Forum on Public Policy

A Philosophical Approach to Claims about Vaccinations and Autism.

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Abstract

By highlighting the critical thinking that (1) analyzes and evaluates arguments for claims about vaccinations and autism, and (2) engages in a form of methodological skepticism that systematically and continuously asks Critical Questions, a philosophical approach is introduced to deal directly and systematically with students' (and publicly popular) misconceptions of (and resistance to) bio-medical knowledge, interventions, and/or technology employed in healthcare or public health. As a result of engaging in a dialogue between philosophy and the bio-medical sciences by means of critical thinking, the educator can help students actively compare their initial conceptions (and publicly popular misconceptions) with more fully scientific conceptions.[1]

I. Introduction

There is much evidence supporting no (or extremely low) correlation between vaccinations and children diagnosed with autism. But, paradoxically, public resistance to thinking critically about this contemporary issue in science[2] seems to have become stronger—usually fueled by bias, misinformation, fearmongering, motivated reasoning, and fallacious thinking.[3] This problem of public resistance is compounded with the reality that science faculty have often avoided teaching controversial issues in science classes, since much of the students' resistance is framed in personal, emotional, or religious terms and science teachers are usually reluctant to address such ideas in class.[4] Moreover, many science instructors are simply not able to master and teach critical thinking

[1]Under the leadership of Dr. Kody Kuehnl (Biologist, Dean of the College of Arts, Sciences, & Technology, Franklin University), the graduate course, *Biology 630/Contemporary Issues in Science*, was designed, developed, and taught by the author of this treatise (based on an application of Talavera, I. 2016. The acquisition of scientific knowledge via critical thinking: A philosophical approach to science education. *Forum of Public Policy*, Vol 2016, No. 2, 1-66.).
[2]For a description and survey of the stark fissures between scientists and citizens on a range of science, engineering and technology issues see Funk, C., and L. Rainie. 2015. Public and Scientists' Views on Science and Society. *Pew Research Center* (http://www.pewinternet.org/2015/01/29/public-and-scientists-views-on-science-and-society/). Accessed December 31, 2016.
[3]Studies Confirm, Vaccines Still Don't Cause Autism. But Are These Studies Helping? (https://www.youtube.com/watch?v=j_zqBPuPx8w); The Science of Anti-Vaccination (https://www.youtube.com/watch?v=Rzxr9FeZf1g); Vaccines Do NOT Cause Autism! What Does? (https://www.youtube.com/watch?v=_fyJM24BiMU). Accessed December 14, 2016.
[4]Nelson, Teaching Evolution (and all of Biology) More Effectively: Strategies for Engagement, Critical Reasoning, and Confronting Misconceptions, 213-225.

well,[5] and/or many science instructors are not entirely effective in passing on scientific knowledge because they are themselves suffering from cognitive dissonance.[6]

The following treatise introduces a **philosophical approach**[7] to claims about vaccinations and autism so that the educator may develop a more robust understanding about this critical issue and deal directly and systematically with misconceptions of (and resistance to) bio-medical knowledge, interventions, and/or technology employed in healthcare or public health.[8] This will be achieved by highlighting the critical thinking that (1) analyzes and evaluates arguments, and (2) engages in a form of methodological skepticism that systematically and continuously asks Critical Questions. By engaging in a **dialogue between philosophy and the bio-medical sciences via critical thinking**, the educator can help students actively compare their initial conceptions (and publicly popular misconceptions) with more fully scientific conceptions.

II. The science behind autism and vaccinations

A working example of the resistance to bio-medical knowledge, interventions, and/or technology crucial to healthcare or public health is the vaccine-associated autism myth that originated in 1998 in the United Kingdom with the discredited Wakefield study (with a small sample of only 12 children). The problem is that many studies (with large numbers of children) have since shown that there is no causal link between the measles, mumps, and rubella (MMR) vaccine and autism. The book, *The Panic Virus: The True Story Behind the Vaccine-Autism Controversy*, documents how all this came to light:

> *…Andrew Wakefield, a British gastroenterologist with a history of self-promotion, published a paper with a shocking allegation: the measles-mumps-rubella vaccine might cause autism. The media seized hold of the story and, in the process, helped to launch one of the most devastating health scares ever. In the years to come Wakefield would be revealed as a profiteer in league with class-action lawyers, and he would eventually lose his medical license. Meanwhile one study after another failed to find any link between*

[5]Unfortunately, learning to teach critical thinking (and assessing an instructor's success teaching it) is not quite so straightforward as the outcome-based minded may think—pragmatically linking, for example, critical thinking with Bloom's Taxonomy. In *Critical Thinking: What Every Person Needs to Survive in a Rapidly Changing World* (Chapter 31: Bloom's Taxonomy and Critical Thinking Instruction: Recall is not Knowledge), the philosopher Richard W. Paul argues that while Bloom's distinctions themselves are important, the common understanding of their link to critical thinking is largely misconceived. See Talavera, I. 2006. The problem of teaching critical thinking: Three approaches. *NADE Digest* 2 (1) (Spring): 63-69.

[6]Eve and Dunn, Psychic Powers, Astrology & Creationism in the Classroom? Evidence of Pseudoscientific Beliefs Among High School Biology & Life Science Teachers, 13-21. See Talavera, I. 2016. The acquisition of scientific knowledge via critical thinking: A philosophical approach to science education. *Forum of Public Policy*, Vol 2016, No. 2, 1-66.

[7]This approach is taken from Talavera, I. 2016. The acquisition of scientific knowledge via critical thinking: A philosophical approach to science education. *Forum of Public Policy*, Vol 2016, No. 2, 1-66.

[8]Misconceptions and resistance need to be confronted, for instance, in biology and life science courses. See Nelson, C. E. 2008. Teaching evolution (and all of biology) more effectively: strategies for engagement, critical reasoning, and confronting misconceptions. *Integrative and Comparative Biology* 48 (2): 213-225.

childhood vaccines and autism.[9]

To make matters worse, two separate alleged evils concerning vaccines and autism have been tied together: the measles, mumps, and rubella (MMR) vaccine proper and vaccines containing the chemical preservative thimerosal, which contains a form of mercury.[10] But, even if this chemical preservative has been removed from most vaccines, there are those who continue to suspect it of causing autism. Accordingly,

> *…the myth that vaccines somehow cause developmental disorders lives on. Despite the lack of corroborating evidence, it has been popularized by media personalities such as Oprah Winfrey and Jenny McCarthy and legitimized by journalists who claim that they are just being fair to 'both sides' of an issue about which there is little debate. Meanwhile millions of dollars have been diverted from potential breakthroughs in autism research, families have spent their savings on ineffective 'miracle cures,' and declining vaccination rates have led to outbreaks of deadly illnesses like Hib, measles, and whooping cough. Most tragic of all is the increasing number of children dying from vaccine-preventable diseases.*[11] [This is alarming, since *[t]he evidence is clear: vaccines are one of the most cost-effective investments in health and development in history.*][12]

To be sure, Autism symptoms tend to become apparent around the same time that children are scheduled to get routine vaccines, but most medical researchers argue that vaccine-associated autism is probably a coincidence. [Moreover,] *…experts studied whether the MMR vaccine could cause autism. To do that, they looked for clues among kids who did and didn't get the vaccine. Since…*[the Wakefield study], *14 studies including millions of children in several countries consistently show no significant difference in autism rates between children who got the MMR vaccine [and] those who didn't. The bottom line: It's very unlikely that the MMR causes autism, researchers say.*[13]

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[9]Mnookin, S. 2011. *The Panic Virus: The True Story Behind the Vaccine-Autism Controversy*. New York: Simon & Schuster, Inc.

[10]This section has been adapted from Downs, M. WebMD Special Report: Autism - Searching for Answers. Autism-Vaccine Link: Evidence Doesn't Dispel Doubts: Many major medical groups say vaccines don't cause autism. Many parents say they do. So who's right? *WebMD*. Reviewed by Louise Chang, MD (http://www.webmd.com/brain/autism/searching-for-answers/vaccines-autism). Accessed Nov. 28, 2016.

[11]Mnookin, S. 2011. *The Panic Virus: The True Story Behind the Vaccine-Autism Controversy*. New York: Simon & Schuster, Inc. Watch how the measles outbreak spreads when kids get vaccinated – and when they don't at The Guardian's herd immunity simulation (https://www.theguardian.com/society/ng-interactive/2015/feb/05/-sp-watch-how-measles-outbreak-spreads-when-kids-get-vaccinated). See also Map of global vaccine rates (http://gamapserver.who.int/gho/interactive_charts/immunization/mcv/atlas.html). Accessed December 13, 2016.

[12]As noted by Gavi of The Vaccine Alliance. See Value of Vaccination (http://www.gavi.org/about/value/). Accessed December 13, 2016.

[13]This section has been adapted from Downs, M. WebMD Special Report: Autism - Searching for Answers. Autism-Vaccine Link: Evidence Doesn't Dispel Doubts: Many major medical groups say vaccines don't cause autism. Many parents say they do. So who's right? *WebMD*. Reviewed by Louise Chang, MD (http://www.webmd.com/brain/autism/searching-for-answers/vaccines-autism). Accessed Nov. 28, 2016.

III. The problem behind autism and vaccinations

Most major bio-medical scientists and researchers say vaccines[14] do not cause autism, but a populist coalition of parents, celebrities, politicians and activists say they do. To be sure, the possibility of a causal *link* between childhood vaccinations and the subsequent development of autism has been of great concern to some that have noticed changes in their children shortly after the children were vaccinated (a disorder known as *regressive* autism). Accordingly, the overarching problem behind autism and vaccinations is that for some people scientific evidence does not dispel doubts about the alleged causal *link* between childhood vaccinations and the subsequent development of autism. Moreover, because some people have not inoculated their children due to the fear of a causal *link* between vaccinations and diseases, a major public health crisis has arisen with vaccine preventable diseases recently increasing in the world.[15]

To avoid being deceived by means of misleading reasoning used in the vaccine-associated autism debate, we need to recognize the common mistakes of reasoning called *fallacies*. Fallacies are bad arguments that may be mistaken for good arguments. Fallacies can have weak inductive argument forms or invalid deductive argument forms, but may also be found in arguments that are not cogent or not sound. Moreover, there are many other ways people accept conclusions for the wrong reasons. For instance, reasons that are unacceptable, irrelevant, or insufficient do not adequately support the conclusion of an argument. All this suggests that a fallacy is committed when an argument under consideration does not justify accepting its conclusion. This happens when the premise or premises do not adequately support the conclusion. This means that the reason or reasons provided as evidence for the conclusion are inadequate for accepting the conclusion.

Let us look at two main fallacies that are behind the vaccine-associated autism myth: **the Fallacy that Appeals to Fear**[16] and **the Fallacy that Mistakes Correlation for Causation**.[17]

A. The fallacy that appeals to fear

An argument that appeals to fear is an emotional appeal that relies on some type of scare tactic to establish its conclusion. Why is an argument that appeals to fear a bad argument? By relying on emotions, an appeal to fear does not provide evidence for the conclusion that one ought to not do something. We need good reasons, not emotion, to establish a claim.

The general form of this argument is the following.

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[14]To investigate how risky are vaccine side effects see CDC: Vaccines & Immunizations: Possible Side-effects from Vaccines (https://www.cdc.gov/vaccines/vac-gen/side-effects.htm#mmr). Accessed December 13, 2016.

[15]See, for example, **FRONTLINE: The Vaccine War: PBS** (https://www.youtube.com/watch?v=VPOrnU3ImxI#t=14.25602); Watch **Vaccines: Calling the Shots** from PBS' NOVA (https://www.youtube.com/watch?v=wqbH40Y9XJw). Accessed December 14, 2016.

[16]For a provocative examination of why we fear vaccines see: Biss, E. 2014. *On immunity: An inoculation*. Minneapolis: Graywolf Press. Also see How one vaccine skeptic became a vaccine supporter (http://www.vox.com/2015/2/6/7992071/how-one-vaccine-skeptic-became-a-vaccine-supporter). Accessed December 13, 2016.

[17]Talavera, I. 2016. The acquisition of scientific knowledge via critical thinking: A philosophical approach to science education. *Forum of Public Policy*, Vol 2016, No. 2, 1-66.

1) **X *is*** afraid of **Y**.

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2) Thus, **X *ought*** not (apply or engage in) **Y**.

But why is this a problem? Well, the above does not have a valid deductive argument form.[18] To be sure, invalid deductive argument forms are problematic because they allow substitution instances (i.e., examples) with true premises and a false conclusion. And, we certainly do not want to be guilty of using our reasoning and the information involved to derive something false from something true.

Consider the following substitution instance (i.e., example) of the above Form:

1) **Kevin** is afraid of **getting his teeth pulled**.

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2) Thus, **Kevin** ought not **get his tooth pulled.**

So, suppose premise 1 above is true. Is it possible that the conclusion may be false? Of course, it is true that Kevin (and many of us!) might certainly be afraid **of getting teeth pulled**. But, the conclusion is most likely false, since his dentist may recommend **pulling** a badly damaged tooth (say from trauma or decay) because of practical concerns about overall dental health.

Likewise, people are **afraid** of a causal *link* between vaccinations and diseases (e.g., autism). But, this does not mean that one **ought not vaccinate a child for the measles, mumps, and rubella (MMR)**. That is because if we suppose premise 1 below to be true, it is possible that the conclusion may be false in the following substitution instance (i.e., example) of the above Form. (Suppose **Kevin** strongly believes that there is a causal *link* between vaccinations and diseases (e.g., autism).)

1) **Kevin** is afraid of **vaccinating his child for the measles, mumps, and rubella (MMR).**

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2) Thus, **Kevin** ought not **vaccinate his child for the measles, mumps, and rubella (MMR)**.

B. The fallacy that mistakes correlation for causation

[18]Referring to David Hume's **Is-Ought** fallacy (see book III, part I, section I of his book, *A Treatise of Human Nature* (1739)), we can say that there is no logical way to get from what *is* (a fact) to what *ought to be* (an objective ethical standard). We cannot have, then, a sequence of statements (a set of premises and a conclusion) where the premises (statements of **facts**) are **intended** to **prove** or at least **provide some evidence** for the conclusion (a statement of **value**). To understand why this is the case, consider the following general **argument**.

1) What **is** so.

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2)**Thus**, what **ought** to be so.

The first thing to note is that the above general **argument** is **invalid**, since the conclusion clearly does not follow from the premises. We cannot get an ***ought*** (a prescription) from an ***is*** (a description) because the **conclusion** states something that is not contained in the **premise**. The **premise** says nothing about what ought to be the case (an **ethical judgment**: something is **good, bad, right, or wrong**).

One way we can think about how events or actions are connected is by appealing to the notion of causation. **Causation**[19] is concerned with **causes** and **effects**. A **cause** is the reason *why* something happens. A **cause** is an event or action that directly makes something happen; an **effect** is *what* happens because of the cause—it is what happens as a result of the cause. The research **hypothesis** is an alleged **causal chain (or pathway)** that **predicts** a hypothesized relationship. From this point of view, **causation** is the capacity of one variable to directly influence another. **Causation** is important in **experimental** studies because it is the bridge that links the **independent** (**A**) and **dependent** (**B**) variables of the research **hypothesis** (If **A**, then **B**), enabling the experimenter to transcend mere correlation. For there to be **support for causation**, however, a systematic method for determining **causation** is necessary. This means that the **cause A** and **causal chain** (**A** *causes* **B**) need to be determined so that given the alleged cause **A**, the alleged effect **B** will result (i.e., the hypothesized relationship may be subject to **testing** by means of experimentation).

There are **four** criteria[20] for figuring out whether or not there is **evidence** for causation (so that **correlation *can* imply causation**): (1) **There exists a strong and consistent correlation, correspondence, or association**. (So that when the alleged cause **A** is present, the alleged effect **B** tends to be present as well and vice versa.) (2) There is a plausible **explanatory model that is consistent with the data** and **fits with other scientific understanding** so we can **explain the correlation**. (3) **There is precedence** so that the alleged cause **A** must **come before** the alleged effect **B**.[21] That is to say, we can **understand the underlying causal mechanism** for what causes what and in what direction. (4) We can predict, in advance, that **A** will cause **B**, since the alleged cause **A** is **plausible** and **likely** to produce the alleged effect **B (because confounding factors, third variables, or alternative explanations, have been eliminated or controlled)**. So, that ***larger*** values of the **explanatory variable** (i.e., the **dose** of, or **exposure** to, the cause) are associated with ***stronger*** responses (i.e., the effect).

Causation is important in *empirical* **science** because, when successfully attributed, the experimenter can establish **beliefs** that are **true** (i.e., the experimenter can establish that claims correspond with reality) and are **justified** (i.e., the experimenter can provide good arguments for believing each claim or deduced implication). According to Aristotle,

> *We suppose ourselves to possess unqualified scientific knowledge of a thing, as opposed to knowing it in the accidental way in which the sophist knows, when we think that we know the cause on which the fact depends, as the cause of that fact and of no other, and, further, that the fact could not be other than it is.*[22]

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[19]For a philosophic enquiry into the ontological problem of causality and specific emphasis on the place of the causal principle in modern science, see Bunge, M. 2009. *Causality and modern science.* 4th rev. ed. New Jersey: Transaction Publishers.

[20]Other sources may provide longer lists of the criteria in different order and/or form. But, all the basic elements for figuring out whether or not there is **evidence** for causation will still be there.

[21]With some exceptions: Battersby, M. 2010. *Is that a fact? A field guide to statistical and scientific information*. Ontario: Broadview Press, 121.

[22]Posterior Analytics (Book 1, Part 2). See Aristotle. 1941. *The basic works of Aristotle*. Edited by R. McKeon. New York: Random House.

To be sure, **a goal of science is to figure out which patterns are real**—one way of achieving this is **to figure out which correlations are really causations**. But, the process of successfully attributing causation is itself not without problems, for the **causal chain** (or **pathway**) of events is often not that clear. For instance, can we be sure that **A** causes **B**, or is it, in fact, the other way around that **B** causes **A**? Or, is there a common factor **C** that can cause one or the other or both? Or, could it be the case that the causal chain (or pathway) of events loops so that both **A** causes **B** and **B** causes **A**?

Moreover, some have difficulty determining what a correlation is and how it is established. And, unfortunately, this, in many cases, leads some to reason incorrectly (i.e., commit a fallacy) that correlation is the same thing as causation. For example, there is a widespread held belief that **fat consumption is linked to heart attacks** (this is a correlational claim). In other words, much fat in your diet is a **risk factor** for getting a heart attack. But, do you really believe that fat consumption is linked to heart attacks? Could it be that there is no *positive* **correlation**, **association**, **relationship**, or a **correspondence between these two changing things**? Consider, for instance, the paradox of high-fat diets that are associated with **reduced** heart disease (this is a *negative* **correlation**). The well-known *Mediterranean diet*, for example, is simply high-fat Greek food that is good for your health. Or, how about consumption of French cuisine that consists of much fat, but is associated with a relatively low rate of heart attack?[23]

What is crucial here to realize is that only by **comparing** rates of the effect in those who are in the target category (e.g., high-fat diets that are associated with heart disease) with those who are not (e.g., high-fat diets that are associated with reduced or no heart disease), can we know if being in a particular category is **correlated** with some possible effect (e.g., getting a heart attack). Accordingly, when searching for correlations, we *…need to compare two samples before making claims about the population generally.*[24] Consider below the argument *form* for this line of fallacious thinking (premise 2 is usually suppressed by the person committing the fallacy).

1. **X** is correlated with **Y**.
2. Correlation is the same thing as causation.

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3. Thus, **X** causes **Y**.

Let us apply this to thinking in regard to causal claims about autism. Some have claimed, for instance, that the real cause of increasing autism prevalence is **increases in organic food sales**.[25] This is because data shows that **increases in organic food sales** and **incidents of children diagnosed with autism** are very strongly associated. We may **operationalize** this as the **hypothesis**: **if children eat organic foods, then they get autism**. But, does this data presented as part of an **observational study** really show that **autism is caused by eating organic foods**? Of

[23]Battersby, M. 2010. *Is that a fact? A field guide to statistical and scientific information*. Ontario: Broadview Press, 99 (adapted).
[24]Ibid, 105; 103 (adapted).
[25]See Suresh, A. 2015. Genetic literacy project: Autism increase mystery solved: No, it's not vaccines, GMOs glyphosate–or organic foods (https://www.geneticliteracyproject.org/2016/09/22/autism-increase-mystery-solved-no-its-not-vaccines-gmos-glyphosate-or-organic-foods/). Accessed January 22, 2017.

course not, since the data only shows a **very strong positive correlation (note: r = 0.9971), but *not* a causal link**. The **argument** for this line of fallacious thinking **applied** to autism is as follows.

1. **Eating organic foods** is **correlated** with **autism**.
2. Correlation is the **same** thing as causation.

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3. Thus, **eating organic foods causes autism**.

A variation of this is called ***Post hoc ergo propter hoc*** (Latin: *after this, therefore because of this*). For our purposes, this simply is interpreted as the following **argument *form*** (**premises 2 and 3** are usually **suppressed** by the person committing the fallacy):

1. **X** occurs ***before*** (getting) **Y**.
2. **X** is **correlated** with **Y** (because of premise 1).
3. Correlation is the **same** thing as causation.

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4. Thus, **X causes Y**.

Consider below the **argument** for this line of fallacious thinking **applied** to autism.

1. **Eating organic foods** occurs ***before*** (getting) **autism**.
2. **Eating organic foods** is **correlated** with **autism** (because of premise 1).
3. Correlation is the **same** thing as causation.

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4. Thus, **eating organic foods causes autism**.

To sum up, a common core understanding of **critical thinking** is about taking some **argument** apart by means of **analysis**, and **evaluating** whether some derived conclusion follows from the evidence. So, when we look critically at the (now fleshed-out) **argument *forms*** above, we can see then that the derived conclusion need not always follow from the premises. Accordingly, because **empirically observed correlation is a necessary, but not sufficient condition for causation**, we have to be **skeptical** about this type of reasoning. If we are not skeptical about this type of reasoning, we might commit the **fallacy of correlation equals causation** (or, **fallacy of false or questionable cause**).[26]

IV. Engaging in a form of methodological skepticism that systematically and continuously asks Critical Questions

[26]Adapted from Talavera, I. 2016. The acquisition of scientific knowledge via critical thinking: A philosophical approach to science education. *The Forum on Public Policy*, Vol 2016, No. 2, 1-66.

Consider the following philosophical approach that, by means of critical thinking,[27] we will apply later on to claims about **autism and vaccinations**.

CRITICAL QUESTIONS

I. BELIEF:[28]

What is the belief? (What is being claimed? What is the conclusion? What is the hypothesis?)

II. SKEPTICISM:[29]

Are there reasons to doubt the belief?

III. CRITICAL THINKING (ANALYSIS + EVALUATION):

A. ANALYSIS:

1. What is the argument for the belief?
2. What is the conclusion? (What is being claimed?)
3. What are the premise(s)? (What is the evidence?)
4. TRUTH: Are the premises true?

B. EVALUATION:

1. How good is the argument?

a. Is it inductive (strong, cogent)?
b. Is it deductive (valid, sound)?

2. How good is the conclusion? (How good is the claim?)

a. JUSTIFICATION: Does the conclusion logically follow from the premise(s)? (Does the claim logically follow from the evidence?)

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[27]Here we have significantly modified and fleshed out Battersby's four basic questions from this philosopher's excellent book: *Is that a Fact? A Field Guide to Statistical and Scientific Information*: 1. What is being claimed? 2. How good is the evidence? 3. What other information is relevant? 4. Are relevant fallacies avoided? This methodological approach to critical thinking and the following application are adapted from Talavera, I. 2016. The acquisition of scientific knowledge via critical thinking: A philosophical approach to science education. *Forum of Public Policy*, Vol 2016, No. 2, 1-66.

[28]For those engaged in the process of the acquisition of **scientific** knowledge, there must be the realization that our beliefs and/or opinions do not always correspond with reality (see Skewed Views of Science: https://www.youtube.com/watch?v=LuEO-K_-vgI. Accessed May 13, 2017.). In this light, experimental studies must be set up as a way to **critically** know reality on its own terms. Accordingly, each hypothesis can be tested for truth by means of experimentation (enter empiricism), but also justified with good arguments for believing it (enter rationalism). This helps to paint an **objective** and **logically consistent** picture of reality.

[29]See J. Schwarcz. 2012. The importance of skepticism in science. *TEDxMontrea*l (https://www.youtube.com/watch?v=YdkPt6DUKuI). Accessed May 12, 2017.

3. How good are the premise(s)? (How good is the evidence?)

a. Is the evidence credible? Plausible? (Are the premises known by personal experience, do they contradict personal experience, do they contradict other statements we know to be true, are they supported by an honest and reputable authority, journal, reference source, or media source we know and trust?)

b. Is each premise reliable, uses language that is concrete and concise, avoids loaded language, uses consistent terms, and sticks to one meaning for each term?[30]

c. Assuming the premise(s) are true, how much support do these premise(s) provide for the claim? (Assuming the evidence is true, how much support does this evidence provide for the claim?)

4. Does the argument meet the burden of proof?

a. Is the argument consistent with the direction of previous (or other) research or evidence?

b. If in conflict with previous (or other) research, does the argument deal effectively with opposing evidence or arguments? Is it strong enough to counter this previous (or other) research?

5. Is there relevant information that is missing?

a. Is there any context or background information of the argument missing? Any assumptions missing? Any ignored or actively suppressed premises? Any hidden third, extraneous, lurking, spurious, or confounding factor or variable omitted?

6. Is the argument fallacious? Are relevant fallacies avoided?

V. Philosophical approach applied to claims about autism and vaccinations

As we have seen, the foregoing highlights critical thinking by analyzing and evaluating arguments for claims by way of a form of methodological skepticism that systematically and continuously asks Critical Questions. Let us apply this philosophical approach to demonstrate how we can deal directly and systematically with students' (and publicly popular) misconceptions of (and resistance to) bio-medical knowledge, interventions, and/or technology employed in healthcare or public health.

Consider the following **made-up** poll report as our example. Let us suppose that on a specific date, a national poll report is published in the **National Enquirer** (a popular tabloid newspaper). The headline states: ***Support for measles, mumps, and rubella (MMR)-vaccinations***

[30]Adapted from Weston, A. 2000. *A rulebook for arguments.* 3rd ed. Indianapolis: Hackett Publishing Co., Inc.

plunges (RESULTS: DON'T VACCINATE: 75%; VACCINATE: 25%). But, after some extensive research, you (the investigator) find out that the *national* poll was based on a street survey carried out in Rodeo Drive (a street in Beverly Hills, California, where the very rich and famous shop, live, and eat). Moreover, you find out that the street survey (claiming a margin of error ± 5 percentage points) asked five-hundred rich celebrities who are very influential political activists: ***Which of the following four options do you support?***

1. Vaccinate at the risk of getting autism from the vaccine (3% supported this option).
2. Seek an alternative (less dangerous) medical approach (27% supported this option).
3. Do nothing (48% supported this option).
4. Vaccinate (22% supported this option).

Furthermore, you find out that the poll was taken just after a major news report about how some influential celebrities fear inoculating their children against childhood diseases because of the link between vaccines and autism.

CRITICAL QUESTIONS APPLIED

I. BELIEF:

What is the belief? (What is being claimed? What is the hypothesis?)

(National) support for measles, mumps, and rubella (MMR)-vaccinations plunges.

II. SKEPTICISM:

Are there reasons to doubt the belief?

We may doubt the belief because of the following reasons.

> **1.** We may question whether the sponsor of the poll is biased and whether this bias affected the poll. The reason for this is that throughout the years, the National Enquirer has developed an unsavory reputation of promoting scandals and fabrications. To be sure, these scandals and fabrications are sought by the general public for their entertainment value. But, as a tabloid newspaper in the business of drawing in readers to increase circulation and income, it is almost certain that their polling was biased and this bias affected the poll.
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> **2.** The people involved do not appear to understand the issue. Sometimes, those that are promoting a particular agenda are individuals who refuse to think critically about an issue because of hardened beliefs and/or motivated reasoning. This *my-way-or-the highway* or *self-serving* belief system may block understanding of an issue. As noted by Battersby, the sad reality is that *...it is the unreflective and uninformed beliefs of many people that determine how they vote*.[31] So, people who have already made-up their minds (in the

[31]Battersby, M. 2010. *Is that a fact? A field guide to statistical and scientific information*. Ontario: Broadview Press, 37.

dogmatic sense) do not think critically. This is because it takes a lot of work and determination

> *...to discover and overcome personal prejudices and biases; to formulate and present convincing reasons in support of conclusions; and to make reasonable, intelligent decisions about* ***what to believe*** *and* ***what to do***.[32]

3. There appears to be self-selection involved by the respondents. Accordingly, we may question whether the respondents of the poll are biased and whether this bias affected the poll. For any such person, what is true (or false) really does not matter in a *my-way-or-the highway* belief system.

4. Does the claim made by the poll report about a population base itself on a sample involving a margin of error? The actual poll did not mention a margin of error. But, after some extensive research, the investigator found out that the street survey poll claimed a margin of error ± 5 percentage points.

5. Does the poll report mistake the information about the sample, for the claim about the population? The poll report definitely mistakes the information about the sample for the claim about the population. One may ask, *Where is the lack of support coming from?* The poll report appears to have intentionally mistaken the information about the sample of five-hundred rich celebrities (who are very influential political activists) for the claim about the population. Shouldn't the headline say **Support for *measles, mumps, and rubella (MMR)*-vaccinations plunges for most rich celebrities sampled**?

6. Does the poll report really reflect the questions asked? The poll report cannot really reflect the question asked, if crucial factors that make up the question are not reported in this poll report.

7. The claim in question (***National*** **support for *measles, mumps, and rubella (MMR)*-vaccinations plunges.**) is not beyond a **reasonable** doubt, since there exists a **hypothesis** that explains the evidence and accounts for it **better** than any other competing explanation—**a best explanation**. A hypothesis $\mathbf{h_2}$ explains the evidence and accounts for it **better** than $\mathbf{h_1}$ whenever it is simpler (i.e., it makes less assumptions), does not raise more questions than it answers, makes testable predictions, fits well with established beliefs, and/or increases the amount of understanding (since it systematizes and unifies well our knowledge). This way of rating or evaluating which hypothesis (claim or belief) is best is called **the Criteria of Adequacy**.[33] Accordingly, hypothesis h_2 (**Support for measles, mumps, and rubella (MMR)-vaccinations among five-hundred rich celebrities who are very influential political activists plunges.**) explains the evidence and accounts for it better than hypothesis h_1 (***National*** **support for *measles, mumps, and rubella (MMR)*-vaccinations plunges.**).

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[32]Bassham, G., W. Irwin, H. Nardone, and J. M. Wallace. 2008. *Critical thinking: A student's introduction.* 3rd ed. New York: McGraw-Hill, 1, emphasis added.

[33]Schick Jr., T., and L. Vaughn. 2008. *How to think about weird things: Critical thinking for a new age*. 5th ed. New York: McGraw-Hill, 179-190.

III. CRITICAL THINKING (ANALYSIS + EVALUATION):

A. ANALYSIS:

1. What is the argument for the belief?

1) Five-hundred rich celebrities who are very influential political activists do not support measles, mumps, and rubella (MMR)-vaccinations.

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2) Thus, (national) support for measles, mumps, and rubella (MMR)-vaccinations plunges.

2. What is the conclusion of this argument? (What is being claimed? What is the hypothesis?)

(National) support for measles, mumps, and rubella (MMR)-vaccinations plunges.

3. What are the premise(s) of this argument? (What is the evidence?)

The evidence consists of the respondents' answer to the question surveyed: *Support for measles, mumps, and rubella (MMR)-vaccinations plunges (RESULTS: DON'T VACCINATE: 75%; VACCINATE: 25%).*

PREMISE: Five-hundred rich celebrities who are very influential political activists do not support measles, mumps, and rubella (MMR)-vaccinations.

4. Are the premise(s) true?

Yes.

B. EVALUATION:

1. How good is the argument?

When we look at the form of the argument above, we can see that the derived conclusion need not always follow from the premise. This is a WEAK **inductive** argument because it has the following form.

1. [Sample][34]

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2. Thus, [population]

2. How good is the conclusion? (How good is the claim? Is the belief true? Does the belief correspond with reality? Is the belief justified?)

[34]The brackets are used to indicate that a statement is being made about what is enclosed.

A WEAK inductive argument form means that the reason provided as evidence for the conclusion is inadequate for accepting the conclusion **(*National* support for measles, mumps, and rubella (MMR)-vaccinations plunges.**).

3. How good are the premise(s)? (How good is the evidence?)

The evidence is not good because assuming the evidence is true, it does not provide much support for the claim. Given that the survey asked only five-hundred rich celebrities who are very influential political activists, the reasoning appears to really go from observations about some of this group's characteristics to a claim about an entire (much bigger) group (i.e., the population on a *national* level).
The evidence is not credible because of the following reasons.

a. The sampling method (known as CONVENIENCE SAMPLING) **was biased** because not only was it not random, but the sampling method was also not geographically and economically representative. The sampling method involved self-selection bias because the subjects (rich celebrities who are very influential political activists) chose themselves to respond. And, those who went to the trouble of responding tended to be those who overwhelmingly DO NOT approve of vaccinations. Furthermore, the sampling method involved other inevitable sampling biases, for instance, consider the bias resulting from non-response attributable to **minority languages**. Since the poll was not geographically and economically representative, the poll was clearly biased in favor of those who frequently visit Rodeo Drive (a street in Beverly Hills, California, where the very rich and famous shop, live, and eat) and speak the dominant language (English). Most likely, thousands of very low-income people and/or thousands of people who do not speak the dominant language benefited from the MMR-vaccine. But, based on the poll's poor sampling, the poll excludes them.

b. The sample was not large enough because of the following reasons.

> **i.** Does the poll report provide a sample large enough to generate the kind of margin of error and confidence level as a reasonable basis for claims about **national** issues (i.e., 1,200 people, ±3 percentage points[35])? For a *national poll*, the 500 sample was not large enough to establish the claim. Hence, the margin of error of ±5 percentage points they claim should not be allowed.
>
> **ii.** Does the poll report provide a sample large enough to generate the kind of margin of error and confidence level as a reasonable basis for claims about **local** issues (i.e., 500 people, ±5 percentage points[36])? The poll report provides a sample large enough to generate the kind of margin of error and confidence level as a reasonable basis for claims about LOCAL issues, since

[35]Battersby, M. 2010. *Is that a fact? A field guide to statistical and scientific information*. Ontario: Broadview Press, TABLE 1, 28.
[36]Ibid.

the survey asked 500 people from California. But, they claim it was a *national* poll.

c. The margin of error was not allowed for and credible. A random sample of 500 people would require a margin of error of about ±5 percent.[37] But, since the respondents were self-selected, the notion of randomness was left out. So, the concept of the margin of error for such a *national* poll is certainly not credible and should not be allowed. As Battersby notes,[38] *[t]he results of polls like this one should never be relied on*. Is it reasonable to assume that the actual margin of error is greater? The margin of error, when reported accurately, is the mathematical ideal. As Battersby notes,

> *[t]he practical constraints of everyday polling mean that the margin of error is undoubtedly greater than the theoretical ideal. Don't let reporters slip misleadingly precise sample percentages by you as if that was the true figure for the population of the country*.[39]

d. There were non-sampling biases. The questions, question order, survey introduction, or interviewer invited biased answers. There was non-sampling bias that directly invited a ***DON'T VACCINATE*** response, since the question wording and order affected the respondent's answers. It appears that the sponsor of the poll was able to easily manipulate the survey's results by providing options that remind respondents of issues critical to any form of vaccination. So, by providing option 4 last (see below), the specific alternatives stated before option 4 may have actually caused people to decrease their support level for vaccination. This results in QUESTION ORDER BIAS.[40]

> ***Which of the following four options do you support?***
>
> 1. Vaccinate at the risk of getting the autism from the vaccine (3%).
> 2. Seek an alternative (less dangerous) medical approach (27%).
> 3. Do nothing (48%).
> **4. Vaccinate (22%)**.

4. Does the argument meet the burden of proof?

a. The argument is not consistent with the direction of research on vaccinations or evidence about the risk of getting the autism from the vaccine. To be sure, there is competing evidence contrary to the poll's claims.[41]

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[37]Ibid.
[38]Ibid, 51.
[39]Ibid, 50.
[40]Ibid, 47.
[41]For web resources for classroom teachers, their students, and students' families, see **Appendix: Competing Evidence Contrary to the Poll's Claims**.

b. It is clear that the argument does not meet the burden of proof because it is in conflict with present scientific/medical research. Moreover, since the argument does not make any attempts to deal effectively with opposing evidence or arguments, it is not strong enough to counter this previous (or other) research.

5. Is there relevant information that is missing?

Other relevant information is as follows.

a. The poll was taken just after a major news report about how some influential celebrities fear inoculating their children against childhood diseases because of the perceived link/correlation between vaccines and autism. Hence, because the poll was taken just after a major news event, it could have easily temporarily influenced people's views (by appealing to fear, for example). For, unfortunately, this leads some to reason incorrectly that correlation is the same thing as causation (i.e., some commit the fallacy of false or questionable cause).

b. It is clear that the respondents lacked thought and information, particularly about such crucial scientific issues. Unfortunately, non-credible answers such as these sooner or later influence public policy. It is a sad reality indeed that ...*it is the unreflective and uninformed beliefs of many people that determine how they vote*.[42]

6. Is the argument fallacious? Are relevant fallacies avoided?

The argument is fallacious because it attempts to generalize properties by drawing conclusions from the sample (part) to the population (whole). This is known as **the part-whole fallacy.**

Relevant fallacies were not avoided. As reviewed above, the value of the poll is undermined by:

a. Reporting sample statistics as if they were population statistics
The poll report appears to have intentionally mistaken the information about the sample of five-hundred rich celebrities who are very influential political activists for the claim about the population.

b. Committing selection bias, self-selection bias, and non-response bias
The sampling method involved self-selection bias because the subjects (rich celebrities who are very influential political activists) chose themselves to respond. And, those who went to the trouble of responding tended to be those who overwhelmingly DO NOT approve of vaccinations.

c. Non-sampling bias created by question phrasing, question order, or poll introduction

[42]Battersby, M. 2010. *Is that a fact? A field guide to statistical and scientific information*. Ontario: Broadview Press, 37.

> It appears that the sponsor of the poll was able to easily manipulate the survey's results by providing options that remind respondents of issues of which are critical of any form of vaccination. So, by providing option 4 **last** (i.e., *Vaccinate*), the specific alternatives stated before option 4 may have actually caused people to decrease their support level for vaccination. This results in QUESTION ORDER BIAS.[43]

VI. Objections and Conclusion

Some object that science and philosophy are concepts so different to each other that both subjects cannot share the positive relationship attributed in this discussion. But, science is primarily concerned with **knowledge** claims and inquiries about physical reality. Accordingly, it may be considered a subfield of the Theory of Knowledge (also known as Epistemology). And, the Theory of Knowledge is a field of Philosophy. Not surprisingly, then, because its focus is to seek knowledge about the composition and order of everything in the physical universe, science may be characterized as *natural* philosophy.[44] As such, it seeks **to analyze and evaluate arguments**[45] for competing hypotheses in order to (as a goal) discover whether our beliefs correspond with the natural world and/or discover whether there are good reasons and arguments for believing so. In addition, by learning how to analyze and evaluate arguments, the characteristics, methodology, and limitations of science may be contrasted to other alleged sources of knowledge.

To be sure, the largest single contributor to understanding science is not the factual content of the scientific discipline, but rather the ability of students to think, reason, and communicate critically about that content. For, *[t]he purpose which runs through all other educational purposes—the common thread of education—is the development of the ability to think*.[46] And, embedded in the very fabric of any scientific endeavor or training is critical thinking. As Jeffrey Lee notes, *[t]he ability to think critically is crucial for scientists. Scientists must be able to make decisions based primarily on reason, not wholly on emotion…*.[47] Accordingly, *science education helps students indirectly by pushing them to develop the critical thinking skills necessary **to evaluate all kinds of phenomena**, scientific, pseudoscientific, and other*.[48] In this sense, the means and methods employed in science may be defined and determined by *any procedure* [of critical thinking] *that serves systematically to eliminate reasonable grounds for doubt*.[49] And, by *systematically* eliminating reasonable grounds for doubt, we address skepticism's critical question whether there are reasons to doubt a belief. In view of that, the higher-cognitive skills of analysis

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[43]Ibid, 47.
[44]Colodny, *Beyond the Edge of Certainty: Essays in Contemporary Science and Philosophy*, The Ethical Dimension of Scientific Research, 276.
[45]As noted by Kuhn, Teaching and Learning Science as Argument, 810: *A conception of science as argument has come to be widely advocated as a frame for science education …. Bricker and Bell (2009) identify argumentation as a 'core epistemic practice' of science and accordingly claim that the goal of science education must be not only mastery of scientific concepts but also learning how to engage in scientific discourse.* Underlying the individual skill in dialogic argumentation, however, is the skill of analyzing and evaluating arguments, which is the core part of critical thinking. Accordingly, throughout this treatise we used the term *argument* the way logicians do, to refer to a logical structure.
[46]Educational Policies Commission, quoted in Bassham, *et al*., *Critical Thinking: A Student's Introduction,* 1.
[47]Lee, *The Scientific Endeavor: A Primer on Scientific Principles and Practice*, 84.
[48]Ibid (136, emphasis mine).
[49]Schick and Vaughn, 173.

and evaluation necessary for students to secure scientific knowledge and scientific habits of mind may be achieved more **directly** by teaching science as critical thinking.[50]

Accordingly, the nature and practice of science is given expression in how the science student and/or scientist uses critical thinking—in what critical thinking makes them do with the means and methods of science, in how critical thinking describes and codifies the physical world, in which aspects of reality critical thinking focuses on, and in which beliefs critical thinking rightly avoids. So, since epistemology and critical thinking are the appropriate focus of attention for understanding the production of scientific knowledge, the foregoing strongly suggests the possibility of a **dialogue between philosophy and the bio-medical sciences** that highlights the acquisition of scientific knowledge via critical thinking.[51]

Thus, critical thinking may be applied to claims about **autism and vaccinations** so that the educator may develop a more robust understanding about this contemporary issue in science, and deal directly and systematically with misconceptions of (and resistance to) bio-medical knowledge, interventions, and/or technology employed in healthcare or public health. In short, by highlighting the critical thinking that (1) analyzes and evaluates arguments, and (2) engages in a form of methodological skepticism that systematically and continuously asks Critical Questions, the educator can help students actively compare their initial conceptions (and publicly popular misconceptions) with more fully scientific conceptions.

Appendix: Competing Evidence Contrary to the Poll's Claims.

Videos (Accessed May 18, 2016):

AUTISM SPEAKS Says the Science is Settled. Vaccines Don't Cause Autism (https://www.youtube.com/watch?v=HyTWIVj4HR4).

Vaccines Don't Cause Autism: Healthcare Triage #12 (https://www.youtube.com/watch?v=o65l1YAVaYc).

[50]A great part of this paragraph is taken from Talavera, I. 2016. The acquisition of scientific knowledge via critical thinking: A philosophical approach to science education. *Forum of Public Policy*, Vol 2016, No. 2, 36.

[51]As noted by Rowe, *et al*. in Redesigning a General Education Science Course to Promote Critical Thinking, 1-2: *A primary goal of education in general, and higher education in particular, is to improve the critical-thinking skills of students (Facione et al., 1995; Van Gelder, 2005; Bok, 2006). Sadly, higher education appears insufficient to the task, with recent studies (Arum and Roksa, 2010; Arum et al., 2011; Pascarella et al., 2011) showing minimal gains in students' critical-thinking and analytical skills during their undergraduate careers, reducing their employment potential upon graduation (Arum and Roksa, 2014).* This entire paragraph was adapted from Talavera, I. 2016. The acquisition of scientific knowledge via critical thinking: A philosophical approach to science education. *Forum of Public Policy*, Vol 2016, No. 2, 1-66.

Studies Confirm, Vaccines Still Don't Cause Autism. But Are These Studies Helping? (https://www.youtube.com/watch?v=j_zqBPuPx8w).

The Science of Anti-Vaccination (https://www.youtube.com/watch?v=Rzxr9FeZf1g).

Vaccines Do NOT Cause Autism! What Does? (https://www.youtube.com/watch?v=_fyJM24BiMU).

References

Aristotle. 1941. *The basic works of Aristotle*. Edited by R. McKeon. New York: Random House.

Bassham, G., W. Irwin, H. Nardone, and J. M. Wallace. 2008. *Critical thinking: A student's introduction.* 3rd ed. New York: McGraw-Hill.

Battersby, M. 2010. *Is that a fact? A field guide to statistical and scientific information*. Ontario: Broadview Press.

Ben-Ari, M. 2005. *Just a theory: Exploring the nature of science*. Amherst: Prometheus Books.

Biss, E. 2014. *On immunity: An inoculation.* Minneapolis: Graywolf Press.

Boersema, D. 2009. *Philosophy of science: Text with readings*. New York: Pearson Prentice Hall.

Bunge, M. 2009. *Causality and modern science.* 4th rev. ed. New Jersey: Transaction Publishers.

Campbell, S. K. 2002. *Flaws and fallacies in statistical thinking*. Mineola: Dover Publications, Inc.

Caste, N. J., and J. H. Kiersky. 1995. *Thinking critically: Techniques for logical reasoning*. St. Paul: West Publishing Co.

Colodny, R. G., ed. 1965. *Beyond the Edge of Certainty: Essays in Contemporary Science and Philosophy*. New Jersey: Prentice-Hall, Inc.

Easton, T. A., ed. 2009. *Taking sides: Clashing views in science, technology, and society.* 8th ed. New York: McGraw-Hill.

Ede, A. 2000. Has science education become an enemy of scientific rationality? *Skeptical Inquirer* 24: 48-51.

Epstein, R. L., and C. Kernberger. 2006. *The pocket guide to critical thinking*. Belmont: Wadsworth.

Eve, R. A., and D. Dunn. 1990. Psychic powers, astrology & creationism in the classroom? Evidence of pseudoscientific beliefs among high school biology & life science teachers. *The American Biology Teacher* 52 (1): 10-21.

Facione, P. A., C. A. Sánchez, N.C. Facione, and J. Gainen. 1995. The disposition toward critical thinking. *The Journal of General Education* 44 (1): 1-25.

Funk, C., and L. Rainie. 2015. Public and Scientists' Views on Science and Society. *Pew Research Center* (http://www.pewinternet.org/2015/01/29/public-and-scientists-views-on-science-and-society/). Accessed December 31, 2016.

Grant, J. 2011. *Denying science: Conspiracy theories, media distortions, and the war against reality.* Amherst: Prometheus Books.

Gross, P. R., and N. Levitt. 1994. *Higher superstition: The academic left and its quarrels with science*. Baltimore: The John Hopkins University Press.

Hume, D. 1739. *A Treatise of Human Nature* (https://people.rit.edu/wlrgsh/HumeTreatise.pdf) Accessed May 25, 2017.

Impey, C., S. Buxner, and J. Antonellis. 2012. Non-scientific beliefs among undergraduate students. *Astronomy Education Review*: 010111-1–010111-12.

Johnson, M., and M. Pigliucci. 2004. Is knowledge of science associated with higher skepticism of pseudoscientific claims? *The American Biology Teacher* 66 (8): 536-548.

Kuhn, D. 1993. Science as argument: implications for teaching and learning scientific thinking. *Science Education* 77 (3): 319-337.

Kuhn, D. 2010. Teaching and learning science as argument. *Science Education* 94: 810-824.

Lambert, K., and G. G. Brittan, Jr. 1992. *An introduction to the philosophy of science*. 4th ed. Atascadero: Ridgeview Publishing Co.

Lee, J. A. 2000. *The scientific endeavor: A primer on scientific principles and practice.* San Francisco: Addison Wesley Longman.

Levine, S., and F. F. Elzey. 1968. *A programmed introduction to research.* Belmont: Wadsworth Publishing Company, Inc.

Mayfield, M. 2001. *Thinking for yourself: Developing critical thinking skills through reading and writing*. USA: Thomson Learning, Inc.

Mnookin, S. 2011. *The panic virus: The true story behind the vaccine-autism controversy*. New York: Simon & Schuster, Inc.

Momsen, J. L., T. M. Long, S. A. Wyse, and D. Ebert-May. 2010. Just the facts? Introductory undergraduate biology courses focus on low-level cognitive skills. *CBE—Life Sciences Education* 9: 435-440.

Moore, B. N., and R. Parker. 2015. *Critical thinking*. New York: McGraw-Hill, Inc.

Moore, J. A. 1999. *Science as a way of knowing.* Cambridge, MA: Harvard Univ. Press.

Nagel, T. 1998. The sleep of reason. *The New Republic* (October 12): 32–38.

National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. 2010. *Rising above the gathering storm, revisited: Rapidly approaching category 5.* Washington, DC: National Academies Press.

National Academies of Sciences, Engineering, and Medicine. 2011. Few health problems are caused by vaccines, IOM report finds (http://www8.nationalacademies.org/onpinews/newsitem.aspx?RecordID=13164&_ga=1.163823423.1617847882.1484791305).

Nelson, C. E. 2008. Teaching evolution (and all of biology) more effectively: strategies for engagement, critical reasoning, and confronting misconceptions. *Integrative and Comparative Biology* 48 (2): 213-225.

Norton, J. D. 1998. *How Science Works*. New York: McGraw-Hill, Inc.

Paul, R. W. 2012. *Critical thinking: What every person needs to survive in a rapidly changing world.* Tomales: Foundation for Critical Thinking.

Pecorino, P. A. 1987. Critical thinking and philosophy. *Informal Logic: A Journal of Queensborough Community College, CUNY* IX. 2 & 3 (Spring & Fall): 141-145.

Popper, K. R. 1963. *Conjectures and refutations: The growth of scientific knowledge*. London: Routledge.

Rowe, M. P., B. M. Gillespie, K. R. Harris, S. D. Koether, L. Y. Shannon, and L. A. Rose. 2015. Redesigning a general education science course to promote critical thinking. *CBE—Life Sciences Education* 14 (Fall): 1-12.

Ruggiero, V. R. 2008. *Thinking critically about ethical issues*. 7th ed. New York: McGraw-Hill.

Rutherford, F. J., and A. Ahlgren. 1990. *Science for all Americans*. New York: Oxford University Press.

Sagan, C. 1996. *The demon-haunted world: Science as a candle in the dark.* New York: Ballantine.

Schick Jr., T., and L. Vaughn. 2008. *How to think about weird things: Critical thinking for a new age*. 5th ed. New York: McGraw-Hill.

Shermer, M. 2011. An epidemic of ignorance. *The Wall Street Journal* (http://www.wsj.com/articles/SB10001424052748704034804576025682621085122). Accessed December 13, 2016.

Suresh, A. 2015. Genetic literacy project: Autism increase mystery solved: No, it's not vaccines, GMOs glyphosate–or organic foods (https://www.geneticliteracyproject.org/2016/09/22/autism-increase-mystery-solved-no-its-not-vaccines-gmos-glyphosate-or-organic-foods/). Accessed January 22, 2017.

Talavera, I. 2006. The problem of teaching critical thinking: Three approaches. *NADE Digest* 2 (1) (Spring): 63-69.

Talavera, I. 2011. Beyond ethical codes: A call for critical thinking in religious culture. *The Forum on Public Policy*, Vol 2011, 1-14.

Talavera, I. 2012. Science and religion: Drawing the line. *The Forum on Public Policy,* Vol 2012, 1-25.

Talavera, I. 2016. The acquisition of scientific knowledge via critical thinking: A philosophical approach to science education. *The Forum on Public Policy*, Vol 2016, No. 2, 1-66.

Taylor, L. E., A. L. Swerdfeger, and G. D. Eslick. 2014. Vaccines are not associated with autism: An evidence-based meta-analysis of case-control and cohort studies. *Vaccine* 32 (Issue 29, 17 June 2014): 3623–3629 (http://www.ufrgs.br/boletimcimrs/vacinasfinal.pdf). Accessed December 12, 2016.

Van Gelder, T. 2005. Teaching critical thinking: Some lessons from cognitive science. *College Teaching* 45: 41-46.

Walker, W. R., S. J. Hoekstra, and R. J. Vogl. 2002. Science education is no guarantee of skepticism. *Skeptic* 9: 24-27.

Weston, A. 2000. *A rulebook for arguments.* 3rd ed. Indianapolis: Hackett Publishing Co., Inc.