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A misunderstanding of spacetime throughout "space" and "time"

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Table of Contents

Abstract- The intention of this thesis is twofold; it revolves around the assimilation of relativity as a case study, and in the process aims to reveal valuable insight about the assimilation of anomalous scientific knowledge as well as about the specific case study of relativity. Chapter 1 examines the scientific and societal context that preceded the acquisition of relativity. After a brief introduction and overview of Newtonian mechanics, it considers the rise of probabilism and the ways in which it revealed underlying nuance in the preexisting Newtonian worldview. Next, it examines the process of reconciling probabilism and classical physics; this illuminates that the Newtonian model of space and time is at the heart of the difficulty. The remainder of the chapter considers the historical context and philosophical implications of Newton's absolute space. Chapter 2 is an explicit discussion about the assimilation of anomalous scientific information. It analyzes the possible responses to anomalous data, differentiating between "acquisition" and "assimilation", and considers the factors which promote these different responses. This offers insight into the process of assimilation, as well as promotes a meta-conceptual understanding for the assimilation of relativity. Chapter 3 considers the extent to which relativity has been acquired and assimilated. It begins by chronicling the acquisition of relativity, transitions into a discussion about the foundations of relativity, and concludes by analyzing the bidirectional influence(s) that relativity and our preexisting worldview have exerted on each other. Ultimately, this illuminates that our traditional understandings of "space", "time", "objectivity", "truth", and "reality" are deeply and fundamentally flawed. Chapter 4 explores the specific tensions between relativity and the traditional definition of "reality". This involves a critical analysis of relativistic spacetime, and its subtle implications for our broader worldview. Chapter 4 concludes with an analysis of the heuristic value of agential realism, as well as a final reflection on probabilism, spacetime, relativity, and what these emphasize about the general assimilation of scientific information.

A Misunderstanding of Spacetime throughout "Space" and "Time"

"Since new paradigms are born from old ones, they ordinarily incorporate much of the vocabulary…that the traditional paradigm had previously employed. But they seldom employ these borrowed elements in quite the traditional way. Within the new paradigm, old terms, concepts, and experiments fall into new relationships one with the other. The inevitable result is what we must call, though the term is not quite right, a misunderstanding between the two competing schools…they are bound to partly talk through each other" –Thomas Kuhn (Kuhn 148)

Chapter 1: Rise and Fall of Classical Physics

"In particular, that which is being evaded is the need for a cognitive structure radically different from the prior existing structure…a more realistic… [view of the] world in which the boundaries between subject and object are acknowledged to be never quite rigid, and in which knowledge, of any sort, is never quite total" -Evelyn Fox Keller (Keller 718)

Section A- Prominence of Newtonian Thought

As Max Jammer notes in "Concepts of Space", pre-Newtonian science treated "space and time [as] being completely heterogeneous and non-interdependent entities" (Jammer 3). To exemplify this, he points out the "Galilean transformation of classical mechanics [in which] t'=t, that is, the transformed time variable is independent of the space variable." (Jammer 3) Newtonian physics represents a major breakthrough in the sense that it was the first scientific model to formally connect the notions of space and time through the concept of motion. This was a "dramatic, theoretical innovation… [which shook science and scientists] loose from their theoretical moorings"; it was, as Kuhn would call it, a "paradigm shift" (Appleby 165, Kuhn 111-134). Newton's laws became the guiding principle for scientists who were "trying to explain newly scrutinized or anomalous phenomena" (Kuhn 63). The interdependent yet ostensibly separable nature of space and time was a crucial tenet in Newton's model. Accordingly, it became an ingrained component in the idealized "concrete problem-solution" which the professional scientific community used for "mapping domains of nature…to create credible expectations for the behavior of phenomena and thereby authorize programs for research." (Kuhn 181) Newton's way of thinking permeated not only the manner in which scientists would explore and explain natural phenomena; it also demarcated which questions would be "scientific" and supplied the terms in which scientific answers were to be expressed and understood. The remarkable success of Newtonian physics for understanding physical forces set the stage for a number of important scientific and technological breakthroughs, and remained the uncontested champion of physics for centuries. As a conceptual and analytical model for science, Newton's mechanics seemed infallible. Many people came to the conclusion that there was nothing conceptually new to be discovered in physics, and that all that remained was more and more precise measurement. World-class physicist Albert Michelson asserted that the "important fundamental laws and facts of physical science have all been discovered"; he even went so far as to un-prophetically declare that "these are now so firmly established that the possibility of their ever being supplanted in consequence of new discoveries is exceedingly remote…our future discoveries…must be looked for in the sixth place of decimals." (Kumar xiii) In this era of Newtonian absolutism and uninhibited scientific positivism, we were all too sure that we had uncovered the structure of reality, and that all that was left was to fill in the details.

<u>Section B</u>- The Rise of "Uncertainty" via Probabilism

Despite the ostensible scientific positivism, Olaf Hansen and Paul Croce make a compelling case that seeds of doubt and uncertainty were sown throughout the nineteenth century. They characterize positivism as “more a belief of science watchers than of scientists”; the popularization of positivism amongst the general public stood in stark contrast to the developments that were occurring in science (Olaf and Croce 3). By the end of the nineteenth century, “epistemic certainty [had] largely disappeared from the intellectual and cultural landscape” of the professional scientific community, yet the general public continued to “cling willfully to conviction and simple commonsense facts.” (Olaf and Croce 3, 5) To characterize the developments in science under the blanket term “uncertainty”, however, gives a very misleading picture. Although many people inside and outside of the scientific community perceived a professional acceptance of uncertainty, scientists were increasingly embracing *probabilism* and not uncertainty per se. The difference between probabilism and uncertainty is subtle but essential. Probabilism sought to “tame chance” by “recognizing it and assuming its role in natural and social phenomena” (Olaf and Croce 7). Probabilists recognized that science could “extend its explanatory reach and build up its confidence with probabilistic patterns”; “in theory, the recognition of chance assumed more uncertainty [but] in practice the use of chance involved an increase of certainty through the manipulation and control of more of the natural and social world.” (Olaf and Croce 7) By admitting, embracing, and analyzing uncertainty on the level of the individual, probabilism enabled scientists to formulate statistical laws which acheived greater certainty on the macro-level. The “application of probability was not motivated by an embrace of uncertainty”, writes Olaf and Croce, but rather “by an enthusiasm for finding certainty within uncertainty.” (Olaf and Croce 7) It is more appropriate to say that scientists’ understanding of “certainty” became more complex and nuanced, than it is to say that scientists gave up their belief in and pursuit of “certainty”. Science uncovered new “truth” and “certainty” as probabilism was gradually assimilated, but this process also indicated that concepts like "certainty", "truth", and "reality" are far more nuanced than their traditional definitions.

One of the most significant scientific accomplishments to be born out of probabilism was Darwin's theory of natural selection. In the past couples of centuries, Darwin's model has revolutionized the way that biological scientists understand the development of a species. It also represents the "culmination of naturalistic trends in the sciences" and signifies "a novel approach to scientific explanation involving probabilities and hypotheses" (Olaf and Croce 99). Darwin's theories "generated bitter and fundamental disagreement" not only because their implications regarding evolution contradicted tenets of traditional religion, but also because natural selection was a "hypothesis [built] on the basis of probability rather than proof" (Olaf and Croce 99). Even Darwin himself "struggled with his relation to the inductive method", as he knew that "the nature of his scientific questions and the answers he proposed challenged the conventional goals of both religious belief and scientific theory." (Olaf and Croce 104) Natural selection represented a radical departure from traditional scientific methodology, which deeply disturbed both religious and scientific thinkers. Accordingly, "the rise to prominence of Darwin's theories…is not a tale of scientific triumph over the unscientific, but a story of the increasing persuasiveness of new scientific methods that looked only to nature for their theories and that replaced expectations of certainty and proof with persuasive and authoritative, yet probabilistic, explanations." (Olaf and Croce 99) By admitting and accounting for uncertainty about the individual animal, Darwin's theories enabled scientists to learn valuable information about the population as a whole.

Unfortunately, the methodology of probabilism was not widely understood, especially outside of the professional scientific community. For many people, probabilism just seemed like a fancy synonym for uncertainty. In this era of mounting skepticism across all walks of life, people had become tired of doubting. They did not want doubt, they wanted answers. Olaf and Croce note that “average citizens had been accustomed to turning to religious leaders and scientists for assurance about fundamental truths and ultimate meaning”, and were deeply discontent when their questions were met with “less final assurance from intellectual leaders and more frank inquiry among multiple viewpoints” (Olaf and Croce 5). The misinterpretation of scientific probabilism as a continuation of this trend towards doubt significantly weakened probabilism’s popular appeal. As William James notes in “The Meaning of Truth”, we “find it satisfactory to cease to doubt…above all we find consistency satisfactory” (James 192). Science continued to expand its horizons through the newfound power of probabilism during the 19^{th} and 20^{th} centuries, but probabilistic explanations lacked absolute consistency on an individual scale. The scientific community was producing answers and explanations, but not ones that quelled the urge for traditional scientific “certainty”. *Even the most complete and accurate probabilistic explanation could be considered entirely inadequate, if the primary criterion was to eliminate all doubt.* Probabilism had opened Pandora’s Box; science progressed by recognizing and accepting underlying degrees of uncertainty, but scientists and the general public had to learn to live with that uncertainty. As probabilism was accepted and acquired, people had to reconcile it with their preexisting knowledge and beliefs. Probabilism and “uncertainty” have been internalized to varying extents, by different people, in different contexts, for different purposes. This process of assimilation has contributed to discrepancies, both within the scientific community and between scientists and the general public, as far as how to think about “certainty”, “truth”, and “reality”. When people lack a consensus about fundamental concepts such as these, the conflicts beliefs are typically deep-seated and the implications are far-reaching; it was only a matter of time until these discrepancies became apparent and problematic. Thus, although scientific positivism proliferated in the 19^{th} century as scientists continued to uncover "absolute truth", it was quickly becoming evident that "truth" is more nuanced and relational than was traditionally recognized.

Section C- Newtonian Absolutism and Anomalous Theories

Newton's mechanics are not easy to fully reconcile with probabilism. Basic applications of probabilism enrich and extend classical physics, but they also suggest fundamental weaknesses in the traditional Newtonian worldview. Probabilism recognizes an underlying degree of uncertainty and relativism, whereas Newton based his physics on a foundation of absolutism and traditional scientific "certainty". Newton's absolutist dogma is conceptually grounded in his understanding of space and time; from there, it spreads outwards and subtly permeates the rest of the Newtonian worldview. Newton's physics were "founded…on the view that *space* is distinct from body and that *time* passes uniformly without regard to whether anything happens in the world." (Rynasiewicz)[1] In order "to distinguish these entities from the various ways by which we measure them (which he called *relative spaces* and *relative times*), Newton spoke of *absolute space* and *absolute time*" (Rynasiewicz). This view of spacetime is commonly referred to as substantivalism, because it treats space and time as though they are actual, substantial entities. In Newton's understanding of the world, absolute space and time are as real as anything physical; space and time *exist* abstractly, as something above and beyond the matter, relationships, and coincidences that space and time contain. This belief is intuitively plausible, but deeply problematic when we consider later developments in science such as probabilism and Einstein's work on relativity. Although our understanding of classical physics has been reconciled with anomalous theories in many ways, there are other ways in which classical physics has skewed and distorted our assimilation of new information. Science has

[1] Online source without page numbers; URL is http://plato.stanford.edu/entries/newton-stm/

gradually transitioned to a more probabilistic and relativistic worldview in the last century, yet the inherent weaknesses in the foundations of classical physics continue to plague us; to varying extents, neither scientists nor the general public have completely assimilated relativity and left behind the shortcomings from their preexisting models of the world. Newton's understanding of space and time is a particularly critical shortcoming, as it provides the fundamental basis for ontological beliefs which embody excessive absolutism. The Newtonian model of "space" and "time" is inextricably tied to an entrenched absolutism that subtly spreads to the entirety of the Newtonian worldview, which in turn makes classical physics particularly difficult to reconcile with the nuance of probabilism and relativity. In situations like these, "involving development of ideas in which the consistent use of the traditional fundamental concepts leads us to paradoxes difficult to resolve", notes Albert Einstein, "in the interests of science it is necessary over and over again to engage in the critique of these fundamental concepts, in order that we may not unconsciously be ruled by them." (Jammer XIV) Reassessing our model of space and time is a crucial step towards reconciling the fundamental anomalies between classical physics and more recent scientific theories, but it is challenging to "give up [the classical paradigm] *in toto*" (Keller 720). Instead, like the frog which sits content in a slowly boiling pot of water until it burns to death, we have made minor alterations to the flawed notions of Newtonian space and time until the point at which paradox became inescapable.

Section D- Space (A) and Space (B)

Newton's substantivalist foundation committed science to the view that space and time are external, inalterable entities. Newton was primarily concerned with explaining phenomena that took place in space when he wrote the Principia, as the notions of space and time had not yet been linked. "As far as classical conceptions of space are concerned, we may safely regard the concept of space as an elementary and primary notion." (Jammer 6) Since "the category of space preceded that of time", "a discussion of space is preferable to that of time" in order to illuminate how "it is…possible…to think [about spacetime] in a different way." (Jammer, XV) Einstein suggests that "the concept of space…was preceded by the psychologically simpler concept of place", which in turn implies that space can be defined in two complementary ways. Einstein contrasts these two conceptions of space "as follows: (a) space as positional quality of the world of material objects; (b) space as container of all material objects". (Jammer XV) There is not a significant substantive difference between these two definitions; they differ slightly in that (a) posits space to be a relationship of and between material objects whereas (b) implies then same, but *also* postulates space to be an additional entity in and of itself, external to material objects. Importantly, the relationships which *are* space (a) are *deducible* from the measurements and calculations made in terms of space (b). Space (b) is therefore a "logically more daring concept of space", since space (b) presupposes the validity of space (a) (Jammer XV). Space (a), on the other hand, can be completely valid without the existence of space (b). These two conceptions of space are interrelated, yet are fundamentally different ways of understanding the relationship between the essence of space to/and the material objects that it contains.

Despite the fact that "both space concepts are free creations of the human imagination, means devised for easier comprehension of our sense experience", the success of Newton's physics led people to recognize space (b) without understanding or considering space (a) (Jammer XV). The Newtonian model predisposed scientists and the general public to consider space (b) as "reality", and space (a) as a mere consequence of that reality. Although space (a) and space (b) tend to produce similar empirical results, unequivocally prioritizing (b) over (a) results in profound restrictions on the way that we understand and quantify our observations.

There are significant conceptual implications that result from the belief that space (a) is nothing more than a derivative of "absolute space", space (b); by espousing (b) and eschewing (a), we have inhibited our ability to fully and coherently make sense of the world around us. Although the Newtonian model of space proved "indispensable for the development of theory…it has required…strenuous exertions subsequently to overcome this concept [of absolute space] – a process which is by no means yet completed." (Jammer XVI) This leaves us with two important questions. First, why did Newton classify space as type (b)? Second, what are the implications of an understanding of space as strictly type (b)? We will consider each of these questions in turn.

Section E- Absolute Space in Newtonian Mechanics

If Newton's "forces" were just describing the spatial relationship of objects that exist in space of type (a), then why did Newton's worldview posit the existence of absolute space? There was one particularly significant scientific motivation for doing so. In order "to give the classical principle of inertia (and therewith the classical law of motion) an exact meaning", notes Einstein, "space must be introduced as the independent cause of the inertial behavior of bodies" (Jammer XVI). Newton posited space (b) for the sake of clarity and convenience, not out of logical necessity. "It was clear to Newton that the space concept (a) was not sufficient to serve as the foundation for the inertia principle and the law of motion"; although he felt uneasy about doing so, he defined physical space as type (b) (Jammer XVI). In Newton's theories, "space is not only introduced as an independent thing apart from material object, but also is assigned an absolute role in the whole causal structure of theory…in the sense that space acts on all material objects, while these do not in turn exert any reaction on space." (Jammer XVI) The success of Newton's physics would ensure that "space of type (b) was generally accepted by scientists", despite the fact that "it required a severe struggle to arrive at the concept of independent and absolute space"

(Jammer XVI). This model of space was heuristically useful for the scientific community, but it is seldom recognized that it was a practical choice rather than a necessary truth.

Significantly, a large part of Newton's motivation for positing the existence of space (b) ("absolute space") was non-scientific. It is important to remember that Newton lived in an era when religion held a great deal of influence and did not react kindly to challengers. In the 1600's, the Catholic Church was extremely powerful and the Spanish Inquisition was in full swing. "At the time Newton composed the Principia", notes Ryan Rynasiewicz, "Galileo's condemnation by the Catholic Church for asserting that the earth is in motion was still recent history" (Rynasiewicz). Although Newton considered "absolute space…a logical and ontological necessity", the motivation behind this was pragmatic and religious rather than scientific (Jammer 101). Newton recognized that the earth was in motion, but it was imperative that his framework be compatible with religious doctrine. "In anticipation…[of] how to reconcile this with scripture", Newton posited that "in ordinary discourse (including the Bible) the terms 'time', 'space', 'place', and 'motion' are properly understood to signify the relative quantities; only in specialized and mathematical contexts do they denote the absolute quantities." (Rynasiewicz). In the Scholium, Newton's "stated intention…is to maintain that absolute space, time, and motion are genuinely distinct from their relative counterparts." (Rynasiewicz) Newton needed to invoke the concept of absolute space in order to avoid religious persecution; accordingly, as Jammer notes, "all Newton's achievements and discoveries in the realm of physics are in his view subordinate to the philosophical conception of absolute space." (Jammer 116)

Additionally, this "stated intention" was reinforced by the fact that Newton himself was a religious man. Newton was not only trying to reconcile his theories with scripture in order to satisfy religious leaders, but to accommodate his own religious beliefs as well. While he was "intimately acquainted with the problems of religion and metaphysics, Newton managed to keep them in a separate compartment of his mind, but for one exception, namely, his theory of space." (Jammer 98) Newton's synthesis of science and religion through the concept of absolute space was "deeply influenced…by More's criticisms of Descartes", which assert that "God is extended in his own way…space is distinct from matter because it is extended but penetrable, whereas matter is extended but impenetrable; and, in tandem, all substances are extended, but whereas some, such as tables and chairs, are impenetrable, others, such as the mind and even God, are penetrable and therefore not material." (Janiak)[2] The religious basis for Newton's work is explicit on page 544 of the Principia, where he writes that "He is eternal and infinite, omnipotent and omniscient; that is, his duration reaches from eternity to eternity; his presence from infinity to infinity; he governs all things, and knows all things that are or can be done. He is not eternity and infinity, but eternal and infinite; he is not duration or space, but he endures and is present. He endures for ever, and is everywhere present; and by existing always and everywhere, he constitutes duration and space." (Jammer 113) Reflecting on this passage, Jammer notes that "Newton identifies space and time with God's attributes." (Jammer 113). The distinction between relative and absolute space allowed Newton to appease religious leaders, made room for his own religious beliefs, and "rendered…the Principia a completeness, as a cosmology… [by giving] the foundations of mechanics and mathematical physics a theological justification, [which was] an idea congenial to Newton" (Jammer 115). Absolute space and time were an instrumentally useful, but logically uncompelled, scientific foundation constructed by Newton.

While the foundation of Newton's substantivalism was epistemologically shaky, it held empirical benefits which made it difficult to dispense of. In particular, the concept of absolute

[2] Online source without page numbers; URL is http://plato.stanford.edu/entries/newton-philosophy/

space and time served to clarify Newton's laws of motion. Although forces have become a well-known element of science, "Newton's canonical notion of a force" or "an 'action exerted on a body' that changes its state of motion…was a confusing notion at the time." (Janiak) Remember, "when Newton wrote the Principia…he was not contributing to a preexisting field of study called mathematical physics; he was attempting to show how philosophers could employ various mathematical and experimental methods in order to reach conclusion about nature, especially about the motions of material bodies…the Principia represented his attempt to reorient natural philosophy" (Janiak). Newton was bound to face an uphill battle because people were accustomed to thinking in terms of Cartesian natural philosophy, in which "the concept of a force plays little if any role" because "all natural change is due to the impacts that material bodies make upon one another's surfaces." (Janiak) By placing "the concept of a force at the very center of his thinking about motion and its causes", Newton's framework represented a fundamental shift from the past (Janiak). Unfortunately, this idea was confusing to many of Newton's readers; the easiest way for other scientists and the general public to make sense of Newton's forces was to ignore the conceptual issue and focus on the technical applications. By "bracketing the question of how to understand forces as ephemeral actions that do not persist after causal interactions have ceased, one can make progress by conceiving of forces as *quantities*." (Janiak) As a result, Newton's forces were not seen as the well-developed and "sophisticated notion of modern physics", but rather "an absolutely given entity, a real physical being" as opposed to "a mathematical abstraction" (Jammer 99). The quantification of forces helped Newton's readers to apply his mechanics in mathematical and practical contexts, but the tradeoff was that the Newtonian model's conceptual foundations were glossed over and poorly understood.

Importantly, this was not quite the same way that Newton himself understood forces. Newton had a more "abstract way of understanding forces…without involving any...physical interaction, Newton thought of forces as quantities that are proportional to other features of nature." (Janiak) Although Newton had posited a space of type (b), it seems as though he recognized that physics was based on relationships from space (a) rather than inherent physical properties. This is evident from his conclusions regarding the fact "that the sun and the earth interact according to this law of gravity." (Janiak) Faced with the question of "how…we know that the sun contains a quantity of matter, that it is a material body with the same basic qualities that characterize the earth or the moon?", Newton cited the *relationship* between the sun and the earth and claimed that we can "infer from finding these properties in the bodies that we have seen" (Janiak). In this sense, Newton recognized that science is based on deductions about properties and objects, derived from relationships and relative truths. Newton is more explicit about this methodology in his conclusion about gravity in proposition seven of Book III of the *Principia*, where he notes that we deduce the qualities of material objects from the interaction of those objects. Newton considered this "the 'foundation' of natural philosophy." (Janiak) From our "perceptions and experiments that provide us with knowledge of the objects and natural phenomena in our neck of the universe…we [can] reach a conclusion concerning objects and phenomena throughout the *rest* of the universe" (Janiak). Although absolute space (in other words, space of "type (b)") was useful for popularizing and applying Newtonian physics, it made it that much easier to lose sight of the fact that "space" in physics is fundamentally concerned with spatial and spatiotemporal relationships rather than material objects per se.

Section F- Implications of Space (A) and Space (B)

It is easier to consider space of type (b) first, since Newtonian physics has made us more familiar with this definition of space. Einstein invites us to consider the example of placing food such as rice or cherries into a box; if we consider space of type (b), then the amount of food which can fit would be "the 'space' of the box"; this "property must be considered 'real' in the same sense as the box itself." (Jammer XV) In this way, the concept of space is no longer completely relational; it "achieves a meaning which is freed from any connection with a particular material object." (Jammer XV) It seems as though some underhand trickery is at play here; is it not the case that space is still relational, and just that the relation is now between two material objects rather than by a "connection with a particular material object"? (Jammer XV) This means of arriving at an absolute space seems suspicious at best, but the problem resides in the notion of absolute space rather than Einstein's example. By extending this concept "of 'box space' one can arrive at the concept of an independent (absolute) space, unlimited in extent, in which all material objects are contained." (Jammer XV) It would follow logically from this absolute space that a material object must always be situated in space, and "in the framework of this concept formation it is quite conceivable that an empty space may exist." (Jammer XV)

On the other hand, if we consider space of type (a) then we recognize that "place is first of all a (small) portion of the earth's surface identified by a name" and that "the thing whose 'place' is being specified is a material object or…group of material objects." (Jammer XV) Accordingly, "one is led to the view that space is a sort of order of material objects *and nothing else*." (Jammer XV, my italics) Space is a relation of sorts, and thus cannot be "empty" or "full" regardless of the presence and absence of material objects. Understanding space in this manner, "one is led quite naturally to reject the concept of empty space" (Jammer, XV). In short, space

(a) is understood to measure the relationship of and between material objects, whereas space (b) is understood to be an external and absolute entity which contains material objects.

Returning to Einstein's example of the box of cherries, how would our ideas about what is "real" change between space (b) and space (a)? In space (b), space takes on an absolute nature, so first and foremost absolute space would have to exist. The cherries and the box each have certain spatial properties; the relationship between them *depends* on their spatial extensions. Accordingly, the material objects (the cherries and box) are fundamental physical entities which serve as measurements of absolute space, and the relationship between them is less "real" because it is contingent on their preexisting properties. But how can this be, if the relationship between their properties was the basis that was used to establish the existence of absolute space in the first place? The logic of space (b) seems viciously circular. In space (a), on the other hand, space is not an absolute or independent entity. Put simply, space is a measure of the relationship between material objects; it "is a sort of order of material objects and nothing else." (Jammer XV) According to space (a), this order is the most fundamental building block of reality. Thus, space (a) accounts for the relationship(s) between one object and another, but does not depend on an absolute scale for measurement nor absolute properties of the material object themselves.

In space (b), we posit real objects in real absolute space in order to deduce relationships. In space (a), objects and space are interdependent; the most "real" thing is relationships, from which we can make deductions. Is it the case that we can only fit 10 "x" in "y" because "y" is 10 times larger than "x"? Or is it the case that these cherries have a certain measurement in absolute space, and this box has a certain measurement in absolute space, and because the measurement of the box is 10x larger (in terms of absolute space) than the measurement of the cherry (in terms of absolute space), that we can only fit 10 cherries in the box? In both cases we can fit 10 cherries in the box, but the resort to absolute quantifications in the latter adds a few extra steps which are unnecessary for answering the question of “how many cherries can fit in the box?” *From the assumption that the cherries and the box are more “real” than the relationship between them, we are forced to take a roundabout method in order to solve certain problems.*

Reverting to an absolute scale for measurement does have its advantages, particularly that it provides a universal standard for making empirical comparisons. Nevertheless, the notion of “objective” measurements and imposing an absolute scale reinforces the epistemological mistake that physics is based on spatial properties of material objects rather than the spatial relationship between them. This contributes to our understanding of the physical world as something external to human minds and bodies, which in turn carries profound implications for conceptualizing “truth” and “reality”. Newtonian physics forces us to revise our experiences so that they can be understood as valid scientific observations, “but once it is on the table it feels right.” (Griffiths 39) Classical physics is not identical to our everyday experiences, but “it seems consistent with our everyday experience…[it] refines and perfects our intuitions, but it doesn’t upset them.” (Griffiths 39) Our understanding of reality as absolute, external, and separable into the distinct entities of space and time has become a deeply ingrained intuition; this results in fundamental conflicts when we try to make sense of relativity. In response to Einstein’s revolutionary work on relativity, we unjustifiably glossed over those conflicts and maintained a largely traditional view of reality. Although relativity should “seem to contradict everything we thought we understood” and undermine “everything we took for granted about the world”, the full impact of relativity was not felt by most (Griffiths 39). Even Einstein himself synthesized relativity with the familiar Newtonian model, rather than replacing it outright. This was a wide-reaching trend; worldviews were revised in consideration of relativity, but they were not radically changed. Einstein’s work on relativity was undoubtedly revolutionary, but its true significance was underappreciated and misappropriated as people held on to a largely classical view of reality. In this sense, relativity represents a wealth of "knowledge acquired, but not yet assimilated." (Evelyn Fox Keller 718)

Chapter 2: Assimilation of Scientific Knowledge

"The mathematics of relativity is on the whole quite simple, the much advertised difficulties of the theory residing mostly in its physical implications, which run counter to some of our most cherished everyday notions…. relativity talks endlessly of space and time, and simultaneity and other familiar things. One forgets all too easily that such things are of the first importance for physical science; that they are part of that shaky foundation on which is balanced the whole intricate and beautiful structure of scientific theory and philosophical thought. To tamper with them is to send a shudder coursing from one end of this vast frame to the other. And to effect successfully a profound change in our ideas concerning them, as Einstein did, is to create a revolution in science and philosophy of transcendental importance"-Banesh Hoffman (Hoffman 5)

Section A- Introduction

What does it mean to say that relativity represents a wealth of "knowledge acquired, but not yet assimilated"? (Keller 718) This is an important statement, and it deserves to be unpacked and examined a little bit more closely. "Assimilation", broadly defined, means "to take in and incorporate as one's own; to absorb" (Dictionary.com). In the context of scientific theories, "assimilation" refers to the way, and extent, to which a theory (such as relativity) is incorporated into one's larger understanding of science and reality. In the century since Einstein published the special and general theories of relativity, how has relativity changed our understanding of the world? In what ways has it been assimilated, and in what ways has it been repressed?

<u>Section B</u>- Acquiring Relativity and Piaget's Theory of Cognition

Keller uses the term "assimilated" because she is drawing on the theories developed by child psychologist Jean Piaget. Assimilation and accommodation are "two of the basic concepts of Piaget's theory of cognition", but his use of these terms "is not quite the same as their common use" because they are used "in the context of his constructivist theory of knowing." (Glasersfeld 126) Piaget asserts that knowledge is acquired by constructing "schemes" which consist "of three parts: recognition of a certain situation, association of a specific activity [or outcome] with that" situation, and the "expectation of a certain result." (Glasersfeld 127) Consider an infant who picks up a spoon and shakes it, expecting the sound that occurs when he shakes his toy rattle. "We call that item a spoon and may say that the infant is assimilating it to its rattling scheme; but from the infant's perspective at that point, the item *is* a rattle, because what the infant perceives of it is not what an adult would consider the characteristics of a spoon but just those aspects that fit the rattling scheme." (Glasersfeld 127) When "shaking the spoon…does not produce the result the infant expects…this may lead to the perception of some aspect that will enable the infant in the future to recognize spoons as non-rattles." (Glasersfeld 127) Piaget refers to unexpected results (in this case, the lack of a rattling noise) and the emotions that they incite as "perturbations", which then inspire different cognitive changes or "accommodations". The "theory that emerges from Piaget's work can be summarized by saying that cognitive change…take[s] place when a scheme, instead of producing the expected result, leads to perturbation, and perturbation, in turn, leads to accommodation that establishes a new equilibrium." (Glasersfeld 128) The establishment of an appropriate equilibrium is a crucial accomplishment, without which data and theories cannot be said to be "completely assimilated".

This fundamental difference between "acquisition" and "assimilation" is reflected in Hymses's model of "communicative competence", which differentiates "between the ability to master grammar and words" and "the achievement of a competent understanding of the meaning involved with using a particular discourse." (Brown 829) The ability to use grammar and words is proof of the acquisition of these "tools of language", but the complete assimilation of a language can only occur once the speaker has "communicative competence" which "involves developing a mastery of the tools of language along with obtaining an understanding of the social, political, and interpersonal significance of using those words." (Brown 829) This points to a key distinction: assimilation is much more thorough than acquisition. The acquisition of knowledge occurs pretty much anytime that data is analyzed and responded to, whereas the assimilation of knowledge requires a more in depth comprehension of data and its integration into broader theories and worldviews. Thus, to "completely assimilate" scientific data, the data must be analyzed <u>and</u> there must be a theory (either new or preexisting) that accounts for, incorporates, and explains the assimilated data. To "completely assimilate" a scientific theory, the theory and any ensuing "accommodations" must be unpacked <u>and</u> there must be a worldview (either new or preexisting) that accounts for, incorporates, and explains the assimilated theory.

Relativity has incited various accommodations in the worldview of the scientific community. As David Griffiths notes, relativity "takes precedence over all other theories… [because] it is a theory of space and time themselves." (Griffiths 39) Professional scientists, particularly physicists, have made countless revisions to their mathematical model of the world in order to accommodate and integrate relativity; although relativity derives from two conceptual tenets and has significant theoretical implications, it has primarily been assimilated as a mathematical theory. Science and technology have prospered greatly from incorporating the insight that relativity has to offer. Relativity has enabled techno-scientific breakthroughs including GPS technology, the creation of the atomic bomb, and a more thorough exploration of astronomical phenomena including black holes, gravity waves, the cosmic big bang, and many more. In light of relativity, new relationships were recognized and old terms were linked in significant and unexpected ways. The inextricable linkage of space and time revolutionized scientists' mathematical model of the world, which in turn enabled them to recognize that length and duration are relative rather than absolute, that energy and mass are intimately related, and that the notion of absolute simultaneity is deeply and fundamentally mistaken. Scientists' mathematical framework is dominated by the theories of relativity, and their conceptual understanding of the world is beginning to shift in response to that mathematical model.

Piaget suggests two distinct yet intricately related levels on which assimilation occurs. For the first, "the sensory-motor level, action schemes are instrumental in helping organisms to achieve goals in their interaction with the experiential world." (Glasersfeld 128) On the second level, "reflective abstraction, operative schemes are instrumental in helping organisms achieve a coherent conceptual network that reflect the paths of acting as well as thinking which, at the organism's present point of experience, have turned out to be viable." (Glasersfeld 128) Piaget's analysis is revolutionary because it asserts that the instrumental function of our conceptual network of "reflective abstraction" is "strictly epistemic", and therefore this "entails a radical shift in the conception of knowledge…that substitutes viability in the experiential world for correspondence with ontological reality" (Glasersfeld 129). This "conception of knowledge and of its relation to the 'real' world" is referred to as a "constructivist epistemology" (Glasersfeld 123). Constructivism puts a distinct twist on the traditional notions of "objectivity", "truth", and "reality"; these phenomena are "not preexistence (in the ontological sense) or the preexistent made manifest to the cognitive mind (in the epistemological sense)" but rather are created and constructed through "our participation with/in and as part of the world's differential becoming." (Barad 361) Piaget stipulates that scientific "knowledge must not be considered an objective representation of an external observer-independent environment…the fact that scientific knowledge enables us to cope does not justify the belief that scientific knowledge provides a picture of the world that corresponds to an absolute reality." (Glasersfeld 135) According to Piaget's theory of cognition, "knowledge…is never (and can never be) a "representation" of the real world" but is rather an attempt to satisfy "the goal of constructing a relatively reliable and coherent model of individual experiential worlds" (Glasersfeld 125, 138). Thus, the complete assimilation of a scientific theory into a broader worldview "is a matter of fit rather than match…[which] means no less but also no more than to have built up a conceptual structure that…appears to be *compatible*" with the data and theory being assimilated (Glasersfeld 134).

Scientists have come to acknowledge many points of tension between relativity and classical physics; Einstein's mathematical framework of relativity suggests the need for a predominantly relational understanding of knowledge and reality, which does not fit neatly with the absolutist tenets of Newtonian mechanics. As a "theory of space and time themselves", the implications of relativity are far reaching and areas of tension with Newtonian physics are both numerous and subtle (Griffiths 39). However, these tensions are typically dealt with by revising the Newtonian model rather than replacing it outright. The example of "mass" and "energy" is demonstrative of scientists' general approach to reconciling relativity with the existing scientific worldview. Mass and energy, which were completely distinct concepts in Newtonian mechanics, were recognized by Einsteinian relativity to be intimately related through the famous equation $E=mc^2$. Although this suggests that mass and energy are secondary concepts, arbitrarily divided from the larger, inseparable reality of mass-energy, these concepts continue to be taught in many disciplines of science as well as used in everyday life. We have surely refined our understanding of mass and energy; physicists frequently acknowledge that there is a relationship between mass and energy, and account for relativity's effects on their practical applications of science, yet nevertheless the concepts of mass and energy remain more intuitive and real to most people than relativistic "mass-energy". This emphasizes two setbacks regarding the assimilation of relativity into our scientific worldview, which has long been dominated by Newtonian physics. First, this illuminates that scientists use relativity to revise, rather than replace, their largely Newtonian worldviews. Although our scientific views change our understanding of the world, it is essential to recognize that our preexisting understanding of the world also exerts an influence on the way that we build and interpret scientific models. The influence between science and society is not simple and unidirectional, but is rather a complex feedback loop which flows both ways. Second, the example of "mass" and "energy" points to a crucial tension within science. While the mathematical side of science is largely dominated by relativity, the conceptual components in science remain conflicted between the revolutionary knowledge acquired from relativity, and the more familiar Newtonian model of the world. This puts science in a weird place; although relativity has enabled a deeper mathematical understanding of the world, science and scientists often lack the conceptual clarity, theoretical framework, and adequate vocabulary to fully express and interpret the significance of that mathematical model. Analogous to how Newton's forces could initially be quantified but not conceptually understood, scientists have begun to master the technical applications of relativity without a comprehensive understanding of relativity's philosophical foundation and conceptual implications. It is in this sense that the knowledge of relativity has been acquired but not fully assimilated, as "the vision implicit in"

Einstein's theory of relativity "still awaits representation in a cognitive paradigm yet more radical than the conventional interpretations have offered us." (Keller 721)

Section C- Responding to Anomalous Data

Clark Chinn and William Brewer supply an invaluable theoretical framework for exploring and explaining the partial assimilation of relativity into our worldview in "The Role of Anomalous Data in Knowledge Acquisition". What are the different ways in which scientists and science "students respond when they encounter scientific information that contradicts their current theories about the physical world?" (Chinn and Brewer 1). They note that assimilating anomalous data and choosing between scientific theories "can never logically compel a scientist to abandon a particular hypothesis because the hypothesis is embedded in a network of beliefs, any one of which might be wrong." (Chinn and Brewer 10) "Abandoning or modifying beliefs in the face of new, conflicting data and ideas" is a cautious and calculated decision for scientists, because "it is frequently more rational to discredit anomalous data than to change theories" in the "endeavor to coordinate theory and data." (Chinn and Brewer 31, 1, 13) Similarly, scientists and nonscientists frequently repress, reinterpret, misunderstand, and partially assimilate theories that cannot be integrated into a coherent worldview. When presented with anomalous data, "there are seven basic responses: ignore the anomalous data, reject the data, exclude the data from the domain of theory A, hold the data in abeyance, reinterpret the data while retaining theory A, reinterpret the data and make peripheral changes to theory A, and accept the data and change theory A, possibly in favor of theory B." (Chinn and Brewer 4) The assimilation of relativity into science and scientists' worldviews cannot be simplified to one of these seven responses, because relativity is not a single piece of data but rather a dense theory consisting of countless data which are assimilated, repressed, and understood to varying degrees (Latour 158-175).

"In order to coordinate new anomalous data with an existing theory", there are "three decisions [which] must be made, either implicitly or explicitly...whether the individual accepts the data as valid, whether the individual can provide an explanation for why the data are accepted or not accepted, and whether the individual changes his or her prior theory." (Chinn and Brewer 13) If a theory is accepted, then the individual must figure out how to incorporate it into their existing worldview. Which of the theory's data are expected, and which are anomalous? How can those anomalies be explained? Which other beliefs and theories are called into question if those anomalies cannot be accounted for? When these points of conflict become apparent and irresolvable, one side has to give. Where the new theory and the existing worldview conflict, one side will inevitably be ignored, rejected, excluded, held in abeyance, reinterpreted, or accepted in a peripheral manner. Conflict is not inevitable; in many instances, particularly when inertial reference frames are moving much slower than the speed of light, the data from the theory of relativity *match* perfectly with the preexisting scientific worldview. When conflicts do occur, it is not an all-or-nothing matter as to which side is accepted, because the theory of relativity consists of countless data. Rather, it varies within each case and on a case-by-case basis. There are some ways in which relativity has tangibly and significantly changed our prior understanding of science, but other ways in which the preexisting scientific worldview still dominates. Relativity represents "knowledge acquired, but not yet assimilated" because it is only partially incorporated into our broader worldview; although it has technically been accepted by the professional scientific community, both scientists and the general public are still in the process of fitting it into their broader understanding of "reality" (Keller 718). There are two separate issues which are essential for exploring the assimilation of relativity into our preexisting worldview. First, to what extent has relativity been assimilated into the preexisting scientific worldview?

Second, to what extent is science assimilated into different peoples' understanding of "reality"? The process of assimilating relativity largely revolves around the crucial tensions between relativity and the preexisting scientific worldview, but it also raises challenging and important questions about how science fits into a broader worldview.

<u>Section D</u>- Factors that Influence the Response to Anomalous Data

Chinn and Brewer "propose that there are four key components that interact to determine how people respond to anomalous data: an individual's prior knowledge, a possible alternative theory, the anomalous data, and the processing strategies that guide the evaluation of the anomalous data." (Chinn and Brewer 14) A critical examination of these factors will illuminate the difficulties of fully assimilating relativity into a broader understanding of reality, as well as suggesting how and why relativity has been assimilated to varying extents, by different groups of people, in different contexts and ways. I will now look at each of these four components in turn.

Prior knowledge is a paramount factor for analyzing anomalous data, choosing between scientific theories, and integrating those theories into preexisting worldviews. Prior knowledge enables data and theories to be recognized as "anomalous", and provides a crucial foundation for figuring out how to deal with those anomalies. Chinn and Brewer cite "four characteristics of prior belief that are especially important in influencing how an individual responds to anomalous information: the entrenchment of the individual's current theory, the individual's ontological beliefs, the individual's epistemological commitments, and the individual's background knowledge." (Chinn and Brewer 14) It is tough to reconcile relativity with the preexisting scientific worldview because Newtonian concepts and theories are deeply entrenched in that worldview. "An entrenched theory…contains one or more deeply entrenched beliefs… [which are] deeply embedded in a network of other beliefs…and participates in a broad range of explanations in various domains." (Chinn and Brewer 15) Generally, "the more entrenched a belief, the harder it [is]… to persuade an individual to change the belief." (Chinn and Brewer 15) The unequivocal acceptance of relativity would have massive ripple effects on the preexisting scientific worldview, because that worldview contains numerous deeply entrenched beliefs and theories which do not fit with relativity. Even though relativity is mathematically accepted, the assimilation of that knowledge into our scientific and general worldview poses further challenges since the implications of relativity "run counter to some of our most cherished everyday notions" (Hoffman 5). When the cause of the entrenchment is subtle and the application of the entrenched theory is widespread, as is the case with Newtonian physics, preexisting beliefs are especially hard to give up. Chinn and Brewer specifically note that the beliefs challenged by "the domains of special relativity and quantum mechanics" are subtle and pervasive, and therefore tensions with special relativity and quantum mechanics are more likely to lead to "rejection, exclusion, abeyance, reinterpretation, and/or peripheral change" rather than complete assimilation and the "abandoning [of]…entrenched beliefs." (Chinn and Brewer 16) When a theory or "schema is…embedded in evidentiary support and is used to support a wide range of other theories and observations that the person believes", it is more challenging to assimilate an anomalous theory and maintain a coherent worldview because the areas of conflict are subtle and diverse (Chinn and Brewer 17). Ontological beliefs, which Chinn and Brewer define as "beliefs about the fundamental categories and properties of the world", are "one class of theoretical beliefs that is so deeply entrenched that it deserves special mention…these beliefs are used to support ideas across many domains or subdomains and…are remote from experience", which makes them "very hard to change." (Chinn and Brewer 17) Again, they cite the pre-relativistic beliefs "that objects…move along a single discrete path" and "that time flows at a constant rate regardless of relative motion" as "mistaken ontological beliefs that have been" particularly resistant to change (Chinn and Brewer 17). Many of our basic ontological beliefs have a heavy Newtonian influence, which "not only lead students to reject accepted scientific ideas but also make it difficult for the students to even comprehend the accepted scientific ideas." (Chinn and Brewer 17) This difficulty is further compounded by our conflicting and unclear epistemological commitments. As far as accepting the mathematical paradigm of relativity, the epistemology is straightforward; there is compelling evidence that relativity is a valid scientific theory. Integrating this theory into our scientific concepts and our broader worldview, however, raises extremely complex questions about the epistemology of reality and the metaphysical significance of science as a discipline. This calls for a much more holistic understanding of science, in which "the more traditional theoretic side of science must be supplemented with a plurality of relevant metascientific aspects." (Tuss 456) Accordingly, the complete assimilation of relativity into our broad worldview would require both the conceptual assimilation of relativity and a complicated philosophical judgement about the role of science in understanding and interpreting reality. In addition to entrenchment of prior beliefs, ontological beliefs, and epistemological commitments, "an individual's background knowledge is an extremely potent factor" in the assimilation of a scientific theory (Chinn and Brewer 18). Chinn and Brewer characterize background knowledge as "scientific knowledge that an individual assumes to be valid but that is not specifically part of the theory under evaluation", and assert that "an individual's background knowledge can have very different effects on how the individual responds to anomalous data" depending on its contents (Chinn and Brewer 18). If an individual has a wealth of background knowledge, then they will often "reject or reinterpret anomalous data", but "if an individual possesses too little background knowledge, [then] he or she will not even be able to understand that the anomalous data are anomalous." (Chinn and Brewer 20) Similarly, background theories (such as deeply entrenched beliefs, ontological beliefs, and epistemological commitments) have an important influence on the assimilation of an anomalous theory into a worldview. In order to fully assimilate a scientific theory, an individual must have enough background knowledge to recognize a theory as anomalous and incorporate that theory into a coherent worldview, without having so much background knowledge that his/her worldview is rigid and inflexible. This highlights a substantial roadblock regarding the complete assimilation of relativity; if an individual has enough background knowledge to understand relativity and unravel some of its philosophical implications, then his/her scientific and general worldviews must already be richly detailed. This level of sophistication, in the wake of Newtonian physics, all but ensures that there will be certain components of the preexisting worldview that are both deeply entrenched, ontologically mistaken, and fundamentally in conflict with relativity. Because of these deep-seated anomalies, the assimilation of relativity into our worldview inevitably leads back to complicated questions about ontology and the epistemological role of science in "reality".

In addition to an individual's prior knowledge, the availability of an alternative is an essential influence on the possibility of changing a theory or worldview. Chinn and Brewer identify "the availability of a plausible alternative", "the quality of the alternative", and "the intelligibility of the alternative" as some of the most important factors for "informed theory change" in science (Chinn and Brewer 21). They note that "the history of science shows that scientists frequently choose to make theory-preserving responses to anomalous data when the data are not accompanied by a plausible theory…[with] a plausible physical mechanism." (Chinn and Brewer 21) Scientists typically cling to their theories in the face of anomalous data, if those anomalous data cannot be incorporated into a coherent alternative theory. This response involves a consideration of the framework that the data implies and fits into, as well as the analysis of the data itself. Assimilating an anomalous theory into a broader worldview requires a consideration of similar factors, but on a larger scale. If the scientific theory is unequivocally accepted, can it be assimilated alongside preexisting beliefs to create a coherent worldview? Akin to how scientists resist theory change in the face of anomalous data without a corresponding theory, scientists and the nonscientists resist modifying their worldviews in the face of an anomalous scientific theory that cannot be completely assimilated into an alternative worldview. Assessing the overall coherency of the alternative worldview provides a vital measure of the plausibility, quality, and intelligibility of that theory; thus, to better understand the assimilation of relativity, it is imperative to consider not only the internal coherency of relativity but also how it interacts with and impacts our prior beliefs. The extent to which relativity is assimilated varies greatly between different contexts and different groups of people, because preexisting knowledge and the rigidity of preexisting worldviews vary greatly to begin with. Relativity has been partially assimilated in most scientific contexts because it is mathematically accessible and increases the "accuracy, scope, and consistency" of science and its practical applications (Chinn and Brewer 21). The mathematical component of relativity is intelligible, which in turn allows scientists to discern that relativity is both plausible and higher quality than the prior mathematical model that guided physical science. The complete assimilation of relativity into science and our broader worldview, however, requires the fundamental understanding and integration of relativity's conceptual and philosophical implications as well as its mathematical structure. The complicated metaphysical questions that are raised by relativity make it extremely challenging to assess the plausibility and quality of relativity as a conceptual framework. We have teased out a few of relativity's conceptual implications by applying it mathematically and scrutinizing the results, but the “axiomatic formalization of the mathematical foundations” and their “implications…for our basic notions of space and time” are not sufficient; they do not imply a complete assimilation of the “foundational conceptual principle[s]” of relativity (Zellinger 631). The assimilation of relativity has been greatly inhibited by the fact that relativity’s conceptual components are unintuitive, sometimes to the point of complete unintelligibility, once we step away from the theoretical domain of mathematics. Accordingly, the scientific acceptance of relativity (in the mathematical sense) sets the stage for an unbearable conceptual friction within our scientific worldview, as well as between our scientific worldview and our broader worldview. This is partially a result of our prior knowledge; deeply entrenched ontological beliefs, unclear epistemological commitments, and a wealth of incompatible background knowledge all play a substantial role in making the conceptual implications of relativity particularly unintelligible. In light of this, there is a decision to be made. One option is to prioritize the preexisting worldview and either ignore, reject, exclude, delay (hold in abeyance), or reinterpret relativity while making minor changes to the preexisting worldview. The other option, prioritizing relativity over all preexisting beliefs, leads to a deep conceptual disturbance which raises the need for a sweeping reclassification of the “physical” and “theoretical” components that make up the world as well as daunting philosophical questions regarding the fundamental nature of “truth” and “reality”. To choose the former is to eschew the discipline of science and its implications, but to choose the latter and unequivocally accept relativity is to acquire knowledge that is profoundly at odds with the existing worldview. Remember, the assimilation of relativity into our worldview is not an all-or-nothing decision, but rather a gradual process that has been advanced and repressed in various ways, some obvious and others subtle. Relativity is accepted as the dominant mathematical model for the physical sciences, and has incited peripheral conceptual change in our scientific and general worldviews. On the other hand, it is significant that Newton's influence was not confined to any specific domain or discipline, but rather it extensively permeated our entire preexisting network of knowledge and beliefs. Thus, although some conflicts between the prior worldview and philosophical foundation of relativity can be reconciled, it is immensely difficult to identify, isolate, and coherently restructure every piece of knowledge (including the object-subject dichotomy, absolute simultaneity, the notion of distinct and separable objects, the separability of space and time, the belief "that objects…move along a single discrete path", the belief "that time flows at a constant rate regardless of relative motion", and much more) that is influenced by the basic ontological principles of the preexisting Newtonian worldview (Chinn and Brewer 17). Our worldview is currently stuck in limbo, caught in a "transitional period" between the old Newtonian structure and knowledge acquired via relativity (Keller 718). This transition is greatly complicated by the fact that Newtonian concepts are pervasively embedded in our everyday language, which makes the philosophical implications of relativity exceedingly tough to grasp and express. This ever-present tension between relativity and "some of our most cherished everyday notions" provides compelling evidence that, although relativity has been tangibly incorporated into our model of science and our understanding of reality, it has not been fully assimilated into our general worldview (Hoffman 5). A complete assimilation of relativity would require that all preexisting knowledge and beliefs be reconciled with the conceptual implications of relativity, but many of those implications are far from being comprehensively understood. In order to assimilate relativity into our current worldview, we would thus have to initially embrace a radical restructuration of our most fundamental concepts and beliefs, both in science and about reality. An unwillingness or inability to restructure our concepts and beliefs is an essential part of "why the classical paradigm is so difficult to give up *in toto*." (Keller 720)

Alongside prior knowledge and possible alternative theories, Chinn and Brewer cite the characteristics of the data itself as an important influence on the response to anomalous data. They "propose that there are three characteristics of anomalous data that influence the response to such data: the credibility of the data, the ambiguity of the data, and the existence of multiple data to rule our prior theory-preserving responses." (Chinn and Brewer 24) Again, relativity has been scientifically accepted and "acquired" because the assessment of these three characteristics has been settled conclusively; there is a wealth of data which is credible, specific, incompatible with the preexisting Newtonian worldview, and explainable in the framework of relativity. To expand our analysis and explore the complete assimilation of relativity, we must consider similar questions regarding the integration of the theory of relativity into our broader worldview. It is imperative to consider the internal characteristics of relativity: is it credible, is it ambiguous, and does relativity (alongside other theories/data) rule out any responses that preserve our prior-worldview? Analogous to how no "anomalous data can…logically compel a scientist to abandon a particular hypothesis because the hypothesis is embedded in a network of beliefs", no theory can logically compel a scientist to abandon a particular worldview (Chinn and Brewer 10). The decision to change a scientific theory or worldview is rational, reflective, and calculated rather than logically compelled. Accordingly, akin to the need to account for a significant interrelation between our prior knowledge and the availability of alternative theories, the characteristics of a scientific theory cannot be understood in isolation. These characteristics are defined in part by the internal coherency of relativity, but they are also heavily determined through the assessment of relativity's role in, and impact on, our broader network of knowledge. Here, it is once again evident that complete assimilation of relativity has been greatly inhibited by its conceptual unintelligibility. The unintelligibility of relativity's theoretical and conceptual implications has, thus far, left us unable to integrate relativity into a coherent and accessible worldview; in turn, this creates ambiguity by raising challenging questions about epistemological and ontological credibility on one level or another. If the role of relativity in science is credible, unambiguous, and incompatible with the prior scientific worldview, should we modify our interpretation of relativity or restructure our beliefs in and about science? What if relativity is fully assimilated into a scientific worldview that is credible, unambiguous, and incompatible with our broader worldview and general understanding of "reality"? Would we then return to questions about the scientific role and meaning of the theory of relativity, would we change the way that we interpret and implement science, or would we be willing and/or able to appropriately restructure the way that we understand and interact with a broader "reality"? These questions are tough to answer with any type of confidence or certainty, as they are both philosophically dense and heavily interrelated. In order to thoroughly and rationally consider the factors that are imperative to any one of these questions, the other questions must already be answered and assimilated into a broad network of knowledge. It is precisely this level of comprehension, however, that was precluded in the first place. The partial assimilation of relativity has suggested the need for "a cognitive paradigm…more radical than the conventional interpretations have offered us"; paradoxically, we need a revised network in order to understand the role of the actor, yet that same actor is an essential clue regarding the structure and properties of the revised network (Keller 721). We need the network in order to contextualize the actor, or a comprehensive understanding of the actor in order to illuminate the network, yet the possibility of either one depends on the prior fulfillment of the other (Latour 212-236). A more comprehensive understanding of relativity's conceptual implications is a vital prerequisite to the rational assessment of the availability, plausibility, quality, credibility, and ambiguity of alternative worldviews which completely assimilate relativity, but this level of conceptual understanding is exceedingly inaccessible (to the point of being “unintelligible”) without such a worldview already in place.

In addition to prior knowledge, a possible alternative theory, and the anomalous data, Chinn and Brewer identify an “individual’s strategies for processing the anomalous data” as “the final set of factors that can affect an individual’s response to anomalous data” (Chinn and Brewer 29). They define “deep processing” as “mental processes such as attending carefully to the contradictory information, attempting to understand the alternative theory, elaborating the relationships between the evidence and the competing theories, and considering the fullest available range of evidence.” (Chinn and Brewer 29) They note that “theory change is more likely when people process contradictory information deeply than when they do not”, but that, “in practice, people frequently fail to process contradictory information deeply” (Chinn and Brewer 29). Similarly, deep processing of an anomalous theory is far more likely to incite a worldview-changing response than processing an anomalous theory superficially. Chinn and Brewer cite two ways that people can “be encouraged to process contradictory information deeply” (Chinn and Brewer 29). The first is “by fostering personal involvement in the issue”, and the second “is to tell reasoners that they will have to justify their reasoning to other people.” (Chinn and Brewer 31, 29) These conclusions are heavily supported by a wealth of research in psychology. If people “are personally involved with the issue, or if they expect to have to justify their reasoning, people process anomalous information deeply and are more likely to change their theories [or worldviews] …otherwise, they are content to process the information superficially, and theory [or worldview] change is less likely.” (Chinn and Brewer 30) This concept of “deep processing strategies” also helps to tie together and explain the other three factors - prior knowledge, a possible alternative worldview(s), and the characteristics of the anomalous theory – which are vital to understanding the process of assimilating an anomalous scientific theory. Piaget's theories teach us that knowledge can never be fully assimilated "passively, because novelty cannot be handled except through assimilation to a cognitive structure the experiencing subject already has…indeed, the subject does not perceive an experience as novel until it generates a perturbation relative to some expected result." (Glasersfeld 136) Prior knowledge is necessary to form an expected result, and an expected result is necessary to experience a perturbation that "may lead to an accommodation and thus to a novel conceptual structure that re-establishes a relative equilibrium." (Glasersfeld 136) Data and theories can only be recognized as anomalous by considering a larger network of preexisting knowledge; "nothing by itself [is] either logical or illogical" and "no set of sentences by itself [is] either consistent or inconsistent", and so the process of assimilating knowledge by analyzing its characteristics cannot take place in complete isolation (Latour 179). The process of complete assimilation requires that the subject simultaneously situate the assimilating knowledge as both an actor (the anomalous theory) and as a network (an alternative worldview). Both of these tasks involve the complex analysis of, and in-depth integration with, a much broader network of preexisting knowledge. Accordingly, deep processing is imperative in order to reveal and encourage rational scientific decisions that enable the construction of a coherent worldview. The assimilation of knowledge involves a complicated preponderance of evidence rather than a straightforward or clear cut decision. Piaget emphasizes the foremost important of perturbations for producing cognitive change, yet it seems that perturbations can only be experienced if a proper conceptual and physical framework is already in place. In a study of "citizen-science projects [which] aim to increase participants' knowledge about science and the scientific process…through the combination of direct participation in a scientific study, interaction with scientists during the project, and use of high-quality educational materials", Brossard found that "no statistically significant change in participants' understanding of the scientific process, attitudes toward science and attitudes toward the environment could be detected." (Brossard 1101, 1107) Brossard concludes "that participants, although involved in the scientific process, failed to concentrate on this process because they were focused on the subject itself…nothing in the experiential context stressed…that they were involved in the scientific process." (Brossard 1115) This has profound implications for the assimilation of scientific knowledge. In order to experience a perturbation, subjects need both an anomalous experience and an adequate framework for analyzing that experience. It is more appropriate to "speak of *sciencing* rather than *science*…to emphasize science as a human activity rather than a disembodied set of facts and principles independent of the knower." (Tuss 456) Our experiences are mediated by our prior knowledge and conceptual framework; accordingly, "citizen-science projects that hope to increase understanding of the scientific process should be framed in a way that makes participants particularly aware of the scientific process in which they are becoming involved." (Brossard 1117) In this context, it is particularly important that, "in practice, people frequently fail to process contradictory information deeply" and that "they attend much more to evidence that support their beliefs than evidence that contradicts them." (Chinn and Brewer 29) In our everyday experiences, we are busy focusing on "the subject itself" and "nothing in the experiential context" stresses to us that we are "involved in the scientific process." (Brossard 1115) Even when we do explicitly concentrate on the underlying scientific processes, our ability to recognize and react to perturbations is greatly diminished by our preexisting worldview and its high correspondence to our experiential reality; the subtlety, complexity, and philosophical density involved in reconciling relativity with the preexisting scientific worldview makes complete assimilation extremely difficult. Without a certain “conversance with a specialized vocabulary and facility with mathematical symbols and formulas”, it is challenging to even “perceive the advantage of mastering” the conceptual model of relativity (Tuss 451, Glasersfeld 137). A proper metaconceptual understanding is “a requisite contextual base for assimilating information obtained through symbolic, vicarious, and other indirect means.” (Brossard 1102) Without such an understanding, knowledge can be acquired but it cannot be fully assimilated.

Section E- Conclusion

The paramount importance of deep processing for the possibility of worldview change ties together prior knowledge, the possibility of an alternative worldview, and the internal characteristics of an anomalous theory in an inextricable feedback loop. These factors are distinct and different yet not entirely separable; they blend together in a mix of science and society, actor and network, subjective and objective, theoretical and physical, sensory-motor and reflective abstraction, utilitarian and epistemic instrumentalism (Latour 212-236). Science revolves around “attempts to coordinate theory and data” in order to achieve an understanding which “is a matter of fit rather than match”; science thus reveals constructive (as opposed to substantivalist or “objective”) truth, which in turn suggests that our worldview “means no less but also no more than to have built up a conceptual structure that, in the given context, appears to be *compatible*” with that truth (Chinn and Brewer 13, Glasersfeld 134). *Science* is a methodology for observing, interpreting, and interacting with a larger reality; it aims to minimize the influence of the subject (scientist) and standardize the discourse about knowledge, through “objective” measurements and categorizations, which in turn enables scientists to systematically *construct* “a relatively reliable and coherent model of…individual experiential worlds” (Glasersfeld 138). In other words, our data, theories, and worldviews are all intimately linked. The guiding scientific principles of “objectivity” and “rationality” illuminate the paramount important of deep processing for the complete assimilation of anomalous knowledge. Any anomalous knowledge needs to be processed deeply in order to rationally decide whether it should be accepted or rejected, as well as to recognize whether or not it is anomalous. This further emphasizes the importance of deep processing, as it is crucial to consider not only the knowledge being assimilated but also the preexisting network of knowledge. If the knowledge is not anomalous, then it must be situated in and explained by the preexisting network of data, theories, and worldview(s); if it is anomalous, then deep processing is necessary to figure out the severity of the anomaly as well as to rationally decide on an appropriate response. The assimilation of a theory revolves around the dual exploration and understanding of that theory, both in the context of the preexisting worldview (the characteristics of the theory “itself”) and in the context of the “resulting” worldview (a possible alternative); “itself” and “resulting” are both in quotation marks, because they each draw on our prior knowledge as well as the theory which is being assimilated (Latour 212-236). Science is a methodical “process of discovery [rather] than a body of static knowledge”, and thus knowledge that is assimilated is not and cannot be entirely independent from our preexisting network of knowledge and beliefs (Chinn and Brewer 18). *Science* can only advance if knowledge is actively and discerningly assimilated according to what is “rational”, as opposed to passively acquired. The superficial processing of knowledge by “memorizing facts and training in rote procedures cannot achieve this”; knowledge can be acquired using these methods, but “it is naïve to expect that they…also generate understanding.” (Glasersfeld 138, 136) It is imperative to deeply process knowledge in order to fully assimilate it into a “reliable and coherent model of…individual experiential worlds.” (Glasersfeld 138)

<u>Chapter 3: Assimilating Relativity: Moving from Newtonian to Relativistic World Views</u>

"It was as if the ground had been pulled out from under one, with no firm foundation to be seen anywhere, upon which one could have built"-Albert Einstein (Kumar 1)

<u>Section A</u>- Acquisition of Relativity

In 1893, Wilhelm Wien "discovered a simple mathematical relationship that described the effect of a change in temperature on the distribution of blackbody radiation." (Kumar 14) Shortly "after Wien published his distribution law, in 1896, [Max] Planck set about trying to place the law on rock-solid foundations by deriving it from first principles." (Kumar 15) Over the next few years, Planck and his contemporaries worked tirelessly resolve discrepancies between experimental measurements and the predictions of Wien's law. After finding systematic discrepancies at "longer wavelengths, they found the difference between theory and observation was so marked that it could be evidence of only one thing, the breakdown of Wien's law." (Kumar 18) By "manipulating the various mathematical symbols of the equations at his disposal", Planck was able to create an ad-hoc mathematical patch that enabled Wien's law to "almost perfect[ly] *match*" the data (Kumar 19, my italics). As Planck's revisions were spread to the professional scientific community, "it quickly became clear that Planck was not simply proposing 'an improvement', some minor tinkering with Wien's law, but a completely new law of his own." (Kumar 19) Planck knew that it was essential to invest his formula with "true physical meaning", or else it would have "merely the standing of a law disclosed by lucky intuition that possessed no more than a formal significance." (Kumar 20) This process was an immense struggle; after what Planck described as 6 weeks of "the most strenuous work of my life", he concluded that "a theoretical interpretation…had to be found at any cost…no matter how high…[I] was ready to sacrifice every one of my previous convictions about physical laws."

(Kumar 20-21) Planck slowly came to realize that he could not explain blackbody radiation without using the atomic model; he reluctantly "accepted that atoms were more than just a convenient fiction, after years of being openly hostile to the atomic theory." (Kumar 23) This acceptance led Planck to realize that energy is transmitted in discrete packets or 'quanta', as opposed to the continuous model of energy flow that was commonly accepted in physics. Ironically, Planck himself failed to grasp the physical significance of this; he "regarded the introduction of the quantum, a packet of energy, as a purely formal assumption to which he really did not give much thought" (Kumar 27). Planck and his contemporaries considered the quantum "nothing more than…a neat mathematical trick on the path to getting the right answer…it had no true physical significance." (Kumar 27) There is a significant difference between the acquisition and assimilation of knowledge; as Kumar puts it, "there is a difference between making a discovery and fully understanding it, especially in a time of transition." (Kumar 29) After spending the better part of a decade trying "to incorporate the quantum into the existing framework of physics", Planck began to realize "the far-reaching consequences of what he had done" (Kumar 29). After years of being a "reluctant revolutionary", Planck admitted that efforts to avoid the quantum theory were useless; exasperated, he declared that "it doesn't help…we have to live with quantum theory…and believe me, it will expand." (Kumar 29)

Albert Einstein was one of the first physicists who "learn[ed] to live with the quantum [theory]." (Kumar 29) In 1905, he submitted a proposal for a quantum theory of light which "was even more radical than Planck's introduction of the quantum." (Kumar 32) This was the earliest version of Einstein special theory of relativity. Einstein gave credit to Planck for the essential role that Planck's concept of the quantum played in Einstein's work on relativity; "it was the extension of Planck's quantum concept to light and radiation that he described as very revolutionary, not relativity [itself].” (Kumar 32) Einstein “regarded relativity as a simply a ‘modification’ of ideas already developed and established by Newton and others, whereas his concept of light-quanta was something totally new…and represented the greatest break with the physics of the past.” (Kumar 33) Although the wave model of light had been universally accepted for nearly a century, “Einstein’s revolutionary point of view [proposed] that light, indeed all electromagnetic radiation, was not wavelike at all but chopped up into little bits, light-quanta”, that act more like tiny particles (Kumar 33). Despite the fact that virtually no one else in the professional scientific community believed in the quantization of light for more than another decade, Einstein knew that he was onto something significant. Using his model of light quanta, Einstein began to accumulate theoretical and quantitative evidence that advanced his framework. In 1911, he wrote to his friend Michele Besso “I no longer ask whether these quanta really exist… [I will] limit [myself] to trying to understand the consequences of the quantum.” (Kumar 65) Einstein recognized that knowledge of the quantum had been acquired, but had not yet been fully unraveled and assimilated. In this way, “Einstein had been the first to learn to live with the quantum, and by doing so [he] revealed a hidden element of the true nature of light.” (Kumar 66)

Section B- Foundations of the Special Theory of Relativity

The Special Theory of Relativity was founded on two main postulates. The first is the principle of relativity, and the second is the universal speed of light. At first glance, neither one seems all that radical. The first postulate, the principle of relativity, “says that the ordinary laws of physics apply just as well in a system moving at constant velocity as they do in one at rest” as long as that system is “moving at *constant speed*, in a fixed direction.” (Griffiths 40) In other words, “the ordinary laws of physics hold in any inertial system.” (Griffiths 41) We have to adjust the numbers and the math to account for the motion of the system, but the key point is that the same laws of physics apply. The second postulate asserts that “light travels at the same speed in all inertial frames- regardless of the motion of the source.” (Griffiths 42) Griffiths cites this as “Einstein’s truly revolutionary proposal”, noting that “it may sound innocent, but a moment’s reflection reveals that it is not just radical, but downright preposterous.” (Griffiths 42) The implications of these two postulates are wide-reaching; relativity is challenging to reconcile with classical physics because it subtly conflicts with our deeply entrenched Newtonian beliefs about ontology and reality in various ways. This makes it extremely difficult to unravel and assess the full implications of relativity, which in turn makes it almost impossible to coherently assimilate relativity and classical physics into a broader worldview.

An important thing to note about the Special Theory of Relativity is that it “is not an account of any particular physical phenomenon”, but rather “a description of the *arena* in which *all* phenomena occur.” (Griffiths 39) Griffiths notes that “it takes precedence over all other theories” because “it is a theory of space and time themselves”; if you consider any physical law or model, the very “first thing to ask would be ‘Is it consistent with special relativity?” (Griffiths 39) For much of classical physics, the answer to that question is a resounding no. Even in the many cases where the empirical data from the classical model *matches* the empirical data from relativity, the implications of relativity suggest a more nuanced way to understand and express our empirical findings. Relativity is the be-all and end-all of physics, because physics is based on observations and events in a universe which is ultimately governed by relativity. The paramount importance and priority of relativity cannot be emphasized highly enough. Our Newtonian model of the world, and our preexisting beliefs which are derived from classical physics, must be reconciled with insights gained from the special theory of relativity; not the other way around.

First and foremost, special relativity invalidates our belief in absolute simultaneity. An easy way to understand the logic behind this is to consider the example of a train car which has "a lightbulb, hanging from the ceiling at the very center of the car." (Griffiths 46). If there are detectors placed at either end of the car and the car is in constant motion, which detector will the light hit first? According to special relativity, we have to invoke the concept of frame of reference in order to answer this question. If we consider "the perspective of an observer on the train, they both ring at the same time (simultaneously), because the light has just as far to travel in both directions." (Griffiths 46) If we consider "an observer on the ground", on the other hand, "the train itself moves a bit during the process, so the light going to the back end has a *shorter* distance to go"; if light travels at the same speed in both directions, the observer on the ground will observe it hitting the back detector first (Griffiths 46). Remember, "relativity has to do with what you *observe"*, once you correct for any errors in judgement and account for all of the data (Griffiths 47). We are accustomed to discrepancies in sight, hearing, and other senses, but special relativity's introduction of a "frame of reference" as something that establishes actual substantive variation between the observations of different observers is revolutionary. The acknowledgement of a tangible interrelation between observer and observed greatly complicates the classical notion of "objectivity". Special relativity posits an insoluble link between space and time, which in turn leads scientists to the inescapable conclusion that "two events that are simultaneous in one inertial frame are not, in general, simultaneous in another." (Griffiths 46). This may not seem groundbreaking in and of itself, but "Einstein liked to say that all the conceptual difficulties of special relativity derive ultimately from the relativity of simultaneity." (Griffiths 47) When we consider the full extent of special relativity's implications, it should be clear that the relativity of simultaneity signified a death blow to "space", "time", and "reality" as we knew them. Although it is not particularly challenging to account for relativity in our everyday applications of classical physics, it is nearly impossible to accept and internalize the concepts that it is founded on.

<u>Section C</u>- Partial Assimilation of Relativity

As far as accounting for the tangible effects of relativity on the mathematical application of classical physics, “there are only three or four fundamental surprises- after that everything begins to fall into place.” (Griffiths 45) These surprises all incorporate the subject/object and observer/observed distinction in one way or another, as these distinctions became deeply problematic with the recognition of the relativity of simultaneity. The notion of measurement, which depends on the absolute separation of observer and observed, is one concept which is particularly impacted. According to the special theory of relativity, the time measurement for a specific event, which is obtained in a stationary reference frame, is greater than the time measurement that would be obtained in a moving frame of reference. This is commonly referred to as “time dilation”, and can be summarized by noting that “moving clocks run slow” (Griffiths 48). The counterpart to time dilation, called “Lorentz contraction”, states that any spatial measurement which is obtained by an observer on the ground will be shorter than if it were made by an observer in motion. This sentiment is captured in the phrase “moving objects are short” (Griffiths 51). Remember, these are constitutive discrepancies and not just what is experienced; it is not that “moving objects *appear* short, or *seem* short, or *look* short; we’re not talking about appearances, here – they simply *are* short, as compared to their rest length.” (Griffiths 51)

It is not hard to see how these complications arise from the relativity of simultaneity. If we consider the notion of spatial measurement, it is clear that it requires us “to read two numbers *at the same time”*; if the object being measured is moving in your frame of reference, then you are bound to “make the most elementary blunder in the book” by measuring the front end and waiting to measure the back end (Griffiths 54). There is no absolute answer to resort to, because "what's simultaneous to *me* is not simultaneous to *you*" (Griffiths 54). The issue is similar if we consider time dilation. For any moving observer, both the moving observer and a stationary observer will observe the clock of the other to be running slow. Any attempt to resort to a third clock will be foiled by the fact that synchronization is problematic once we consider relativity; you may claim that your clock was synchronized with another and is thus more correct than mine, but "from *my* perspective your clocks weren't synchronized in the first place" (Griffiths 54). The relativity of simultaneity takes into account the inextricable relationship between space and time, and in the process destroys the notion of absolute measurement; in turn, this forces us to recognize the monumental role that frames of reference play in our own experiences. It is significant that different frames of reference play constitutive roles in creating "reality". In our daily lives, we are tempted to say that something is absolutely moving or absolutely at rest, but special relativity reveals this urge to be mistaken. Considering that a subject's position in and movement through spacetime (in other words, their "frame of reference") influences "reality", it does not make sense to talk about "objective" measurements, events, and occurrences in the way that they are traditionally defined by the Newtonian worldview. When a train flies past you at 80 mph, you can say that the train is moving relative to the tracks, relative to the surrounding trees, and relative to you, but those are all just relative reference points. If you consider passing the train "in empty space...with no Earth to confuse the issue", then it is clear that you "*each* [are] moving, relative to the other, and each [are] at rest, in [your] own reference frame." (Griffiths 52) *Measurements are always relative to something; there are no absolute measurements.*

Recognizing that an underlying degree of relativity exists in our measurements and traditional "objectivity" is a revolutionary change in worldview. As we assimilate the subtle implications of moving from Newtonian "space" and "time" to Einsteinian spacetime, it becomes increasingly clear that many of our preexisting concepts and beliefs are tainted by the entrenched attitude of Newtonian absolutism. In order to create a coherent scientific worldview, we need to reconcile the conceptual framework from classical physics with the insight gained from relativity. Merging these two networks of knowledge and beliefs has been no easy task; although relativity should take scientific priority over classical physics, the truth of the matter is that our integration of relativity has been more of a process of give and take. Relativity has altered and enriched classical physics, but classical physics has also influenced our understanding and assimilation of relativity. This is evident from the example of mass and energy. As "old terms, concepts, and experiments fall into new relationships one with the other", Einstein realized that the variables in certain laws needed to be revised (Kuhn 148). Following the realization that mass and energy are intimately related in relativistic spacetime, Einstein began to conceptualize energy in more nuanced terms that the traditional definition. Einstein broke down conventional "energy" into relativistic energy, rest energy, and relativistic kinetic energy, noting that kinetic energy could be "converted into rest energy, and hence the mass increased." (Griffiths 61) Although "this is *not* the same as classical" ways of thinking about mass and energy, "it is close when the velocity is much less than the speed of light." (Griffiths 60) Despite the shift towards a fundamentally relational understanding, the concepts of mass and energy are commonly used; although we recognize the inextricable relationship between the two, our conceptual framework is still stuck in terms of Newtonian mass and energy rather than relativistic mass-energy. This is indicative of the general assimilation of relativity; people recognize the flaws in their preexisting beliefs in some ways, but project them onto their understanding of relativity in others.

Mathematically, scientists are compelled to accept relativity because it allows for a greater degree of accuracy. In the process, scientists come to recognize shortcomings in their preexisting worldviews via implications that are subtly embedded in relativity. The extent to which these are understood, accepted, and repressed varies greatly; the conceptual foundation of relativity is neither as intelligible nor as compatible with classical physics as relativity's basic mathematical implications. Furthermore, the chance of feeling any type of perturbation between classical physics and relativity is minimal because they *match* in our regular everyday experiences. This makes relativity easy to ignore on a conceptual basis, since the practical and mathematical results via classical physics or relativity would be equivalent. Nevertheless, the assimilation of relativity reveals subtle and far-reaching implications which potentially have something valuable to contribute to our broader worldview. For example, relativistic energy illuminated that fact that "nothing with (rest) mass can travel at the speed of light" because "it would take an *infinite* amount of energy" to accelerate it to that speed (Griffiths 62). The only thing that could travel at the speed of light would be massless particles; although Newton's laws deny the existence of massless particles (given that "you couldn't exert a force on it" and "it couldn't exert a force on anything else"), "in relativity it is just conceivable that there *could* be massless particles, provided that they always travel at the speed of light." (Griffiths 63-64) Although classical physics claims that such particles do not exist, these particles have been experimentally verified. They are called photons; while they have no mass and travel at the same speed (c), quantum mechanics suggests that the difference between a high and low energy photon manifests itself as the color of that photon (Griffiths 64). In the process of assimilating new scientific information, we open ourselves up to new viewpoints and perspectives; these are an essential basis for reassessing our preexisting beliefs and maintaining a coherent worldview.

By analyzing and reconciling a multiplicity of perspectives, we become aware of new concepts, relationships, and phenomena. Ultimately, this is what enables us to construct a more "reliable and coherent model of…[our] individual experiential worlds." (Glasersfeld 138) Thus, although relativity and classical physics *match* for a large class of basic practical applications, it would be a mistake to assume that the conceptual framework of relativity does not have significant value and nuance to contribute to our preexisting worldview. There are implications of relativity which we have yet to unpack, and there are parts of our scientific worldview which are profoundly at odds with relativity and spacetime. Although scientists have introduced new concepts and recognized new relationships via the process of assimilating classical physics and relativity, problematic artifacts from the preexisting Newtonian worldview remain. Relativity represents a radical and revolutionary conceptual framework; in practice, however, the insight that we have gained from relativity has only served to produce minor changes in our broader worldview.

As we saw with the quantification of Newton's forces, there is a big difference between acquiring an idea and fully internalizing its conceptual foundation. "The key fact [that] Einstein discovered" is that "the combined speed of any object's motion through space and its motion through time is always precisely equal to the speed of light", but "these two kinds of motion are always complementary." (Greene 49) Objects do not move through space at various speeds and endure through time, but rather move at a constant rate through spacetime. Accelerated movement through space will thus result in a slower passage of time, and vice versa. Although "the effects of special relativity are most pronounced when speeds through space are a significant fraction of light speed…the unfamiliar, complementary nature of motion through space and time always applies." (Greene 49) Scientists adjusted their variables to account for this relationship between space and time, yet continued to think of them as separable entities. We still think in terms of the old paradigm, measuring the spatial properties of physical objects as they move and interact through time. *Special relativity represented a conceptual revolution, in that it showed space-time to be indivisible and inextricably linked.* This is what Minkowski was alluding to when he claimed that “From now onwards space by itself and time by itself will recede completely to become mere shadows and only a type of union of the two will still stand independently on its own." (Minkowski 37) This, however, did not come to pass; relativity was acquired and spacetime was accepted, but they have not yet been fully assimilated. Relativity has tangibly revolutionized our scientific model of space and time, yet our understanding of spacetime remains woefully incomplete and suffers from critical tensions with the preexisting Newtonian worldview. The full conceptual significance of relativity has been cognitively repressed, as people continue to think about space-time in terms of 3 dimensions of space + 1 dimension of time rather than an indissoluble whole. If we consider the full implications of understanding spacetime as irreducible and inseparable, then it should be abundantly clear that relativity undermines our traditional notion of reality far more than has been acknowledged.

Chapter 4: Reconciling Relativity and “Reality”

“We shall see that this ‘truth’ is limited, and we shall consider the extent of its limitation.”

-Albert Einstein (Einstein 13)

Section A- Introduction

A large part of the reason that relativity has been so challenging to assimilate is because our understanding of “space” and “time” is more than just an abstract scientific model; it has become a crucial component in how we interpret the world around us. “The feeling that time flows is deeply ingrained in our experience and thoroughly pervades our thinking and language”, notes Brian Greene, adding that "habitual, colloquial descriptions…refer to a flowing time." (Greene 142) The classical notion of time has set its roots as "something we are within, something that is fully integrated into our day-to-day existence, something that is so pervasive, it is impossible to excise – even momentarily – from common language (and) our reasoning" (Greene 177). Relativity has been accepted and the model of spacetime has been acquired, but we need to unpack and internalize the implications of this model in order to fully assimilate relativity. As we move from Newtonian "space" and "time" to Einsteinian spacetime, we need to reorient our understanding of "objectivity" and "reality" to be compatible with the conceptual framework suggested by relativity. As we saw with the example of probabilism, science can make significant progress by recognizing underlying levels of subtly and nuance within our traditional absolutist concepts; that being said, this is not an easy or comfortable process but rather a piecemeal struggle to attain a coherent scientific worldview. Akin to "certainty" and probabilism, the cost of learning about "reality" via relativity is that "reality" is revealed to be far less straightforward than we had traditionally recognized. Just as Darwin's theories disturbed both scientists and religious thinkers, the assimilation of relativity is sure to involve challenging and wide-reaching revisions to our traditional ways of thinking. Relativity offers an opportunity to construct a better scientific worldview, but not without effort and conflict along the way. To better understand reality, we may first have to concede that there is no "reality" (Latour 178).

In my final chapter, I will consider the implications of moving from Newtonian "space" and "time" to Einsteinian spacetime. One of the most significant consequences of this shift is that "truth" and "reality" cannot coherently be defined as ontological preexistence; instead, we need to recognize a greater degree of nuance and think about the ways in which reality is (inter)-actively created as opposed to passively discovered. In a universe ultimately ruled by general relativity, in which "the stage warps as matter tells space how to curve, and space tells matter how to move", it is apparent that we can no longer think about reality in quite the traditional sense (Rosenblum and Kuttner 258). This is evident in Brian Greene's discussion of space, time, objectivity, consciousness, and free will. Next, I will examine Karen Barad's theory of agential realism, which represents her attempt to assimilate the fundamental tenets of an anomalous scientific theory with the largely incompatible framework of classical physics. Barad's work serves two purposes; first, it is an excellent case study, as it is indicative of general trends in the process of assimilating anomalous scientific information. Secondly, agential realism is an interesting heuristic framework because it accounts for and coherently expresses the unintuitive interrelation between spacetime and matter that will be discussed in Section B. Barad attempts to rescue as many of our Newtonian beliefs as possible, while steering clear of the epistemological weaknesses and mistakes that continue to plague classical physics. Agential realism is highly speculative and does not represent the solution to assimilating relativity, but it helps to provide a heuristic understanding of how our traditional notions of "truth" and "reality" can be enriched by recognizing underlying degrees of nuance which have been glossed over all along. This makes it easier to accept and embrace relativity on a fundamental level, as well as to recognize the ways in which relativism is already present in our everyday lives and experiences. I will conclude by considering the legacy of Newton's framework, in light of relativity and quantum mechanics, as well as what all of this demonstrates about the assimilation of anomalous scientific information.

Section B- Moving from Newtonian "Space" and "Time" to Einsteinian Spacetime

As Brian Greene notes, "*not everything in relativity is relative*." (Greene 58) Despite the fact that "absolute space does not exist" and "absolute time does not exist", he posits that special relativity implies that "absolute space-time does exist." (Greene 59) Greene suggests that "just as we envision all of space as *really* being out there, as *really* existing, we should also envision all of time as *really* being out there, as *really* existing, too." (Greene 139) Greene analogizes spacetime with a loaf of bread, and takes special relativity to mean that we each cut our "now" slices at slightly different angles (Greene 135). This notion is problematic in and of itself. If "we are all *within* spacetime" and "every experience you or I ever have occurs at some location in space at some moment of time", then how can we possibly reconcile our notions of passing time and free will with an absolute spacetime whole? If spacetime is absolute and deterministic, then it seems that "the flowing river of time more closely resembles a giant block of ice with every moment forever frozen into place." (Greene 141) Our entire lives are frozen within a small section of that block, and accordingly everything that we have ever done, thought, and said must be set in stone. The only way to rescue our notion of free will and passing time would be to admit that spacetime is not "absolute", at least in the *traditional* sense of being both complete and consistent. If "every moment *is*" and "can change no more than a particular location can move in space", then we need to recognize and account for some level of indeterminacy if we are to preserve any type of freedom regarding the way that we interact with the world (Greene 141).

General relativity plays a crucial role in this apparent paradox. As Einstein himself pointed out, "as for the question of the absoluteness of space-time in general relativity, it no longer has the character of something which acts without being acted upon" (Rynasiewicz). While ours may be "an egalitarian universe in which every moment is as real as any other", "the essential structure of spacetime – the separation into future, past, and elsewhere – is absolute, in special relativity." (Greene 132, Griffiths 67) If our notion of free will is correct, then sentient life forms have a very odd relationship with spacetime. Spacetime is a sort of container of all conscious beings' thoughts and actions, but at the same time conscious life exerts an influence on spacetime itself. An absolute spacetime, at least according to the traditional definition of "absolute", does not leave room for this type of dualistic interrelation. Although spacetime is absolute in the sense that it contains "past, present, and future *equally*", "the notion of *now*" nevertheless "plays a central role in our worldview" and influences our actions, which in turn shape the "absolute" spacetime loaf (Greene 138). In terms of a Minkowski diagram, "at each moment your forward light cone represents the future…the only region you could possibly influence…[and] the backward light cone is your past – the region of spacetime that can possible influence you." (Griffiths 66) Time may not flow in absolute spacetime, but it does seem to flow for the conscious beings that inhabit spacetime; this is an essential discrepancy.

Figure 1

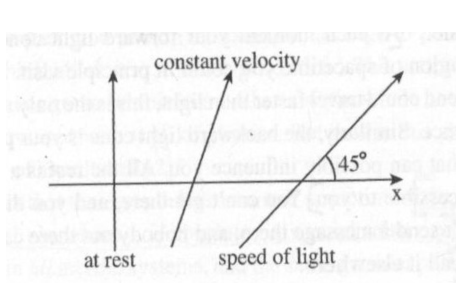
(Griffiths 65)

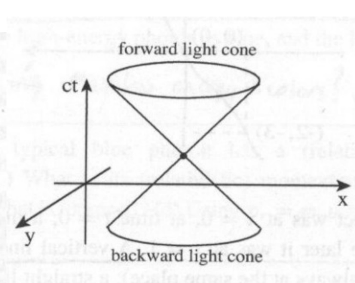
Figure 2

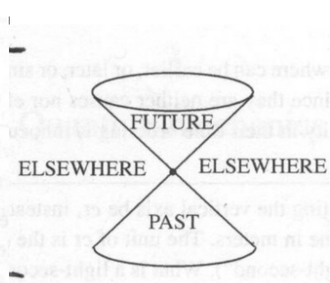
(Griffiths 66)

Figure 3

(Griffiths 67)







If we are correct in thinking that time influences our conscious decisions (which it seems that it does, if only the past can influence "right now" and if "right now" can only influence the future), then the "passage" of time exerts a weird influence on spacetime which is difficult to analyze. We have traditionally used "reality" as "our shorthand term for the existence of physically real properties" which are independent from observation, but relativity vastly complicates the notions of "physically real" and "independence" by inextricably linking space and time (Rosenblum and Kuttner 187). Are past and/or future objects capable of being "physically real"? Is being "real" a matter of traditional ontological preexistence, or is "reality" more appropriately modeled as something which is actively created and developed? Does it make sense to posit a strict dichotomy between observer and observed, subjective and objective, material and theoretical? Can any object be *completely* independent from any other object, if they are both a part of the 4-dimensional spacetime whole? Without the fundamental presupposition of absolute simultaneity, derived from the core belief in absolute space and absolute time, other concepts which have been subtlety influenced by Newtonian thought begin to lose their coherency. What is the significance of this analysis? It reveals a trend of making the same mistakes time and time again, mistakes which all relate to the way that we think about spacetime. We consider objects and measurements absolute, when we should be focusing on the relationship between them. We always find ourselves searching for an "absolute reality" and an answer for the way that things "really" are, yet we rarely stop to consider that such an answer may not exist; that constantly evolving spatiotemporal relationships might be all that there is to "reality". We ignore the fact that scale matters, and assume that "reality" must be something which can be added up and broken down without altering its essnetial properties. Relativity revealed that spacetime is an inextricable entity, yet we continue to think in terms of space as separable from time. The concept of a frame of reference suggests that we need to reconsider the way that we think about reality, and recognize that we are a *part* of it rather than idle observers.

Section C- Agential Realism

There are significant implications to the recognition that we are active participants in a reality which is influenced and created, rather than "discovered". The bidirectional interrelation of spacetime and matter is one particularly difficult implication, as it stands in stark contrast to the absolutism of space and time in the traditional Newtonian model. Although Barad provides a useful and plausible heuristic model for the unintuitive interrelation of spacetime and matter, this is not her explicit intent. Rather, Barad's theory of agential realism is focused on crafting Bohr's Copenhagen Interpretation into a plausible worldview without altering its fundamental tenets.

Barad characterizes her assimilation of the quantum theory as a "relational ontology" which is free from the "ontological and epistemological presuppositions that are challenged by the quantum theory." (Barad 352) Barad uses the similarities between Einstein and Bohr's worldviews as a jumping-off point, noting that they "share a belief in humanism" despite the "important differences between them" and their theories (Barad 352). Although "Einstein wants the human observer removed from the system of interest while Bohr insists on the constitutive role of the human observer in measurement observations, both presume that the notion of the human is a well-defined concept that refers to an individually determinate entity with inherent properties, like the ability to engage in cognitive functions that make the universe intelligible." (Barad 352) Barad cites this as a central "presupposition [which] has been an obstacle to resolving some of the long-standing problems in quantum theory, such as the Schrodinger cat paradox, the EPR paradox, and the measurement problem." (Barad 352) This presupposition is problematic, especially in the wake of relativity, because it gives human consciousness an extremely privileged frame of reference. Why should we be so special as to collapse wavefunctions and force the probabilism of the micro-world into a macroscopic "reality"? Barad's "account understands the human not as a supplemental system around which the theory revolves but as a natural phenomenon that needs to be accounted for within the terms of this relational ontology", noting that our world "requires us to take account of the fact that we are part of that nature which we seek to understand." (Barad 352) "Rather than giving humans privileged status in the [quantum] theory, agential realism calls on the theory to account for the intra-active emergence of humans as a specifically differentiated phenomena…quantum theory has something to say about the ontology of the world, of that which we are a part- not as spectator, not as pure cause, not as mere effect." (Barad 352)

Agential realism fits very well with everyday experience and common intuition, despite the fact that it uses vocabulary which is strange and foreign. This is a small price to pay; after almost four centuries of interpreting the world in terms of Newtonian concepts, we lack some terms for describing our experiences outside of that framework. Barad knows that she is using unfamiliar jargon, so she elaborates on her fundamental concepts by using concrete examples from science and nature. To illustrate the falsity of the strict traditional dichotomy between subject and object, Barad invokes the analogy of a blind man with a cane: "the man can hold the cane tightly so that it functions as an instrument of observation (an extension of the person trying to negotiate the room)" or, "on the other hand, he can hold it loosely so that it becomes an object of observation." (Barad 358) "The cane is neither inherently part of the object nor the agencies of observation"; the man can observe the cane or use it as a tool to observe his surroundings, but he cannot do both at the same time (Barad 358). In general, this suggests that "the line between subject and object is not fixed and it does not preexist particular practices of their engagement, but neither is it arbitrary…rather, object and subject emerge through and as part of the specific nature of the material practices that are enacted." (Barad 359) This echoes the sentiment of Bohr, for whom "the relation between knower and known is much more intimate" and the "inherent fixed Cartesian distinction between subject and object is an unfounded prejudice of the classical worldview" (Barad 359). To Bohr and Barad, the "inseparability of…relation as it is materially enacted constitutes the very possibility for understanding…phenomena objectively…intra-acting, not merely intervening, is entailed in both experimental and theoretical practices." (Barad 359)

This requires a profound rethinking of spacetime, science, and reality about which Bohr and Einstein "were always slightly at cross-purposes" (Kuhn 148). For Barad, "what is made manifest through technoscientific practices is an expression of the objective existence of particular material phenomena." (Barad 361) Barad believes that reality does exist; "this is, after all, a realist conception of scientific practices", but it is not *reality* in the traditional Newtonian sense (Barad 361). "Unlike in traditional conceptions of realism", Barad's agential realism claims that "objectivity is not preexistence (in the ontological sense) or the preexistent made manifest to the cognitive mind (in the epistemological sense) …objectivity is a matter of accountability for what materializes, for what comes to be…it matters which cuts are enacted: different cuts enact different materialized becomings." (Barad 361) We play a role in what comes to be and what cuts are made, since we are both participants and observers at all times.

This brings us full circle to a revised understanding of objectivity, spacetime, and reality. Barad notes that "objectivity can't be a matter of seeing from somewhere, as opposed to the view from nowhere (objectivism) or everywhere (relativism), if being situated in the world means occupying particular coordinates in space and tine, in culture and history." (Barad 376) We should "resist the familiar conception of spacetime as a preexisting Euclidean container that presents separately constituted bodies with a place to be or a space through which to travel…the spacetime manifold does not sit still while bodies are made and remade", because "the relationship between space, time, and matter is much more intimate" (Barad 376). In this sense, agential realism clearly and distinctly embodies a fundamental understanding of space as type (a) rather than type (b). "Space and time (like matter) are phenomenal…they are intra-actively produced in the making of phenomena; neither space nor time exist as determinate givens outside of phenomena…as a result of the iterative nature of intra-active practices that constitute phenomena, the 'past' and the 'future' are iteratively reconfigured and enfolded through one another: phenomena cannot be located in space and time; rather, phenomena are material entanglements that 'extend' across different spaces and times." (Barad 383) This means that "the production of the new can't be located and it certainly can't be owned" and "neither the past nor the future is ever [completely] closed." (Barad 383) The past does not change, but there is "intra-active generation of new temporalities, new possibilities, where the 'new' is the trace of what is yet to come." (Barad 383) This gives us a better sense of the complex relationship between conscious beings and spacetime referenced in Brian Greene's discussion of spacetime. A relativistic reality consists of "an ever-changing multidimensional topological manifold of spacetimematter", as opposed to a "three-dimensional object located in space with the barest hint of time thrown in for good measure, that not only comes across as spatialized but is literally represented spatially." (Barad 388) "Spacetime itself is…reconfigured through an ongoing intra-active engagement, and bodies are among the differential performances of the world's dynamic intra-activity, in an endless reconfiguring of boundaries and properties, including those of spacetime …techno-scientific…practices entail space-time-matter-in-the-making." (Barad 376)

In turn, this forces us to reconsider our traditional notion that knowledge and truth are founded upon external, absolute, physical events. William James questioned this understanding in the 1800's, noting that "throughout the history of philosophy the subject and its object have been treated as absolutely discontinuous entities…and thereupon the presence of the latter to the former, or the 'apprehension' by the former of the latter, has assumed a paradoxical character which all sorts of theories had to be invented to overcome." (James 102) Barad echoes this sentiment, arguing that "knowledge making is not a mediated activity…knowing is a direct material engagement, a practice of intra-acting with the world as part of the world in its dynamic material configuring, its ongoing articulation." (Barad 379) Barad notes that "knowing and being are material practices", but thinks of them as "entangled…knowing is a distributed practice that includes the larger material arrangement... [it is] a specific engagement of the world where part of the world becomes differentially intelligible to another part of the world in its differential accountability to and for that of which it is a part." (Barad 379) While Barad's explanation seems to contain an inherent duality, this is by design rather than an error. Our entire lives embody this relativism; conscious beings influence spacetime and spacetime influences us. The relationship is indissolubly intertwined, as the way that we perceive spacetime and its parts influences how we choose to interact with it/them. In a nutshell, "it matters to the world how the world comes to matter" and sentient life forms (such as humans) "are living testimony to the inseparability of knowing, being, and doing." (Barad 380) Reality does not consist merely of "a web of causal relations that we are implicated in", for "we are a much more intimate part of the universe than any such statement implies." (Barad 394) Rather than thinking of the future as "the end point of a set of branching chain reactions", Barad thinks of it as "a cascade experiment" in which "not even a moment exists on its own." (Barad 394, 396) For Barad, notions "such as 'this' and 'that', 'here' and 'now', don't preexist what happens but come alive with each meeting" because "the world and its possibilities for becoming are remade with each moment." (Barad 396) Barad, akin to Greene, demonstrates that a fundamentally relativistic model of spacetime goes hand in hand with achieving a more nuanced and relational understanding of objectivity, truth, and reality.

Section D- Newton's Legacy and Concluding Remarks

In light of recent scientific developments, such as relativity and quantum mechanics, what remains of Newton's framework and legacy? Newton's worldview was not perfect by any means. First, it was heavily influenced by the religious views of Newton and his contemporaries. Additionally, it was inhibited by the general public's lack of scientific education and distorted by the preexisting obsession with traditional, absolute "certainty". Many of the foundational assumptions underlying "the Newtonian mechanistic worldview, and what we today call classical physics, [are] challenged by modern physics." (Rosenblum and Kuttner 31) At the time (and for centuries thereafter), Newton's worldview represented a major breakthrough for science and our understanding of spacetime, in the sense that it linked space and time through motion, forces, and other similar concepts. Yet, in consideration of Einstein's work on relativity, Newton's work was a vast understatement of the extent to which "space" and "time" are truly interconnected.

Although Newton's worldview has often been revised and improved, many "aspects of Newton's legacy will forever endure." (Rosenblum and Kuttner 31) Newton's work played an essential role in establishing "science" as its own distinct discipline, separate from that of natural philosophy. There were religious undertones in Newton's work, but he was also revolutionary for the extent to which he did manage to divorce the spiritual from the physical. Newton's model may not have been perfect, but it served as an invaluable stepping stone for enabling physicists to make sense of the physical world. Newton's recognition that space and time are intricately related was a conceptual breakthrough of monumental importance. It is true that Newton failed to recognize and assimilate the extent to which spacetime was inextricable, but Einstein's realizations would likely never have been possible without the groundwork that Newton laid.

Einstein's work on relativity represented the first major challenge to the framework that Newton had posed centuries earlier. Relativity was revolutionary because it jeopardized the view of space and time that science had taken for granted since the discipline began; although aspects of Newton's work had been refined and retouched, relativity challenged Newtonian physics on a more fundamental level. The full implications of relativity redefined space and time, and in turn threatened many of the basic tenets of classical physics, from the notion of physical objects to the concept of an absolute reality. These implications, however, are understood and assimilated to varying degrees. From a glossed-over summary of relativity, one could mistakenly conclude that relativity means nothing more than synthesizing our traditional understandings of "space" and "time" into a quasi-traditional spacetime. The significance of relativity as a conceptual revolution is not apparent until it is deeply processed and actively assimilated.

When relativity was first tested and empirically confirmed, people did not know what to make of it. Outside of the upper echelon of the professional scientific community, relativity was promoted and understood in basic, overly reductionist terms. The general public celebrated Einstein's accomplishments, but continued to perceive their lives in more familiar Newtonian terms. Many academics could tell you that relativity implied that space and time are actually spacetime, but very few could really explain the significance of that statement. Scientists recognized and accepted Einstein's insights, but were primarily concerned with mastering them on an empirical and practical basis rather than unraveling and understanding what they implied for our conceptual model of the world. Relativity was tangibly and significantly acquired, but it has yet to be completely assimilated. Although relativity radically undermined the traditional understanding of space and time, and thus shifted the paradigm for mathematical science, Newton's worldview continues to dominate the way that we interpret and explain our daily experiences. Relativity implies that we need to make some major conceptual adjustments in regards to the way that we understand both spacetime and reality, but these adjustments have not been fully made in most contexts. We still think in terms of separable physical objects, change over time, and absolute external reality, despite the fact that these notions are derived from the outdated Newtonian model of absolute space and time. We have continued to interpret our lives through a heavily Newtonian framework, but being explicit about that can help us to appreciate and understand the challenges that relativity poses to the classical worldview.

Questions about spacetime, science, and the role of science in a broader "reality" are essential to the assimilation of relativity. These mysteries hint at the intricate entanglement of epistemology, ontology, and metaphysics which lies at the very foundation of scientific inquiry. The tensions between classical mechanics and relativity are profoundly subtle and challenging to interpret, but it is clear that our understanding of concepts such as truth, free will, reality, change, measurement, space, and time are at the heart of this debate. Relativity suggests that many of our traditional dichotomies, such as that between observer/observed and objective/subjective, are fundamentally flawed. Relativity highlights the need to embody a radically different conceptual framework and hints at necessary components of that framework, but does not make the entirety of the relativistic worldview readily accessible to us. An examination of the ways that "space" and "time" have been misunderstood throughout spacetime is a crucial step towards clarifying the shortcomings of our preexisting beliefs and assimilating the conceptual revisions that a more fundamentally relativistic worldview demands. In the words of Albert Einstein, "we cannot solve our problems with the same thinking we used when we created them." (BrainyQuote) A deeper, more nuanced understanding of Einsteinian spacetime, and its implications, could provide the foundation that we need in order to assimilate the theories of relativity, reinterpret the world around us, and reconcile fundamental inconsistencies in how we conceptualize "reality".

Analogous to probabilism and "certainty", relativity has helped to reveal underlying complexities in our traditional understanding of "objectivity". In turn, this has challenged many of the conventional Newtonian dichotomies and suggested the need to revise our worldview on a fundamental level. This is indicative of the assimilation of anomalous information in general; as we assimilate anomalous scientific data and theories, we are forced to think more deeply about our preexisting network of knowledge and beliefs. Reconciling anomalous scientific information with a preexisting framework is a complicated task, which involves a number of thorny and interrelated questions. It is never as simple as considering a single theory or piece of data in isolation, for our data, theories, and worldviews are all intimately linked. These complicated and subtle relationships, which are not readily apparent at first glance, can only be revealed gradually through an active process of assimilation. Thus, although assimilation is obviously essential for dealing with anomalous information and figuring out how to situate it in our broader worldview, it is also fundamental for constructing and maintaining a coherent worldview in the first place. *Science* cannot be placed on a pedestal and "observed", free from the relativism of observers and subjectivity and societal influences. This speaks to the essential role of assimilation in creating and maintaining scientific progress; for it is only through the active processing of anomalous information that scientists can gradually unpack its subtle implications, and thereby work to attain the intelligibility necessary to uphold the *scientific standards* of rationality and objectivity.

As we attempt to build a “reliable and coherent model of individual experiential worlds”, the deep processing of perturbations, via assimilation, is an invaluable approach (Glasersfeld 138).

Bibliography

Appleby, Joyce Oldham., Lynn Hunt, and Margaret C. Jacob. Telling the Truth about History. New York: Norton, 1994. Print.

Brossard, Dominique, Bruce Lewenstein, and Rick Bonney. "Scientific Knowledge and Attitude Change: The Impact of a Citizen Science Project." *International Journal of Science Education* 27.9 (2005): 1099-121. Web.

Brown, Bryan A. "Discursive Identity: Assimilation into the Culture of Science and Its Implications for Minority Students." *J. Res. Sci. Teach. Journal of Research in Science Teaching* 41.8 (2004): 810-34. Web.

Chinn, C. A., and W. F. Brewer. "The Role of Anomalous Data in Knowledge Acquisition: A Theoretical Framework and Implications for Science Instruction." *Review of Educational Research* 63.1 (1993): 1-49. Web.

Einstein, Albert. *Relativity: The Special and the General Theory*. Princeton UP, 2015. Print.

Glasersfeld, Ernst Von. "Cognition, Construction of Knowledge, and Teaching." *Synthese* 80.1 (1989): 121-40. Web.

Greene, Brian. The Fabric of the Cosmos: Space, Time and the Texture of Reality. New York: Vintage, 2004. Print.

Griffiths, David Jeffrey. Revolutions in Twentieth-century Physics. Cambridge: Cambridge UP, 2013. Print.

Hansen, Olaf, and Paul Jerome Croce. "Science and Religion in the Era of William James. Vol. 1: Eclipse of Century, 1820-1880." The Journal of American History 83.2 (1996): 611. Web.

Hoffman, Banesh. "Relativity." *National Mathematics Magazine* 14.1 (1939): 5-25. *JSTOR*. Web.

James, William, Fredson Bowers, and Ignas K. Skrupskelis. The Meaning of Truth. Cambridge, MA: Harvard UP, 1975. Print.

Janiak, Andrew. "Newton's Philosophy." Stanford University. Stanford University, 2006. Web. 27 Jan. 2016.

Keller, Evelyn Fox. "Cognitive Repression in Contemporary Physics." Am. J. Phys. American Journal of Physics 47.8 (1979): 718. Web.

Kuhn, Thomas S. The Structure of Scientific Revolutions. Chicago: U of Chicago, 1970. Print.

Kumar, Manjit. *Quantum: Einstein, Bohr, and the Great Debate about the Nature of Reality*. New York: W.W. Norton, 2009. Print.

Latour, Bruno. *The Pasteurization of France*. Cambridge, MA: Harvard UP, 1988. Print.

Minkowski, H., Vesselin Petkov, and Fritz Lewertoff. Space and Time: Minkowski's Papers on Relativity. Print.

Rosenblum, Bruce, and Fred Kuttner. Quantum Enigma: Physics Encounters Consciousness. Oxford: Oxford UP, 2006. Print.

Rynasiewicz, Robert. "Newton's Views on Space, Time, and Motion." Stanford University. Stanford University, 2004. Web. 27 Jan. 2016.

Tuss, P. "From Student to Scientist: An Experiential Approach to Science Education." *Science Communication* 17.4 (1996): 443-81. Web.

"Albert Einstein Quote." *BrainyQuote*. Xplore. Web. 28 Apr. 2016.