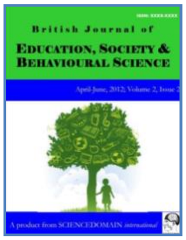

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Friend or Foe? Common Sense in Science Education from the Perspective of History and Philosophy of Science

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Authors' contributions

This work was carried out in collaboration between both authors. Author CHY conceptualized the research study, wrote the first draft of the manuscript and made subsequent revisions. Author JMC revised the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Currently there are two divergent views about the role of common sense in science learning. Educators who side with the notion of restructuring view science learning as an incremental process based upon the student's prior knowledge of everyday physical phenomena. On the other hand, for educators who embrace reconceptualization, science education is concerned with conceptual change against common sense. Although there are plenty of studies pertaining to this topic using cognitive psychology and psychometrics, it is rare for educators to take history and philosophy of science into account for determining the role of common sense in science education. The objective of this article is to fill this vacuum by introducing two perspectives to the relationship between common sense and science concepts, namely, trumping common sense by science and trumping nonsense by common sense. Numerous examples reveal that although certain common sense approaches seem to be detrimental to science learning, which favor learning by reconceptualization, debunking misconceptions could also be built upon common sense beliefs borrowed from other domains.

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1. INTRODUCTION

1.1 Objective

Currently there are two divergent views about the role of common sense in science learning. In the camp of "restructuring," common sense is treated as a friend rather than a foe. Following this approach, science education should aim to restructure existing common-sense-based concepts into scientific reasoning. On the other hand, in the camp of "reconceptualization," common sense is regarded as a hindrance to science education and thus flawed concepts must be replaced with correct ideas. While educational researchers have been consulting voluminous cognitive psychology research that investigates how misconceptions affect science learning [1-9], it is rare for educators to take history and philosophy of science into account for determining the role of common sense in science education. The objective of this article is to fill this vacuum. In addition, although the school of restructuring endorses using tacit dimensions and the existing framework as the learning foundation, sometimes it is difficult to work with the existing common sense when it is completely flawed. Therefore, at the end the authors provide the readers with concrete examples of how some common sense beliefs, which are not directly related to the subject matter, can come to rescue the learners from misconceptions.

1.2 What is Common Sense?

In general, common sense is often defined as a set a cognitive processes (knowing, understanding, perceiving) or a belief system that is shared by most people without need for debate [10]. Interestingly enough, the term "common sense" is not commonsensical at all. Indeed, authors have differed on their ideas about what it is [11-13]. In the mainstream it is typical to use the terms "common sense" and "intuition" interchangeably. For instance, in discussing "commonsense physics knowledge," rather than giving a precise definition, Sherin [12] simply equated common sense with "intuitive knowledge" (p.536) based upon the premise that there is a universal consensus of what intuition is. However, intuition varies from person to person. For instance in the 1980s, the J. Paul Getty Museum in Los Angeles paid $10 million to acquire a so-called "sixth century BC" marble kouros. The museum employed a scientist to utilize a thorough test in order to validate the piece, but at first sight an art historian told the museum that the kouros was a fake! And the art historian was right [14]. In this case, the art historian has the intuitive knowledge that the scientist lacks. The sound intuition of the art historian resulted from accumulating decades of experience with ancient arts. Obviously, intuition varies from person to person, depending upon the background knowledge and experience.

Specifically, in science when common sense is viewed as prior knowledge and experience, it is very problematic and confusing because numerous people at different times and places have different background information. For instance, one hundred years ago, any university student could easily have proved that it is impossible for light to behave sometimes like a wave and sometimes like a particle [15]. This so-called "common-sense" was an obstacle to science learning. In a similar fashion, those who were exposed to Newtonian mechanics first might find Einstein's theory of relativity incomprehensible. To them the concept of "absolute space" under the Newtonian worldview is common sense. However, it is noteworthy that when Newton introduced the concepts of color spectrum of light and action at a distance, he also faced strong resistance from prominent scholars because these concepts seemed to be nonsensical [16]. Scientific realists in the philosophy of science assert that scientific theories go beyond naïve empirical data to posit the existence of non-observable entities. In this view, common-sense-based Newtonian physics could be discarded because quantum mechanics provide us with a more accurate description of reality [17]. But we will be in trouble if all mechanical engineers disregard Newtonian mechanics. By the same token, Einstein, Podolsky and Rosen did not believe in “entanglement” in quantum mechanics, because it contradicted the common-sense notion that a particle could be here and there concurrently [18]. No doubt there are quite a few incompatible elements among these physics theories even though they share a common goal of exploring the ultimate reality in a physical sense. Nonetheless, they describe different realms of the same world and at some point in the history of science some ideas were taken as common sense.

The philosophical background on the role of common sense in science can be traced to Platonic and Aristotelian influences. Redekop [11] analyzed the usage of common sense by looking into the Platonic knowledge. Plato conjectured that there exists the ideal form beyond our imperfect sensory experiences and thus it could not be the foundation of true knowledge. Later medieval thinkers swung to the Aristotelian school, in which the starting point of scientific reasoning was said to be known assumptions and obvious empirical sense. Modern science moved away from the Aristotelian legacy and questioned conventional wisdom. In the 18th century, Thomas Reid attempted to reinstate the value of ordinary experience in scientific inquiry. Interestingly enough, while Redekop positioned the Platonic tradition as an inquiry approach downplaying common sense, some other scholars traced the use of intuition back to Plato. For example, Gödel took an "intuitionistic" position to mathematics by asserting that we have intuitive knowledge of abstract mathematical objects no matter what our sense perception tells us [19]. Later logical positivist Carnap expressed his objection against Gödel intuitonistic approach and the Platonic tradition [20-22]. These conflicting interpretations of Plato are caused by associating common sense with sensory experience in one school and equating common sense with intuitive ideas regardless of sense perception in another camp. Unfortunately, none of the definitions presented above are entirely unproblematic, and each reflects unresolved debates between philosophical and methodological camps.

In cognitive psychology the term “common sense” has a very specific meaning. Usually it is referred to as “folk psychology” or “mind-reading”—how humans make sense of the behaviors of other people by projecting how we would think and act onto other minds. This folk psychology or common sense is a particular set of cognitive abilities to predict and explain behaviors [23]. Wimmer & Perner [24] asserted that certain false beliefs of children arise from misguided folk psychology or common sense: Children don’t understand that their common sense beliefs can misrepresent reality. However, in the context of science learning the scope of common sense beliefs go beyond predicting and explaining human behaviors only.

Taking the above diverse views into account, it is summarized that there are two major approaches to define common sense, namely, the experiential approach and the genetic approach. The former adheres to the tradition of associating common sense with intuition, experience, and background knowledge whereas the latter is tied to the tradition of focusing on folk psychology and innate cognitive abilities. A typical example of the former one is to view common sense as practical intelligence (street smart) [13]. In this perspective common sense is opposed to “academic intelligence,” “book smart [13] (p.913) or “clever silliness”

[25] (p.867). Those researchers made a conjecture that highly intelligent or well-educated people tend to be unable to solve practical problems due to lack of common sense or real-world experience (e.g. What would you do if your car broke down on an interstate highway during a blizzard?) However, this definition is too narrow to be applicable in science learning, because usually science students need to solve both theoretical and practical problems during the learning process.

Rausch [26] introduced a variant of the experiential approach by adding a developmental component. According to Rausch, common sense is the ability of making sound decisions, and adults are more capable of making good judgment than teenagers. Following this line of reasoning, "experience and learning that translates itself into better judgment and reasoning ability, accounts for this change. More precisely, new knowledge led to thought habits that became so solid that hardly a moment has to be spent on decisions to which they apply. That is how common sense and judgment mature" (p.413). However, this definition is too broad to be useful. We could absorb different types of knowledge throughout our developmental stages. In this sense, whatever we learn from our schools, our churches, our parents, our friends, our coworkers, and many others could constitute common sense. On the contrary, some authors define common sense in terms of innate ideas. For example, Redekop [11] defined common sense as follows:

> …those untutored cognitions, intuitions, or "mental instincts" that are elicited in the course of everyday experience, and help to structure that experience. They occur as the result of innate, hardwired mental mechanisms that produce the "self-evident truths" that all healthy human beings perceive just by being in the world – things like the existence of external objects that persist even when we are not observing them, the existence of causal relations between observed events, the existence of human responsibility and intention, basic moral intuitions, an "instinct" for language and basic numerical properties, certain logical inferences, and much more (p.399).

Redekop explicitly excluded all cultural and experimental elements from his definition. However, this approach is still limited because any disposition, inclination, or tendency must be actualized or enhanced by experience. For example, children have the "number sense," the innate ability to count and to judge relative magnitudes [27] (p.327). Nonetheless, how children conceptualize numbers and learn math depends on what number systems they are exposed to (e.g. Arabic, Roman, Chinese…etc.). Dehaene [28] posited that the Chinese names of numbers are easier to remember than their English equivalents. As a result, Chinese children are able to learn mathematics faster than their American counterparts. In other words, complex equations seems more natural or commonsensical to Chinese students. Usually our natural tendency or innate ideas, such as the "number sense" are cultivated early in life and thus it is very difficult, if not impossible, to dis-entangle between nature and nurture.

To rectify the limitations of both approaches, in this study the authors adopted the definition of common sense provided by Clawson [29]: Common sense is rooted in genetic and memetic (cultural) legacies developed early in life. "Common sense consists of our conscious, semi-conscious, and even sub-conscious values, assumptions, beliefsand expectations about the way the world is or should be" (p.470).

1.3 What is Science Learning?

Although there is no universal definition of science learning, scholars and practitioners usually follow the implicit and conventional definition. Today the term “STEM” is often used to denote the demarcation of these four domains: science, technology, engineering and mathematics. Under this framework, science and mathematics are located on the theoretical side whereas technology and engineering are treated as applied sciences. Between science and mathematics, the latter is considered even more theoretical than the former. This convention is expressed in the guideline to science education named “Benchmarks for science literacy” [30]. In the chapter entitled “the nature of science,” science is described as developing “many interconnected and validated ideas about the physical, biological, psychological, and social worlds…The means used to develop these ideas are particular ways of observing, thinking, experimenting, and validating” (p.3). In the next chapter the nature of mathematics is said to be a form of inquiry relying “on logic and creativity” (p.23). In another chapter, the nature of technology is identified as a tool of “extending our abilities to change the world” (p.41). Although sometimes the line of theoretical and applied sciences is not clear-cut, the authors do not dispute that technology learning is not an integral part of science education. To be specific, today many American community colleges provide learners with training in computer programming, website authoring, server configuration, and so on. However, even if the graduate is proficient in trouble-shooting a crashed laptop, installing a server or developing a website, he or she might not acquire the critical thinking and model-based reasoning that are found in science and math learning.

However, based on the new insight pertaining to the nature of science and mathematics, the authors cannot accept the strict demarcation between science learning and math learning. Conventionally, natural science is equated with experiments and observations while mathematics is believed to be non-empirical and logical. As a matter of fact, today fundamental physics and astronomy highly rely on mathematical modeling in addition to empirical data [31]. On the other hand, the belief that mathematics is based on the logical and axiomatic method is no longer true. On the contrary, mathematics, just like physics, chemistry, and biology, is subject to revision based on our experience with the physical reality. One obvious example is that Euclidean geometry was found to be problematic when its theorems were applied to the three-dimensional world [32]. Lakatos went even further to argue that the reasoning mode of math is equivalent to that of empirical science [33]. In light of the recent advancement of experimental mathematics such as Monte Carlo simulations, Yu [22] asserted that limiting mathematical inquiry to the domain of logic is unjustified. Rather, Monte Carlo simulations demonstrate that mathematics is on par with other experimental-based sciences.

Taking the preceding discussion into account, in this article the authors define science learning as acquiring experimental, observational, logical, and mathematical skills to inquire the theoretical structures, processes and relationships of the entities in the world. With that said, science learning includes learning of physics, chemistry, biology, geology, astronomy, and mathematics, but learning of engineering and technology is excluded.

2. RESTRUCTURING VS. RECONCEPTUALIZATION

2.1 Restructuring and Tacit Dimension

Educators who side with the notion of restructuring the cognitive framework view science learning as an incremental process based upon the student's prior knowledge of everyday physical phenomena [34-37]. In other words, science concepts are enhanced ideas based on experiences in daily lives. These experiences make students construct a set of intuitive ideas and theories about how the surrounding world works [38,39]. This idea is in alignment to the mental model proposed by Johnson-Laird [40]. According to Johnson-Laird, human learning and reasoning is based on the construction and evaluation of mental models that represent our empirical world, instead of counting on formal logic. Following this pedagogical approach, new knowledge could be built upon the old knowledge. Prior knowledge derived from common sense is called the "anchoring conceptions" [34], "the rudimentary kernels of more sophisticated knowledge" [41] and "the starting point for development" [36]. Hence, there is no need to completely replace naïve ideas or common sense; rather, the existing knowledge could be restructured and enhanced by scientific knowledge [42,43]

Restructuring is tied to the notion that children possess implicit knowledge about how the world works. For example, according to neo-Piagetian models of cognitive development in psychology [44,45] children make errors in problem solving not only because they lack the cognitive ability to understand the underlying logic of the tasks, but also because children fail to inhibit an overlearned strategy (previous knowledge) and fail to activate the appropriate logical strategy [46,47]. Piaget devised many experiments demonstrating the constraints on thinking during early childhood. A famous set of experiments involved conservation tasks, which emphasize that the amount of substance remains the same even when its appearance changes [48,49]. For example, in the conservation of liquid experiment a child is presented with two identical glasses containing the same amount of liquid. The liquid from one glass is poured into a tall, narrow glass. If young children are asked whether one glass contains more liquid or both glasses contain the same amount, they will insist that the narrower glass, in which the liquid level is higher has more. Piaget argued that young children between the ages of 2 to 6 years old will fail to understand conservation of liquids because of focus centered and static reasoning [50]. In other words, young children reason from prior knowledge, focus only on what they see, and notice only the immediate condition. It does not occur to them that they could reverse the process and re-create the liquid level observed moments ago [51,52].

Another example of how common sense conceptualizations lead to unsuccessful problem solving comes from the class-inclusion problem [49]. In the class-inclusion problem, children are presented with 10 daises and 2 roses and then asked whether there are more daises or more flowers. Children under 7 or 8 years of age will erroneously think that there are more daises than flowers. Children typically fail to perform the appropriate comparison and instead compare the extensions (i.e., the relative numbers) of the two subordinate classes. Researchers argue that errors in the class-inclusion task reveal more about children's inability to resist interference than their ability to grasp underlying logic [53-55]. Although there is growing evidence indicating older children and adults need to inhibit previous knowledge to avoid misconceptions [47], some findings suggest that children are more likely to provide a successful response when a common sense strategy is used to help children determine there are more elements in the superordinate class (e.g., flowers) than in one of the two subordinate classes [55,56].

2.2 Reconceptualization and Paradigm Shift

On the other hand, for educators who embrace reconceptualization, science education is concerned with conceptual change. This conjecture is built upon the philosophy that the mind of students is not like a sheet of blank paper, which is left to the teachers to deposit correct information. On the contrary, the mind of most students has already been preoccupied with flawed common sense. Very often, our common sense contradicts correct scientific concepts, though common sense, as a codification in our natural language is unavoidable in science instruction [57,58]. For example, most students perceive force as an innate or acquired property of objects, which implies that forces are not seen as arising from an interaction between objects [59].

Some misconceptions in science are so resistant that many past and present instructional remedies have been ineffective in conveying the correct ideas. Even innovative instructional interventions have generally failed to improve their understanding [60]. Some researchers asserted that the robustness of the misconceptions could be explained by the notion that learning correct science concepts involves a paradigm shift of the worldview [61-63]. In this view, misconceptions are not just naive, inaccurate or incomplete isolated pieces of knowledge (with respect to the complete and correct scientific conceptions that could be re-organized); rather, they could be the self-sufficient, alternative conceptions that blocking the incoming correct ideas [64,65]. Thus, science teachers must devote tremendous efforts to undo common-sense-based misconceptions held by students in order to redirect them to the right concepts. Prior research has shown that reconceptualization challenges students to modify or change their alternative conceptions for better scientific ideas [66,67].

It is noteworthy that the development of *Force Concept Inventory* (FCI) is considered the seminal milestone of the reconceptualization approach. An early instrument for measuring students understanding of Newtonian mechanics was the Mechanics Diagnostic Test (MDT), which was developed for introductory-level college students at Arizona State University and included local high school students as subjects [58]. Collected data showed that the MDT pre-test scores were consistently low and that there was very little improvement in spite of corrective treatments. Thus, to augment the MDT, the *Force Concept Inventory* was developed in 1992 [68] and about half of the FCI questions are borrowed from the MDT. An updated version of FCI was released in 1995 [59,69]. The target audience of this version of FCI includes both college and high school students in physics classes. The FCI development inspired a massive movement of research and development aimed at improving introductory physics courses by debunking misconceptions. Some of these developed courses are based on cognitive psychology [70]. Recently a simplified version of FCI (SFCI) had been developed and the target audience is extended to middle school students [71]. The following item is adapted from FCI in order to illustrate how FCI emphasizes detrimental effects of misconceptions (FCI developers are concerned that item exposure would affect effective use of FCI and thus the actual item could not be shown here):

A Ford Explorer and a Honda Accord crashed into each other. During the collision:

(A) The Ford Explorer exerts a greater amount of force on the Honda Accord than the Honda Accord exerts on the Ford Explorer.
(B) The Ford Explorer exerts a force on the Honda Accord, but the Honda Accord does not exert a force on the Ford Explorer.
(C) The Ford Explorer exerts the same amount of force on the Honda Accord as the Honda Accord exerts on the Ford Explorer.

(D) Insufficient information. It depends on the speed of the two vehicles.

The correct answer is (C) whereas Distracter A and B are mapped to the misconception that most active or larger agent produces greatest force and Distracter D represents the misconception that a faster object exerts a greater force. These misconceptions are based on the “conflict metaphor” in action, in which students often see an interaction as a conflict between competing forces, and they think that victory belongs to the stronger [72].

3. TWO PERSPECTIVES TO THE RELATIONSHIP BETWEEN COMMON SENSES AND SCIENCE

While the aforementioned studies utilized psychometrics and cognitive psychology to address the issues of common sense and misconception, this analysis employs history and philosophy of science. In history and philosophy of science there are also two major perspectives to the relationship between common senses and science concepts. These are trumping common sense by science and trumping nonsense by common sense. Each of these will be discussed in the following sections.

3.1 Trumping Common Senses by Science

As the name implies, the notion of trumping common sense by science is similar to reconceptualization in science education. There is a well-established Western philosophical tradition that human perception is regarded as being unreliable [73]. With the advance of fundamental physics, physicists reveal the subatomic world that our naked eyes could not see before. For some scientists only those attributes that apply to the fundamental entities, or to aggregates of fundamental entities, such as mass, position, electric charge, and so on really exists. Common-sense perception is nothing but illusory [74].

Further, according to Wolpert’s [75] the nature of scientific knowledge is unnatural; common-sense thinking and formal scientific reasoning are two extremely different views toward knowledge. One end of the polarity is the comfortable ignorance of never having considered that things could be otherwise, whereas the other is ongoing self-examination of the evidence and subsequent corrections. This view is echoed by a recent outcry of resistance to science by people who hold beliefs about the immaterial nature of the mind [76]. According to Bloom and Weisberg, the problem with teaching science to children is not what the student lacks but what the student has, which is an alternate conceptual framework based on common sense. In Bloom and Weisberg’s view, the “common sense” that the mind is fundamentally different from the brain comes naturally to children. Preschool children accept that the brain is responsible for some aspects of mental life, such as solving math problems. But at the same time they also deny that the brain has something to do with loving one’s brother. To Bloom and Weisberg, the mind is the brain, and therefore they are resentful that this type of nonscientific concepts, grounded in common-sense intuitions, are transmitted by seemingly trustworthy sources.

There are several shortcomings in this view. First, under this conflict model, common sense is conveniently and unfairly pushed into the category of any concepts that go against certain scientific views. Specifically, for Wolpert the common-sense attitude is a mode of lazy thinking that could not consider alternatives. But Fuller [77] objected to Wolpert’s perspective by pointing out that the goal of developing a final theory in fundamental physics (e.g. string theory) is to produce a theory whose parts could not have been otherwise. If Wopert’s view stands, then even Nobel Prize laureate Steven Weinberg's view is problematic because his elegant physics theories could not allow alternatives.

Next, Bloom and Weisberg [76] assert that mental life emerges from physical processes and the common-sense psychology that postulates the mind is fundamentally different from the brain has become a mental block to science learning. However, Bloom and Weisberg’s conjecture is unsubstantiated. The nature of mind has been hotly debated and remains inconclusive in cognitive sciences and philosophy of mind [78-85]. For example, although Dennett [86] declared that human consciousness can be fully explained by using a compelling computer metaphor; counter-arguments are equally compelling. To be more specific, Penrose [82,83] argued that consciousness is so complicated that it transcends the formal logic employed by a deterministic computer. In short, this conflict model tends to over-generalize the negative effect of common sense and as a result legitimate scientific reasoning, such as the indeterminacy of the nature of mind, is mis-classified as unscientific.

Finally, in this camp many times the terms “common-sense” and “intuitions” are used interchangeably or/and sometime the two terms are combined into “common-sense intuitions.” Actually there is a subtle difference between the two terms. While common sense is based upon empirical sensory input, intuition is usually associated with innate ideas, such as mathematical intuition proposed by Gödel [87-89].

3.2 Trumping Nonsense by Common Senses

In contrast to the preceding view, some scholars assert the positive role of common-sense thinking in science. This view is known as “trumping nonsense by common sense.” One of the examples of this type of “trumping” is resolving the paradox of motion, also known as Zeno's paradoxes. Contrary to common sense, Zeno found that the belief in change is mistaken, and motion is just an illusion. Zeno's paradoxes consist of different scenarios. One of those is the paradox of a flying arrow: for motion to be happening, an arrow must change the position which it occupies. In any one chunk of time, the moving arrow must either travel to where it is located or travel to where it is not situated. But it cannot move to where it is not located because there is a single instant that the arrow must be in some place and it cannot move to where it will be because it is already there. If the arrow cannot move in a single chunk of time, then it cannot move in any instant. Hence, motion is impossible.

Besides the paradox of motion, there are many other paradoxes in physics that sound right by sophisticated reasoning but are at odds with our common sense. For example, in theory a year could be divided into infinitely smaller units and so could a minute. "Infinity" in the former is equal to "infinity" in the latter and hence a year is said to be the same as a minute. Hicks [90] proclaimed that common sense rebels against these absurdities and put scholarly inquiry back on the right track.

While it is true that our common sense is right in these instances, it is important to point out that the paradox of motion is settled once and for all by calculus, not by common sense. Further, refutation of the equity between a year and a minute is owing to the introduction of the concept “Planck time,” the smallest unit of time for physics to reason about time in a meaningful way. Thus, we can assert that it is impossible to divide any temporal sequence infinitely. In this case, common sense and scientific reasoning work hand in hand, in which the former doubts the absurdity and the latter substantiates the rejection.

Further, cognitive psychologist Mayer [40] discovered that many misconceptions in science learning among novices, particularly for motion, are due to contamination by incorrect concepts. Consider this example: A metal ball is put into the end of a curved metal tube. The ball is forcefully shot through the tube at a high speed, so that it comes out the other end of the tube. What is the path that the ball will follow after it comes out of the tube? Some students drew a curve and gave explanations such as the following:

> "The momentum that is acquired as it went around here [through the tube], well, the force holding it has given in angular momentum, so as it comes around here [out of the tube], it still has some momentum left, but it loses the momentum as the force disappears."
>
> "The ball will continue to move in a line away from here [end of tube]. It will keep going until some force acts on the ball. If no force acts on the ball, it will just continue."

The above incorrect answers seem to be based on a medieval conception of motion—impetus. Under this theoretical framework of motion, when an object is set into motion, it acquires a force or so-called impetus that keeps it moving. The correct answer, according to Newtonian mechanics, is a straight line.

Interestingly enough, this type of misconception could be corrected by common sense before invoking Newtonian mechanics. A teacher could ask a student, "When the hose is curved and the faucet is turned all the way up, what is the path that water would be forced out?" Even if the student never takes any course on Newtonian mechanics, it is likely that by common sense alone he/she could reason that it is a straight path rather than a curved path. In this case, common sense alone is conducive to scientific learning.

4. APPLICATIONS

Taking the preceding review into account, it is futile to make a blanket statement to generalize the effects of common sense for all science topics. Hence, it is strongly recommended that science teachers address the issues of common sense and science on a case-by-case basis. Many science learners are confused when the teachers bluntly reject their misconceptions arising from common-sense conceptualization. What follows may be a sophisticated theory that would "undo" their common sense. However, it is the conviction of the authors that a sophisticated theory should not be the first choice; rather, to debunk misconceptions the teacher might consider using the common-sense approach that the learner feels just as comfortable as the first attempt. But what can be done when the existing common sense is completely faulty? Unlike the restructuring approach that utilizes the existing concepts related to the same subject matter as "anchoring knowledge," the common sense at the disposal of the instructor could be borrowed from other domains. In the following section this will be discussed in detail.

4.1 Examples from Astronomy

One of the widespread urban myths related to science is that the lunar landing in 1969 was a hoax. According to the hoax theory, NASA set up a studio in the Nevada desert and filmed the faked lunar landing there. People used the photos taken by the astronauts as evidence: in those photos there are no stars in the background. What we can see is just a black background. We can observe stars on earth even though the atmosphere blocks the light. If the astronauts were really situated in outer space without the atmosphere as an obstacle, should their pictures show more stars than what we can see on earth? Plait [91], a professional scientist, did not use complicated theory of physics to explain the phenomenon. Rather, he used a common sense approach that could be easily understood by any laypersons: when we take a photo at night, our camera adjusts the exposure to the foreground subject (e.g. people). In a photo like this, we can see a clear and well-lighted subject but the background is dark. This is exactly what happened in outer space. It requires a very long exposure for the dimmed stars in the background to show up in the picture. If the camera shutter opens for a split-second, only the foreground can be captured. The same physics principle applies to both Earth and outer space. Hence, a misconception that in outer space you can photograph more stars can be clarified by using common sense.

Another popular argument against the validity of lunar landing is: A powerful rocket that is capable of landing on the Moon should have burned out a huge crater on the surface, but there is no crater left by the Apollo space ship. Again, Plait did not appeal to complicated physics. Instead, he debunked the myth using the common sense approach [91]: When a driver parks a car, does he move the car at 100 kilometers per hour? The answer is: of course not. Rather, the driver de-accelerates the car so that he could bring the car to a full halt gradually. By the same token, the astronauts had to slowly land the spaceship instead of crashing it. Although the rocket was capable of 10,000 pounds of thrust, they had a throttle, too. First, the astronauts fired the rocket to deorbit. Then, when they approached the Moon's surface, they throttled down to about 3000 pounds of thrust. If the learners are still confused, the research team would use another example based on our common sense: when we travel by flight, how would the pilot land the aircraft? Does he land the airliner with the full power of the engine or perform a "soft" landing?

Another popular urban legends related to astronomy is that the Hubble Space Telescope (HST) cannot be used to observe the moon because HST was built to photograph objects in remote galaxies. With that said, the moon is too close and is moving too fast for HST to maneuverable enough to track [91]. Similarly, in a battle field you cannot shoot your enemy within 10 feet from a tank because there is no room for the tank to maneuver. By common sense it seems to be a convincing argument. Nevertheless, we don't need to use any complicated theories of physics to illustrate how HST could capture the image of the Moon. Plait used a term borrowed from military, which is commonsensical: Ambush. Hubble cannot track the Moon, and indeed there is no need to track it. The astronomers simply configured HST into the "ambush mode," pointing it to an anticipated location. When the Moon moved into the position, the HST camera took a short exposure. People thought that HST was made for observing faint objects in remote galaxies by a very long exposure. If so, how could HST capture the image of the moon? Plait used this analogy: It is like taking a picture from a moving car. If you take a long exposure, the trees will look blurred due to the motion of the car. But if you use a very fast shutter speed, the trees will look sharp and motionless. Anyone who uses a camera knows exactly what Plait was talking about. Again, the common sense approach came to rescue.

4.2 Examples from Statistics and Probability

Next, we will discuss common misconceptions in statistics and probability, and how the common-sense approach could alleviate the problem. "Linda's problem" is one of the most cited examples of conjunction fallacy in statistics and probability [92]. In many experiments, the participants were told to read the following passage:

"Linda is 31 years old, single, outspoken and very bright. She majored in philosophy. As a student, she was deeply concerned with issues of discrimination and social justice, and also participated in anti-nuclear demonstrations." Next, the participants were asked to choose a statement that is more probable:

1. Linda is a bank teller.
2. Linda is a bank teller and is active in the feminist movement.

People who took an elementary probability class could tell that the probability of two independent events is lower than that of a single event: $P(A\&B)<P(A)$ and $P(A\&B)<P(B)$. However, in many experiments of the Linda's problem, about 90% selected the second statement. One plausible explanation of this widespread fallacy is that our common sense fools us. Most people might regard Statement 2 as more typical or representative, given the description of Linda from the passage. As a result, their reasoning is a form of "natural assessment": If it is more typical, it must be more probable [93].

There are other well-known examples of the conjunction fallacy. In a study conducted with undergraduate students from Stanford University, the subjects were asked to rate the probabilities of the following statements:

1. Mr. F selected by random sampling from a population of all ages had one or more heart attacks.
2. Mr. F selected by random sampling from a population of all ages had one or more heart attacks, and is over 55 years old.

58% of the subjects asserted that the second statement is more probable [94]. Needless to say, the opposite is true because the first statement consists of one event while the second one has two, which makes it less probable. But how does this happen? Why do most people tend to choose the wrong answer? Again, it seems sensible to say that older people have a higher chance to have one or more heart attacks; after all it is typical!

Another version is a real-life example: during the cold war foreign policy experts were asked to rate the probability of the following two events:

1. The USSR would invade Poland.
2. The USSR would invade Poland and the US would break off diplomatic ties with the USSR.

It is important to emphasize that the raters were foreign policy experts, not ordinary people or undergraduates. Surprisingly, the second statement was perceived as a more likely one [93]. Actually even experts relied on natural assessment. Given the fact that the US and the USSR were rivals during the Cold War, it seems "natural" or sensible that the US would retaliate against the USSR after the invasion.

Many math teachers attempt to undo the misconception by walking through the calculation, such as assigning a probability to event A and another one to event B, and then explain the multiplication rule: $P(A \& B \& C \ldots \& Z) = P(A) * P(B) * P(C) \ldots * P(Z)$. But there is an easier way: the common sense approach. Using frequencies instead of probabilities can substantially reduce the error rate of the conjunction fallacy. Based on this approach, the Linda problem was re-packaged as follows [95]:

There are 100 persons who fit the description of Linda. How many of them are:

Bank tellers? __ of 100.
Bank tellers and active in the feminist movement? __ of 100.

After the reformulation in the form of arithmetic, all subjects gave the right answer [96]. This reconfiguration of the problem by rescaling was also used by one of the authors of this article. For example, when the students were asked to compare the Cronbach Coefficient Alphas of the two groups (0.8 vs. 0.7), most students have difficulties in seeing the difference. After all, by common sense the gap of 0.1 does not appear to be a big deal. Then the author reframed the problem by saying: “Let’s use 100% as the scale. 0.8 is 80% and 0.7 is 70%. Think about your grade. Usually 80% is a B and 70% is a C. In this case, is there a significant difference?” Although the nature of this problem is not the same as the Linda’s problem, likewise, none of the students made a mistake when the scale is from -100 to 100, instead of from -1 to +1. In short, we don’t need sophisticated statistical or probabilistic approaches to remediate the fallacy. Using frequency or percentage in arithmetic, which is based on our common sense, can work very well, too.

5. CONCLUSION

The preceding review indicates that neither reconceptualization nor restructuring could capture the entire picture of the relationships between common sense and science learning. One of the sources of the problem is that very often common sense is unfairly presented in a negative fashion in order to promote a particular agenda, such as the materialistic view of cognition. It is true that sometimes our prior knowledge, no matter if it is sourced from common sense, intuition, conventional wisdom, or previous training, hinders us from advanced science learning. The conflict model of force is an obvious example. But on some occasions, common-sense and scientific reasoning could work side by side to debunk flawed concepts, as shown in the cases of resolving the paradoxes of motion and infinity. Sometimes common sense alone is sufficient to counteract misconception, as indicated by the examples of water going out of a garden hose, taking photos at night, parking a car, and using frequency to solve the Linda’s problem. Nonetheless, even if so-called common sense and science could not collaborate in some situations, they could still coexist because they might describe different realms of our world in a meaningful way, just like different scientific theories address different aspects of the reality. According to Maxwell [74], both common sense and scientific theory provide comprehensive descriptions of the world. These two descriptions are compatible, since they are different descriptions of different levels of knowledge. We need common sense knowledge to live in this phenomenal world everyday while the subatomic world is conceptualized in a different realm.

The examples illustrated in the last section show that not all common senses are detrimental to science learning, no matter if the contents are designed for children or adults. Although some common senses seem to be detrimental to science learning, which favor learning by reconceptualization, indeed debunking misconceptions could also be done by using common senses. Instead of forcing the learners abandoning their existing mental framework, the instructors could go with their mental flow to provide remediation. Even if some common sense beliefs might misrepresent reality, it doesn’t necessarily imply that they are detrimental to learning. On the contrary, misconceptions and misrepresentations generate teachable moments. Based upon the view of history of science introduced by Kuhn [97], Gopnik and Meltzoff [23] contended that when learners encounter an anomaly that yields an absurd conclusion (e.g. Linda’s problem, the problem of heart attack patients), auxiliary conjectures would be added to save the existing conceptual framework. Nonetheless, at a certain point the inquirer must admit that a new and better theory is needed. In short, while certain common sense beliefs, which could fit nicely into the existing conceptual model, could facilitate debunking misconceptions, erroneous common sense beliefs could also be beneficial to learning by creating teachable moments.

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