Thinking Like A Scientist About Real-World Problems:
The Cornell Institute for Research on Children Science
Education Program

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Abstract

We describe a new educational program developed by the Cornell Institute for Research on Children (CIRC), a
research and outreach center funded by the National Science Foundation. Thinking Like A Scientist targets students
from groups historically underrepresented in science (i.e., girls, people of color, and people from disadvantaged
backgrounds), and trains these individuals to reason scientifically about everyday problems. In contrast to
programs that are content based and which rely on disciplinary concepts and vocabulary within a specific domain
of science (e.g., biology), Thinking Like A Scientist is domain-general and attempts to promote the transfer of
scientific reasoning. Although the full evaluation of Thinking Like A Scientist must await more data, this article
introduces the conceptual basis for the program and provides descriptions of its core themes and implementation.
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“Scientific thinking tends to be compartmentalized, viewed as relevant and accessible only to the
narrow segment of the population who pursue scientific careers. If science education is to be
successful, it is essential to counter this view, establishing the place that scientific thinking has in the
lives of all students. A typical approach to this objective has been to try to connect the content of
science to phenomena familiar in students’ everyday lives. An ultimately more powerful approach
may be to connect the process of science to thinking processes that figure in ordinary people’s lives”
(Kuhn, 1993a, p. 333).

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Psychology honoring the professional legacy of Rodney R. Cocking. It is dedicated to his memory.
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1. Introduction

When the first author of this article was in school, back in the Pleistocene era, the science curriculum was rich in content. Lesson after lesson explored the phylogeny of mammals, plate tectonics, the moons of Jupiter, principles of botany, white blood cells, and disease—you name it. This author attended a high school specializing in science, then went on to major in science in college. Despite this intensive scientific steeping from ages 6 to 22, however, not once were strategies for thinking scientifically ever articulated and elucidated as such. Students were thought (and hoped) to extract such principles of scientific reasoning as a result of in-depth instruction in specific content. Some did (and many of them enjoy science to this day, using scientific thinking in their personal and professional lives), but others did not, and for this group, the specifics of the science lessons they learned are long forgotten. Quite frankly, even for those students who managed to extract the principles of scientific thinking and ultimately pursued careers in science, our memories of the content of the lessons we were taught are generally fuzzy at best. It is enough to make one wonder whether the way science is taught could potentially be improved so that, ideally, all students are left with a set of tools they can use to help them think rigorously and scientifically throughout their lives about a whole range of problems and issues, both professional and personal. Having a set of scientific thinking tools as students leave 12th grade would be optimal, even for those who do not pursue science education beyond high school.

It was precisely this thinking that motivated the educational program developed by the Cornell Institute for Research on Children (CIRC), which is called Thinking Like A Scientist. Thinking Like A Scientist seeks to reach students through innovative materials that train thinking and reasoning in the scientific method about problems in daily life. These skills, in particular, are associated with intellectual achievement and success in high school, college, and everyday life. Thinking Like A Scientist exercises taught by science and/or social science teachers focus on the following themes central to scientific reasoning applied to practical problems: (a) Ask the question: “What is science?”; (b) Define the problem: See many sides; (c) Distinguish fact from opinion: What constitutes evidence?; (d) Weigh evidence and make decisions; (e) Move from science to society; and (f) Revisit, reflect, and review. Through the lessons taught as part of this project, we hope to impart an understanding of how to analyze problems and think scientifically about everyday real-world problems. Our lessons also show how science can appropriately be used to inform public policy—they discuss how science impacts our society by contributing to policy decisions that affect all of us. Our lessons provide students with the scientific thinking tools we believe are essential to effective decision making in daily life.

An important goal of this work is to seek ways to increase the representation in science careers of girls, people of color, and people from less-privileged backgrounds. In particular, we hope to encourage these students to continue their education beyond high school and possibly pursue careers in science in the future. To accomplish this goal, the program (a) utilizes lesson content that will interest students who may have been turned off to more traditional science instruction in the past, (b) incorporates discussions and activities that relate the material to students’ daily lives, (c) seeks students who match the demographic profile by working within schools in geographic areas that match this profile, and (d) concludes each lesson with an informational section on a variety of science careers and occupations. The explicit goal of this last aspect of the program is to raise students’ awareness of the various career options available, together with providing information about the training these careers require and how one can obtain this training despite economic hardship.
We begin the description and evaluation of this program by reviewing the research on the development and training of scientific thinking, then move to discussing the concept of transfer of knowledge and its relevance to our goals. An actual lesson from our program is presented to show how the scientific thinking themes are instantiated in actual classroom activities. We analyze the problems and issues concerning the assessment of scientific thinking and show how we are evaluating students. Finally, we describe our goals for the upcoming years during which we will continue to develop and implement this instructional program.

2. Background

2.1. Literature on teaching scientific thinking

To better understand how students can be taught how to think scientifically, it is helpful to understand how researchers, whose findings inform teaching practices, study the development of scientific reasoning. Koslowski (1996) distinguishes two prominent approaches to studying this development. The first approach focuses on content knowledge and conceptual reorganization. The alternative approach explores strategies used for informal hypothesis testing that are not specific to any content area. In her review of the literature on the development of scientific reasoning skills, Zimmerman (2000) provides a succinct overview of these domain-specific and domain-general approaches. The domain-specific approach requires the use of conceptual knowledge to solve a task in a particular domain of science. For example, in their study of participants’ reasoning about scientific processes, Miller and Bartch (1997) asked children and college students to consider the changeability of and explanations for biological, psychological, and mechanical functions. Pauen (1996) used a weight-pulling task to test children’s and adults’ interpretations of the physics of motion by requiring them to reason about the interaction of forces. Moreover, Hood (1995, 1998) tested children’s reasoning via a displacement task that explored participants’ theories about gravity. Of interest to practitioners of this approach are conceptual changes, misconceptions, and the content and structure of naïve mental models that people hold about particular scientific phenomena (Zimmerman, 2000).

Contrary to the domain-specific approach, the domain-general approach to studying scientific thinking investigates experimental design and hypothesis testing. Of primary interest to this approach is the development of reasoning skills about causal relationships that are transferable to other domains of knowledge (Zimmerman, 2000). Accordingly, proponents of this approach have used multiple methods to investigate participants’ coordination of theories and evidence, which is considered requisite for the development of scientific thinking skills (e.g., Koslowski, 1996; Kuhn, Garcia-Mila, Zohar, & Anderson, 1995). For example, Kuhn, Amsel, and O’Loughlin (1988) and Koslowski (1996) presented participants with evidence that was embedded within hypothetical scenarios (e.g., development of a stain remover; strategies to increase book sales) to investigate their evaluation of evidence (with and without the influence of preconceived theories), their interpretations of causal relationships (i.e., by manipulating the covariation and independence of evidence), and their interpretations of divergent evidence. Researchers have also advocated the exploration of domain general strategies without disregarding participants’ domain-specific content knowledge (e.g., Kuhn, 1993a). Novel methodologies that have been employed by researchers include the use of the microgenetic method to study participants’ development of scientific reasoning strategies (Kuhn et al., 1995; Siegler & Crowley, 1991) and the examination of children’s and
adults’ strategies for generating and interpreting evidence in the context of self-directed experimentation (Schauble, 1996).

Akin to the dichotomy in the scientific reasoning literature, of primary concern to both researchers and science educators is how to best bring together domain-specific content with generalizeable reasoning strategies (e.g., thinking with the scientific method). One common theme is the importance of linking science to real-world contexts. Such strategies recognize the significance of scientific thinking beyond the context of science itself (Kuhn, 1997). In this view, a number of researchers have emphasized the links between scientific and informal reasoning (Kuhn, 1993a, 1993b), recognizing the similarities between the latter and scientific inquiry in terms of the ways in which, for example, scientists utilize rules of argumentative thinking to communicate scientific claims (Jimenez-Aleixandre, Rodriguez, & Duschl, 2000) and coordinate theory with supporting and divergent evidence (Bell & Linn, 2000). Our educational program also emphasizes the multiple links between scientific and everyday thinking and reasoning; in fact, we built upon these links to derive the six themes underlying the program, which represent metacognitive strategies for thinking like a scientist about real-world problems.

2.2. Training metacognition and academic success

Over the past 20 years, research on higher order thinking skills has established a firm connection between metacognitive skills and academic success. For example, metacognition has been associated with both intelligence (Sternberg, 1986) and improved learning (Borkowski, Carr, & Pressley, 1987). In this light, and as educators recognize the importance of students’ ability to transfer knowledge and skills across multiple contexts (e.g., Halpern, 1996), the training of metacognitive skills has become an increasingly important component of children’s education. Within specific domains, researchers have investigated metacognitive skills training in, for example, mathematical problem solving (e.g., Desoete, Roeyers, & De-Clercq, 2003), reading (e.g., Schmitt & Hopkins, 1993), and memory (e.g., van-Ede, 1996).

In the scientific domain, approaches to teaching metacognitive skills (i.e., teaching students to think scientifically) can be broadly grouped into two camps. In one method, students are instructed in the content of particular domains of science with the expectation that they will extract the scientific thinking process on their own. This way of teaching is reminiscent of the more traditional, teacher-centered, instructional style in which students are taught facts about science, participate in domain-specific activities, and conduct experiments without explicit training in scientific thinking. For example, in many science courses, students participate in experiments based on given hypotheses intended to generate a priori outcomes. Although such lessons do inform students of the processes that scientists use in experimentation, they neglect to definitively teach the higher order metacognitive skills required for authentic scientific inquiry (i.e., generation of hypotheses, evaluation of evidence). This approach is much like the implicit instructional styles that have been used to teach the nature of science, of which scientific thinking is an integral component. In that curriculum structure, students are expected to gain an understanding of the nature of science through instruction that excludes an explicit explanation of that concept (see Khishfe & Abed-El-Khalick, 2002).

More recently, researchers and educators have emphasized the integration of scientific thinking skills with the concepts of particular domains of science. In this process, metacognitive skills are explicitly infused with content. The impetus for this change in ideology was recognition that implicit teaching styles were deficient in endowing students with more generalized scientific thinking skills. The realization of the need for educating students in higher order skills that transfer to multiple domains...
of science, reflected in the 1996 *National Science Education Standards*, has led to the continuing development of many innovative approaches to teaching scientific thinking. Notably, the majority of programs aimed at explicitly teaching scientific thinking make use of computer simulations because, as noted by de Jong and van Joolingen (1998), learning via computer simulations is closely related to the constructivist scientific discovery learning process (e.g., Klahr & Dunbar, 1988).

For example, Hollingworth and McLoughlin (2001) developed an online environment, *metaHEAD*, to promote metacognitive skill development in university science students. This approach was predicated on the assumption that science students may be limited in the quantity of knowledge they can acquire within a given domain and it is therefore more important to impart more generalized thinking skills that students can transfer to future learning situations (Hollingworth & McLoughlin, 2001). The online program utilizes constructivist educational design principles to present simulations within a series of phases during which students are taught problem-solving skills, tested for transfer of the skill, and ultimately reflect on their own reasoning. The Instruction in Scientific Inquiry Skills (ISIS), part of the Air Force Fundamental Skills Training Project, employs a similar stepwise approach to teaching thinking skills that are applied to the context of ecology (e.g., Steuck & Miller, 1997). ISIS uses computer simulations to teach middle- and high-school students to form hypotheses, design experiments, and draw conclusions about problems contextualized in real-world scenarios. Non-technologically-based programs include training students in argumentation in the context of genetics (Zohar & Nemet, 2002).

Regardless of the medium of instruction, the overall goal of the integrative approach is to train students in scientific inquiry as it is carried out in authentic science (e.g., Dunbar, 1995; Schunn & Anderson, 1999; and see special section of *Science Education, Volume 86*(2), 2002, devoted to teaching authentic inquiry in science classrooms).

### 2.3. Transfer of scientific knowledge

Typically, when students’ learning about scientific thinking and reasoning is evaluated, an unfortunate finding is that the learning seldom generalizes beyond the specifics of the content that was taught (Barnett & Ceci, 2002). To some degree, then, we should not be surprised by students’ failure to transfer scientific thinking to content beyond that which was explicitly taught. Cognitivists have long been aware of the contextual constraints on students’ knowledge (e.g., Ceci, 1991). The preschool child who seems to possess knowledge of a “halving rule” will quickly yield to situationalism when probed: For example, in response to the question “If I cut an apple in half, how many pieces will I have?” the child accurately replies “Two”. However, when the issue is pursued with “If I cut a carpet in half, how many pieces will I have?” the child may reply, “It depends on how large the carpet is.” (Ceci, 1996).

From such observations, it comes as little surprise that children taught scientific principles often do not spontaneously extend such learning beyond the content and procedures taught. Brown et al. (Brown, 1989; Brown & Campione, 1990; Brown & Kane, 1988; Brown, Kane, & Echols, 1986; Brown, Kane, & Long, 1989) conducted a series of experiments designed to study whether young children generalized their training but found that they did so only under very constrained circumstances. For example, some of these experiments (Brown, 1989; Brown & Kane, 1988) showed that children can transfer some principles, such as “hide, using visual mimicry as a defense mechanism,” from one animal to another. Children transferred most successfully when they understood events at a causal level rather than when
they merely learned to replicate particular behaviors. That is, they transferred when they developed a deep rather than surface understanding.

However, the problem of limited generalization of scientific reasoning does not end with children, as it can be found among college students at the nation’s most elite universities. For example, Gick and Holyoak (1980) showed only limited successful transfer of analogical reasoning using the classic Dunker tumor radiation problem and a military analogy with college-aged participants. Students were presented with the following military problem: “A general wishes to capture a fortress located in the center of a country. There are many roads radiating outward from the fortress. All have been mined so that while small groups of soldiers can pass over the roads safely, a large force will detonate the mines. A full-scale direct attack is therefore impossible. The general’s solution is to divide the army into small groups, send each group to the head of a different road, and have the groups converge simultaneously on the fortress.” The radiation problem described an analogous situation in which a type of ray could be used to kill a cancerous tumor; however, in the dosages needed it would also kill surrounding tissues. The solution is to spread the rays around the patient’s body so they converge simultaneously on the tumor from different locations, thus not killing the surrounding tissues.

Gick and Holyoak (1980) presented college students with one or more such stories followed, either immediately or after a few minutes break, by the radiation problem. Data showed that those students who were trained with the closest analogy in terms of its proximity to the radiation problem were more likely to come up with the solution to the tumor problem. However, most students did not transfer their prior learning unless they were given an explicit hint (i.e., when they were explicitly told to think about the new problem in the context of the training problem). Similarly, Reed, Ernst, and Banerji’s (1974) college students failed to demonstrate transfer beyond the specifics of their training. Reed et al. investigated transfer between the missionary–cannibal problem (how to get safely across a river in a limited-capacity boat without having the cannibals in the group ever outnumbering the missionaries) and a directly analogous problem substituting wives and jealous husbands for missionaries and cannibals.

Other researchers have investigated the ways in which training can be conducted to most readily facilitate such a deep scientific understanding in students. These various approaches focus on getting the students to work with the training materials at a deep, structural level. For example, Catrambone and Holyoak (1989) used comparison questions to promote induction of a general schema from multiple examples, which then improved transfer, and Cummins (1992) also found that interproblem processing (focus on comparison questions) promoted more transfer than intraproblem processing (focus on specific wording or details). Similarly, Needham and Begg (1991) found that problem-oriented training (e.g., trying to explain) resulted in greater generality of problem-solving performance than memory-oriented training. Finally, Halpern, Hansen, and Riefer (1990) enhanced students’ skill in making inferences from a studied passage by including analogies in their training materials, presumably encouraging a focus on deep, structural processing.

In sum, attempts by researchers to engender the broad-based transfer of scientific reasoning skills in students have been no more successful than the efforts of curriculum developers. Students appear to learn the specifics of the lessons but they do not generalize beyond them. Recently, Barnett and Ceci (2002) proposed a taxonomy for understanding when and why transfer of scientific learning occurs. In their model, the roles of various forms of context loom prominent. One of these concerns the type of cognitive process involved in the generalization of knowledge, specifically a shift from surface-level,
verbatim teaching of facts to the inculcation of an awareness of the internal workings of the students’ cognitive systems—so-called metacognitive awareness.

3. Cornell Institute for Research on Children (CIRC) approach to training scientific reasoning

3.1. Shifting the metaphor

In our work, as part of CIRC, we have conceptualized the training of scientific reasoning differently from the way many curriculum developers have in the past. Specifically, we view our attempts to train students to reason scientifically as a form of metacognitive training rather than science education. One might argue that this is merely a terminological “sleight of hand,” using a different vocabulary to refer to the same phenomenon. This would be incorrect, however. Numerous studies of training students in metacognitive skills have demonstrated the feasibility of instilling deep, transdomainal modes of awareness. For example, in the areas of memory development and reading comprehension, Pressley has conducted numerous studies demonstrating the success of metacognitive strategies at improving performance (see, e.g., Pressley, Borkowski, & Schneider, 1987; Pressley, Ross, Levin, & Ghatala, 1984; Pressley, Snyder, & Cariglia-Bull, 1987).

More closely related to our current work in science education is the research of Williams et al. (Williams et al., 1996, 2002) on increasing students’ practical intelligence for school, which was accomplished via training in five metacognitive themes underlying practically intelligent thinking. In that program, known as the Practical Intelligence for School Project (PIFS), researchers sought to boost school achievement by creating an intervention that would develop practical intelligence for school in middle-school students. Researchers worked with teachers in Connecticut and Massachusetts schools over a 2-year period. Teachers were trained to deliver a five-part program designed to promote the development of practical intelligence by emphasizing five sources of metacognitive awareness: knowing why, knowing self, knowing differences, knowing process, and revisiting. A broad range of assessments was administered in a pre–post design both to the children receiving the practical intelligence program and to matched control children. Williams et al. (1996, 2002) found that the program successfully enhanced both practical and academic skills in each of the target skill areas (reading, writing, homework, and test taking) in children from diverse socioeconomic backgrounds and attending diverse types of schools. Their results supported the importance of the acquisition of cognitive and metacognitive insights during adolescence. The results of Williams et al. (1996) also showed that training in metacognitive skills enhanced adolescent achievement over and above traditional g-based approaches to learning. The success of PIFS inspired much of CIRC’s science education program.

In sum, based on the results from these studies of metacognitive training of various academic material (PIFS, memory, reading, etc.), we wondered whether scientific reasoning might also be amenable to metacognitive induction. To adumbrate our conclusion, we do not yet know—the critical evaluation must await far more training and data gathering. However, we believe that there is a solid basis for pursuing this avenue in the hope that when students are taught metacognitive strategies, they will remember and continue to apply these strategies across content areas, beyond the classroom, and throughout their lives.
3.2. Thinking Like A Scientist: An example of educational programming from CIRC

Consider an example of how we have instantiated our goals regarding training students to think scientifically into actual classroom lessons and activities (see Fig. 1). Fig. 1 displays a lesson on the motivating effects of praise, based on a recent review by Henderlong and Lepper (2002).

As previously noted, much of the content that students are taught about science will likely be forgotten. However, this does not mean that content is not important and cannot be used advantageously. Learning is impeded if students are not interested in a topic. Therefore, efforts must be devoted to framing topics in a compelling manner. Geology and fuel cells may be important scientific issues, but they may not be inherently interesting to most teens, particularly those teens in our target demographic groups who may have been turned off to science in the past. Rather than attempting to spin these topics in a fun way—an approach often taken by classroom teachers wishing to make dense or difficult material seem more interesting to students—Thinking Like A Scientist uses content that is naturally interesting to most students to capture and hold their attention. To select such topics, a general search of the psychological literature was conducted to find top-journal review articles and meta-analyses addressing issues relevant to today’s youth and their interests, as well as topics that are easily accessible to students who may not have a strong educational background. Examples of our lesson topics include the scientific basis of extrasensory perception, the controversy surrounding silicone breast implants, the effects of hypnosis on pain, the consequences of self-esteem, approaches to treating depression, and the effects of playing violent video games on behavior.

Once students’ attention is piqued by the interesting topic, more resources (and especially time) can be devoted to examining the underlying scientific principles and relevant scientific thinking on the issue. Coupled with this process is the explicit message to students that science is relevant to them and can easily be integrated into their lives. Instead of skirting the issue of scientific thinking and using examples that will likely not be a part of extracurricular conversation, as is often the case with the traditional science curriculum, this project infuses each lesson with anecdotes and examples that are relevant to students and that consequently can be used to illustrate thinking in the scientific method. It is essential to use topics relevant to students’ daily lives because familiarity with a lesson topic allows personal experience and knowledge to be brought to bear on learning, beginning a cycle that perpetuates interest and subsequent learning.

The familiar nature of the lesson topics helps reinforce the first theme of Thinking Like A Scientist: “What is Science?” Thinking Like A Scientist shows students that science explains a myriad of things that are often encountered but not inspected. This is accomplished not only within the lessons but also by the topics of the lessons themselves. Consider the lesson on the motivational effects of praise on children presented in Fig. 1. Compliments are a part of everyday life (or at least they should be), and by showing that complimenting behavior can be scientifically examined, Thinking Like A Scientist illustrates how science permeates everyday life in ways that students most likely have never considered. The topic of praise behavior is relevant because the youth are experienced in giving and receiving compliments as well as being familiar with their effects. As seen in Fig. 1, students can be engaged in a discussion of who likes compliments and why right at the outset of the lesson. Instead of relating scientific principles to Mendel’s hybridization of seeds, for example, in the CIRC program students are encouraged to make connections with their personal experiences.
In the second theme of each lesson we ask students to define the problem and see many sides of the issue at hand. In the example of the praise lesson in Fig. 1, this entails coming up with a working definition of praise and exploring when praise has positive effects versus possible negative effects.

**Gain Attention/Interest:**

Who here likes to get compliments? Pretty much everyone. Why do people like compliments? Do you know anyone who prefers not to be complimented? Why does she or he feel this way? (Solicit responses and discuss).

If nearly everyone likes compliments, then the more the better, right? Or wrong? Can compliments ever be bad? This lesson discusses the effects of praise on motivation.

**Activity**

*Go around the room and have everyone give an example either of their favorite type of praise to receive or of the favorite compliment they received in the past. Have them relate this example to how/if the praise/compliment influenced their motivation to perform that behavior. Also ask what they think would happen if they received this compliment more frequently.*

Fig. 1. Sample lesson from the Cornell Institute for Research on Children Thinking Like A Scientist Educational Program.
What is Science?

It may seem obvious that compliments are good, but are they always? When they are good, how good are they—what exactly is their effect on children, and why? Should we shower kids with constant compliments? Scientists answer these questions in a very specific way. Simply going home and asking their own kids, or sitting around and talking about it among themselves, is NOT what scientists do. Scientists actively seek to show if what they suspect may, in fact, be wrong. Sometimes they cannot show that an idea is wrong, and they wind up accepting that the idea is right. Scientists conduct experiments that help them eliminate all possible incorrect answers. Through these experiments, they eventually reveal the correct answer. This process is called proof by disproof.

Let’s say you want to find seashells. Your friend tells you that the only seashell she has ever seen was at the beach, so that must be the only place you can find them. Is that a valid conclusion? No—you have to check. So, let’s say you go to all the beaches in the world and you find seashells on all of them. Is that good enough to justify your friend’s conclusion? Can you now say, “the only place you can find seashells is on a beach”?

No—you have to double-check. You might find seashells in a museum, or on the ocean floor, or as a decoration in a hotel. If you hypothesized that seashells are only found on beaches, you would have to check TWO things.

1. Beaches have seashells.
2. Seashells can’t be found anywhere else.

Now, let’s say someone tells you that gray hair is caused by old age. What would you have to check?

1. Some elderly people have gray hair.
2. Young people never have gray hair.
3. Everyone with gray hair is old.

You have to find instances of your answer, as well as show that other explanations are false. You have not only to find support for your answer, but you must disprove other potential answers as well.

Define the problem: See many sides

Let’s make sure we are all on the same page regarding the meaning of the term “praise.” This is an important part of science; clearly defining your terms allows other people to know exactly what you are discussing. This is called a working definition. It’s called a working definition because it’s the particular definition that you are choosing to use. Clear working definitions are important because different people define things in their own way. For example, what you consider “a lot” of praise may be quite different than what someone else considers a lot of praise.

Example: When measuring an amount of exercise, one person might consider “exercising a lot” to be every day, while another could think of it as a couple times a week. A professional athlete might think of it as more than once a day.

Fig. 1 (continued).
What exactly is a compliment/praise? Can anyone give a definition? A typical definition of praise includes:

- a positive evaluation of another’s ability, performance, or traits
- the belief by the person giving the praise that the praise is valid.

We discussed earlier some positive aspects of praise; can anyone give any examples of when praise might be a bad thing? This is how we see the various sides of the issue. (Solicit responses.) A possible example could be an overbearing parent praising her/his child and creating performance expectations that are too high and cannot be met. Another example of praise being bad is complimenting a person with an eating disorder on how she/he has lost weight. The intention may be good, but supporting an unhealthy behavior is not.

Fact versus opinion: What constitutes science?

Is praise bad? Is it good for some people, but bad for others? If we wanted to know, what could we do to find out? What is a fact about praise, and what is just an opinion? What is good evidence about how praise works, what is bad evidence that should not convince us, and how do we know the difference?

What do the following cases tell us about the answers to these questions?

- A friend telling us a story about a bad experience with praise.
- Someone who needs to get compliments all the time.
- Reading a story in the newspaper about someone going to jail after growing up in a bad environment and being criticized by his parents constantly.

All of the above are excellent examples that illustrate certain effects of praise for certain people, but they are not scientific evidence—instead, we can think of them as anecdotes, or examples about individual people. They are not scientific evidence because each only applies to one person, and these people may represent special cases or circumstances. Actual scientific evidence explains things about many people—it allows us to generalize what we know so we can predict how others will behave under similar circumstances.

In scientific research, evidence can be gathered in many ways. For example, one study investigating praise and motivation had a group of young kids color. The kids naturally considered coloring fun. Researchers told some of the kids in advance that they would receive a reward for coloring. Other children either received no reward, or received a reward but did not expect it.

Afterwards, researchers found that the kids who expected the reward were LESS likely to want to color compared to the other children. The kids who expected a reward connected coloring with working for a reward (e.g., gaining the approval of their parents) instead of connecting coloring with fun.

These results are considered evidence because they were found by randomly selecting the kids who received the praise and that they are told about, whether via television, a teacher, or a textbook, is the end of the story. Consequently, the students never consider the possibility that multiple viewpoints exist. Focusing on a familiar hypothesis, such as that “praise benefits children,” allows students to concentrate more fully on the objectives of the theme, which is that issues can be viewed from more than one perspective. Students then proceed to discuss examples pertinent to their lives. Asking whether
praise can have negative effects evokes comprehension and retention more easily than a less familiar topic, such as botany. Additionally, using a familiar topic gives teachers the opportunity to discuss issues about which students already have opinions.

Example: Using anecdotes as evidence would be like using Shaquille O’Neal as an example to decide that most people are about 7 feet tall. We know that that most people are not 7 feet tall, but this is the kind of incorrect conclusion that could be drawn when we don’t use scientific evidence. To find the average height of all adults who lived in a particular city, a scientist would randomly choose a group of names from a list of all of the adults who lived in that city and measure their heights. This is called random selection and would give a more accurate measure of the true average height of adults in that city.

### Weighing Evidence and Making Decisions

So let’s return to our question: **Is praise good or bad?** Does it help or hurt children’s motivation? Let’s first define a couple of different types of motivation: intrinsic and extrinsic.

Scientists look at children’s intrinsic or internal motivation, which means their inner push or desire to accomplish things. They also look at children’s extrinsic or external motivation, which means the type of push that comes not from inside oneself but rather from outside—say, from someone else, from a promise of a reward (like a candy bar), or a prize. In general, intrinsic or internal motivation is better. People who do things because they want to intrinsically tend to do a better job for a longer time than people who do things because of an extrinsic or outside push. Intrinsic motivation is more powerful. Now back to praise and motivation.

**Scientists have found that praise can be both good AND bad, depending on how it is interpreted by the child receiving it.**

In order for praise to be helpful to internal motivation, it must have (and be seen as having) the following attributes:

- **Sincerity.** Is the praise honest? Why would this matter? What would change if the praise was insincere or dishonest?
- **Performance attribution.** It is important for the cause of success to be perceived as a result of achievement and not effort. For example, praise is being told you did well rather than being told you “tried hard” or gave a “good effort”.
- **Autonomy.** Praise should not be the reason for performing an action but instead it should be an unexpected addition. The actual performance of an action should be separate from the praise can have negative effects evokes comprehension and retention more easily than a less familiar topic, such as botany. Additionally, using a familiar topic gives teachers the opportunity to discuss issues about which students already have opinions.

**Thinking Like A Scientist** uses these preexisting opinions as a means of facilitating students’ ability to “Distinguish Fact from Opinion and Ask What Constitutes Evidence” (representing the
third theme). The praise lesson in Fig. 1 differentiates personal opinion and experience from the systematic gathering of evidence through a discussion of anecdotes and examples, such as how a friend having a bad experience with praise differs fundamentally from an experiment in which one measures the influence of praise on a randomly selected group of kindergarteners. The purpose of this theme is to enlighten students regarding the varying degrees of quality inherent in different

Moving From Science to Society

Nearly everyone gives and receives compliments frequently. Just because you intend something to be a compliment does not mean it will be taken as one. In order for praise to increase motivation it must be perceived in a particular way. Not everyone will interpret praise in the same way. Knowing how to give better and more effective compliments can help us all. In particular, knowing how to give compliments that will be interpreted positively by the recipient will build and strengthen the internal motivation of that person. Knowing this fact can help teachers, coaches, employers, and anyone else trying to increase the motivation of another person.

Activity

Go around the room again asking the students how learning this has influenced their opinion regarding the favorite compliments discussed earlier and how it will influence their complimenting behavior in the future.

Revisit, Reflect, and Review

As we have discussed, the scientists doing research on how children respond to compliments have found that children tend to react in a certain way to certain types of compliments. As more scientists work on this question, we might find out new things. For example, we might find out that boys respond differently to compliments than do girls, or that younger children respond differently than older children, or that people from one culture respond differently to compliments than do people from another culture. Many of these interesting questions still need to be answered. This is why scientists revisit questions, reflect on their answers, and review what they have discovered in the past. Knowledge about science is always changing, increasing, and being updated—this is what science is about.

Fig. 1 (continued).
types of information. Because students have a preexisting schema involving praise and its consequences, *Thinking Like A Scientist* is able to illustrate for students the differences in how scientists and laypeople view information.

Once the distinction is made between fact and opinion, it becomes possible to “Weigh the Evidence and Make Decisions” (theme four of the program). In this part of the lesson, the conclusions of the Henderlong and Lepper (2002) article are distilled, and the lesson then describes...
the scientific requirements that must be met for a statement to be considered praise and to increase motivation. *Thinking Like A Scientist* makes assigning varying levels of importance to assorted pieces of evidence more manageable for students because it capitalizes on student familiarity with the evidence. Accordingly, this strategy allows students to devote more cognitive resources to the process of evaluating evidence rather than having them expend time and mental energy on deciphering arbitrary content. As with the rest of the lesson, the reasoning behind this approach is that an increase in student familiarity with the content augments students’ ability to grasp the scientific methods at work.

Once the sources of evidence have been critically examined and students understand the scientific conclusions relevant to the topic, *Thinking Like A Scientist* “Moving from Science to Society” (theme five). At this point, lessons discuss potential real-world applications of the topic that further solidify the relevance of science to the real world and to students’ lives. Thus, the lessons come full circle both by connecting students’ lives to science and by relating science to students’ lives. The activities in this section of the lesson accomplish this goal by asking students to consider how what they have learned has changed their thinking about praise, for example, and how their new understanding will influence their future praising behaviors. Finally, the program’s ultimate theme calls for students to “Revisit, Reflect, and Review.” Here, the program illustrates the importance of continual reevaluation in science as well as the value of checking the validity and applicability of findings over time. In the praise lesson, for example, we explore potential areas of further study on praise that could yield new and relevant information as further research becomes available. This point is stressed to students. Serving as a conclusion to each lesson, the revisit–reflect–review theme stresses the ongoing nature of science as well as the continually evolving nature of the process of thinking scientifically.

In short, the *Thinking Like A Scientist* educational program (a) uses content appropriate to its audience (b) to capitalize on the students’ prior interest and knowledge (c) in the teaching of the principles of sound scientific thinking and reasoning (d) via the six themes organizing all *Thinking Like A Scientist* lessons.

4. Implementation of the program

The implementation of the program involves many steps that are tailored to the needs of individual schools, teachers, and students. We provide all materials to the school, including self-contained full lesson plans suitable for students in Grades 8 through 12. These lessons do not in any way conflict with teachers’ current curricula; the lessons are completely modifiable by teachers to meet their particular curricular and educational goals. In the past, teachers who used our materials taught one or two lessons per week in their science (usually biology) or social science classes. These teachers chose which lessons they wished to teach and the order in which they wished to teach them. We provided assistance and support, but the teachers had complete freedom to do what was best for their students.

We induce schools to participate by discussing benefits with them. In return for a school’s participation in our program, we offer (a) complete copies of our program for interested teachers to use; (b) stipends for schools and participating teachers; (c) assistance from advanced graduate students and CIRC Fellows; (d) results from our study at all participating schools, showing what
works about our program and why; and most importantly, (e) an opportunity for teachers to expand their approaches and skills to benefit their students. Teachers also enjoy the experience of being part of a project sponsored by Cornell University and funded by the National Science Foundation, and contributing to the process of making this work possible.

5. Evaluation

The issue of how to evaluate our program has proved thorny. Some previous educational interventions have been deep in audience participation but shallow in evaluation. To improve upon this, we seek to assess the students exposed to our materials to ascertain whether they absorb the metacognitive skills and learn how to use these skills in a meaningful way. Our goal is to simultaneously test comparable students, both in participating and nonparticipating classrooms (the latter are often on the wait list to receive the program in the near future). Despite a broad search, we have found no formal or standardized assessments that measure the types of scientific thinking we hope to train. Therefore, we designed our own assessment (see Appendix A for sample questions). Our test does not focus on the specific content of the science lessons we have designed; rather, it seeks to measure students’ extraction of the scientific thinking skills embodied in the themes described above. This is gauged by assessing students’ ability to recognize science when it happens and to think like a scientist when solving real-world problems. Because the test is not related to the lesson content, it is fair to the control-classroom students who have not yet participated in the program. Our goal is to administer matched pre- and posttests both to students who are receiving the program and to students who have not yet received the program at the beginning and end of the semester (approximately 6 months apart). In the meantime, their normal classroom teachers will teach our materials to the students in the experimental condition. Our hope is that we will eventually be able to document meaningful increases in the ability to think like a scientist as a result of exposure to our program.

6. Conclusions

In this article, we describe a novel method for inculcating and evaluating the development of scientific reasoning skills in students, particularly those from traditionally underrepresented backgrounds. Our educational program seeks to improve upon existing programs that focus on specific content (with the expectation that students will extract scientific reasoning skills) or those that explicitly train scientific thinking but in the context of a particular domain of science. *Thinking Like A Scientist* attempts to accomplish this goal by focusing the content of the lessons on real-world topics that students find relevant to their own lives, rather than by teaching scientific thinking skills within the traditional domains of science for which the content may be less personally engaging. It is our expectation that this approach will result not only in the increased use of scientific thinking within domains of science but that these skills will transfer beyond the

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1 A copy of the complete evaluation instrument is available from the first author.
classroom to students’ everyday lives. We are initiating large-scale evaluations of *Thinking Like A Scientist* that will determine whether our expectations are correct. However, we already have ample evidence that students from low-SES backgrounds enjoy the lessons and remain focused on the instruction—important and worthy goals in their own right for our target groups of students, many of whom are in remedial classrooms and are on the verge of dropping out of school altogether. *Thinking Like A Scientist* has also passed the important hurdle of being judged flexible and easy to use by teachers, who also appreciate the solid scientific basis that underpins the lessons. Reaching these students with the message that science is worthwhile and enjoyable, that thinking scientifically can become part of their lives, and that continuing their education in science is both possible and even practical is without doubt our foremost mission and an essential goal for our society as a whole.

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Appendix A. Examples of questions from the assessment developed to evaluate the *Thinking Like A Scientist* Educational Program (the item response form is presented only for the first item in each set)

*Part I. Questions (n = 11 items) in this group ask if the person is behaving scientifically*

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Jordan goes to test-drive a car and the dealer tells her that she needs the more powerful V8 engine, instead of the V6. After test driving both, Jordan decides the V6 engine is good enough for her. Is Jordan behaving scientifically?

Jamaal reads his horoscope one morning, and then that evening he tells his brother that several predictions in the horoscope came true. The next day, Jamaal starts making decisions based on his horoscope. Is Jamaal behaving scientifically?

*Part II. Questions (n = 3 scenarios with multiple items) in this group ask about making decisions based on science*
Carlos has a sore knee. It hurts whenever he plays sports. He is thinking about trying a special knee brace. Carlos wants to make a decision based on science. How important should each of the following pieces of information be to Carlos when he makes his decision?

(a) His grandmother tried the brace and it did not work.
(b) His doctor said 8 out of 10 people who use the brace feel better.
(c) A television commercial for the brace claims it always works.
(d) Carlos’s coach said the brace helped three other boys on the team.

Part III. Questions (n = 17) in this group ask you to tell us about yourself

In general, I like school.
I think science is a boring class.
I think women can be good scientists.
I trust the ideas scientists come up with.
My friends think scientists are “nerdy.”

References


