several examples of good and bad reasoning in class discussion. Then, we asked students to identify these elements within their own reasoning in context of different assignments. In particular, we required students to evaluate their own written responses to pretests they took for each course module and improve their responses in terms of use of evidence, appropriate and accurate vocabulary, and logical reasoning with some feedback from the instructor and their peers. On this paper, we discuss the background and motivation for the study, share the rubric students used for

**TABLE 1.** An exemplary portion of the Thinking About Thinking rubric.

| | | For each item, assign a √+ (outstanding), √ (adequate), √- (needs improvement) or 0 (missing or clearly inadequate). | | | |
|---|---|---|---|---|---|
| | | **Relevance** | **Clarity** | **Vocabulary** | **Adequacy** |
| **Claims** | Identify the claims in your reasoning and write in the space below. | | | | |
| | | | | | |
| **Assumptions** | Identify the assumptions in your reasoning and write in the space below. | | | | |
| | | | | | |
| **Evidence** | Identify the supporting evidence for your claims (data, observation, or previously accepted principles) and write in the space below. | | | | |
| | | | | | |

evaluating their written responses, and discuss preliminary data on the first time use of the rubric.

## BACKGROUND AND MOTIVATION

This study involved pre-service teacher education course (SCI 210) for twenty-four liberal art majors at Cal Poly Pomona. This hands on activity course is one of the three-quarter required science courses and covers topics such as properties of matter, heat and temperature, energy, and light and colors. In last three years, we have been collecting data on student learning of the content, scientific reasoning abilities, as well as their attitude towards science and learning by inquiry. [9,10] Students in this course are somewhat underprepared; have little or no preparation in science, and some even express an aversion to science in general or state repeatedly that they are "not good in science."

As a natural part of an inquiry approach in this course, students were regularly guided through activities that followed the cycle of scientific methods and required scientific reasoning using experimental observations and logics. However, some students had difficulties understanding the structure of a scientific explanation: their reasoning often lacked the basic elements of scientific arguments, rarely used data and observations as evidence, nor followed a chain of logical reasoning to drive conclusions. For example, they frequently restated their answers using different wordage as their reasoning and explanations or skipped the reasoning sections of the assignments all together. To address these difficulties, we have designed a formative rubric called Thinking About Thinking (TAT) to help students to improve the quality of their reasoning by allowing them to take charge of their own progress.

## THINKING ABOUT THINKING

The TAT formative assessment rubric, unlike summative rubrics does not tell students what they did right or wrong, it does not necessarily include what an expert example looks like either. The TAT rubric is an assessment of self-learning in which the goal is to provide feedback for immediate improvement of one's learning process. [11] The TAT is developed to help students to evaluate their own answers and reasoning in an inquiry-based learning environment. By using TAT students utilize iterative cycles of evaluation, feedback, and revisions, to improve their own reasoning.

There are many suggestions for a list of skills experts see essential for critical and scientific thinking. [12] Here we adopted a selected list of thinking skills we found essential to scientific reasoning. Originally, we started with a very basic rubric that only included claims, assumptions, evidence, and clarity of the expressions. After a few class experiences with the rubric, we added additional components such as relevance, vocabulary precision, and adequacy to the original version of the rubric.

In this study, students first learned about the essence of scientific thinking and worked in-groups of two to analyze some good and bad examples. Students were asked to highlight each sentence of the given example and, using the TAT rubric, deconstruct the statements in order to identify the hidden elements of the scientific argument in each case. Later, in many occasions students evaluated their own written reasoning statements to make sure the inclusion of scientific reasoning elements in their thought process. In addition, they rated the relevance, clarity, and adequacy of each of their statements. Finally, students made several revisions with the feedback from the instructor and their peers to improve the quality of their reasoning.

Table 1 illustrates the first part of the TAT rubric in which students identify, present, and rate the different parts of their own reasoning elements. In the second part of the rubric (not shown here) students modify any reasoning statements that did not receive a perfect rating (√+) and with the feedback from the instructor and their peers try to advance the quality of their reasoning to more scientifically sound ones.

We used the TAT rubric to examine the presence of the different reasoning elements such as claims, assumptions, and evidence in student papers. Furthermore, we evaluated the relevance, clarity, use of accurate and precise vocabulary, and the logical

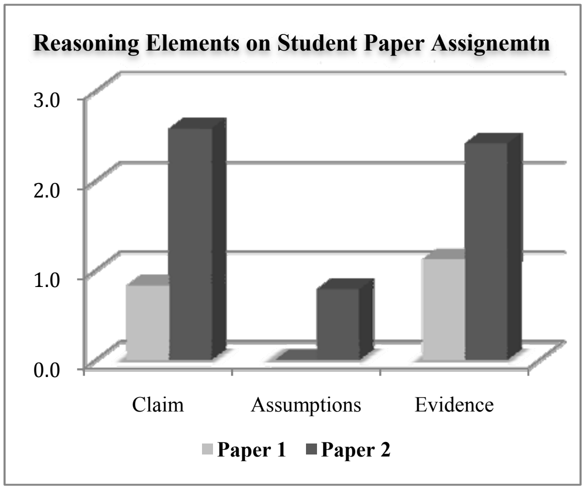


**FIGURE 1.** Bars represent the average number of the times each reasoning elements was present in student writing assignments (regardless of their competence.)

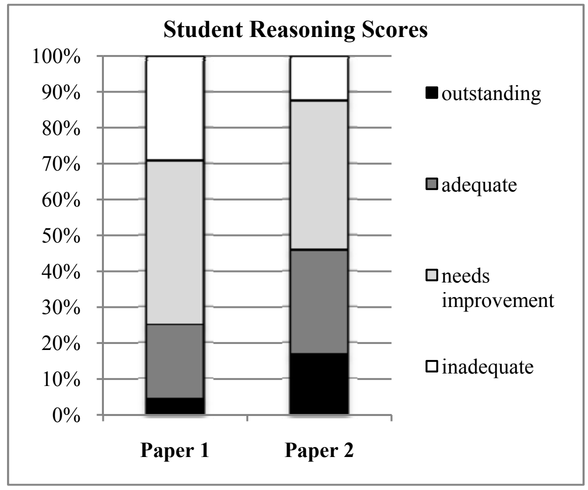


**FIGURE 2.** Bars represent the percentage of the students whose paper assignment received scores shown at the right side of the figure (n=24).

## RESEARCH STUDY

We introduced the TAT rubric to SCI 210 students right after students completed their first paper assignment (beginning of the fourth week). The objective was to provide a formative feedback to help students to develop and improve their scientific reasoning ability and by reflecting on their own thought process, recognizing the different components of reasoning, evaluating and weighting these components against the elements of a standard scientific argument, and filling up the gaps in between. Students used the rubric for several different assignments throughout the quarter including their responses to two course midterm examinations, some of the homework exercises, and pretests for each course module.

The effect of the TAT rubric was measured by the analysis of the two short paper assignments (5-7 pages) in week 3 (before TAT was introduced) and later in week 10. Both writing assignments required students to reflect on their learning and asked them to describe a sequenced series of observations and experiments that led to their understanding of particular topics. The first paper was focused on the concepts of sinking and floating and the second one was on topics of heat and temperature.

flow. Figure 1 shows the average number of the times students used each reasoning element throughout each paper. On this bar graph we have only considered the presence of the different elements rather than evaluating their quality, accuracy, or the adequacy. Over all students demonstrated a higher competence level on stating their claims, recognizing the assumptions, and using classroom observations as their supporting evidence on the second paper. For example, on the second paper students more often explicitly identified the claims they were supporting by restating them either at the beginning or the end of their arguments (from 0.8 to 2.6 times in average); they referred to class observations as their evidence noticeably more frequently (from 1.1 to 2.4 times in average); and began to overtly state the assumption, something that was totally missing on all the first paper assignments. The competence was not built up simultaneously for all the elements and the changes followed a different pattern for each part of scientific reasoning. For instance, there was a larger change on how often students stated their claims than identified their assumptions. In addition, the number of the irrelevant statements was noticeably decreased and students used relatively more precise vocabulary on their second writing paper compared to the first one.

Although the structure of student ideas was improved and contained more of the essential elements of the scientific reasoning, the clarity of each statement and the way they were connected to the previous and the next idea were still lacking adequate lucidity on the second paper assignment. Most of the reasoning elements, although present, were isolated and the logical connection among theses components was loose or missing. In many cases, the adequacy of the reasoning statements was not sufficient or compelling.

To assign grades and to compare student pre and post rubric paper assignments more carefully, we scaled the √+ (outstanding) to 3 points, √ (adequate) to 2 points, √- (needs improvement) to 1 point, and assigned 0 for missing or clearly inadequate reasoning statements. The students received "outstanding" (average scores of 2.5-3.0), "adequate" (average scores of 2.0-2.5), "needs improvement" (average scores of 1.5-2.0), or "inadequate" scores for less than 1.5 pointes scores. Figure 2 shows the percentage of the students receiving each of the possible four scores. These results reflect some improvement in the quality of students' reasoning in the second paper when compared to the first one. The darker bottom portion of the bars represents the percentage of the students who received perfect scores. Notice the increase in the height of the black bars on paper 2 (from 4% to 17%) suggesting more students demonstrated outstanding level of reasoning and the decrease in the white ones (from 29% to 13%) showing less students had submitted inadequate work. Although the number of the times students referred to class observations and identified claims and assumption was increased on paper 2, in some cases the logical connection among the ideas were missing and or the observation and class experiment was only merely mentioned rather than specifically being used to support the student ideas. As a result, still more than 40% of the students needed improvement in their reasoning abilities (light gray portion of the bars) and 13% (white portion) were clearly presented inadequate statements in their papers even after using the TAT rubric (see Fig. 2**)**

## DISCUSSION

Through inquiry activities, students gather observable, empirical and measurable evidence subject to specific principles of reasoning; however, they do not explicitly think about the process of their learning and the different stages of reasoning that leads to concluding physical principles they use later. In this study, the use of TAT provided a shared concept of scientific thinking and entailed higher cognitive skill levels than merely knowledge and comprehension. [13] The mechanism for this rubric is an explicit recognition and evaluation of one's thought process through meta-cognition; the thinker continually and rigorously check her or his thinking to mold it to standards of excellence.

The preliminary data shows some improvement on student ability to recognize the necessary components for a well-reasoned argument and acknowledge the significant role of data and observations in scientific reasoning. Furthermore, the use of TAT encouraged students to utilize the essential elements of reasoning in their own reasoning more often. Over all TAT led to some positive effect in student reasoning in the context of the course paper assignments. After using the TAT rubric, students used class observations as evidence for their reasoning, and identified claims and assumptions more often; however, sometimes the logical connection among the ideas were missing or the use of evidence was merely limited to a list of experiments without a detailed explanation on how the observations in the given experiment would support their reasoning. Over all, we did not observe a significant shift in refinement, adequacy, and clarity of student logical reasoning.

Critical reasoning and scientific thinking is a complex activity that requires the coordination of many high-level cognitive skills, inductive, deductive, and logical reasoning. Additionally, it requires a good comprehension of the problem, use of observation, drawing inferences, and precision in language, all of which requires great deal of practice and time for development. Perhaps there was not sufficient time or practice for the full development of scientific reasoning skills over the period of seven weeks students used the TAT rubric.[14] Also, we suspect regardless of our efforts, some students perceived the rubric more as a checklist rather than a tool for improving their reasoning. Finally, the TAT rubric is a work in progress and we plan to modify it to include the coherency and the reasoning links among different ideas in the scientific argument more explicitly.

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