Wither the Experimentalist: Some Consequences of Taking Both Science and Religion Seriously

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Presented to the Oxford Institute of Methodist Theological Studies
Draft Version, August 7, 2007

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1 Introduction

> *"Science without religion is lame, religion without science is blind."*
>
> -Albert Einstein

1.1 Science and Religion in the Present Age

The present age is an age of science and technology. We live in a world where many many aspects of life depend on current trends in science and technology. We live in a society that holds up the ideal the "scientific method" as a means by which we can increase our knowledge and understanding of the world. Being scientific implies being rigorous, impartial, rational, and reality based.

Indeed, we live in a society where the value ascribed to the scientific approach goes beyond the current and promised practical technological benefits. In our age, the scientific method is seen as a powerful prescription for determining all kinds of difficult and yet important and profound truths. Science has an impressive track record for discriminating fact from fiction, truth from falsehood, and myth from reality. We depend on the scientific method to identify the healthiest foods, the safest vehicles, and the most reliable communications networks. We see problems in health, medicine, conservation, and the environment that desperately call out for clear solutions based on sound scientific understanding. We rely on scientific research to objectively evaluate new products, new medical claims, and new discoveries. When a decision needs to be made, when a resource needs to be allocated, or when a solution must be endorsed, there is no more persuasive argument than that a choice is "scientific".

And yet, even as science impacts and permeates our lives, we also live in a society where scientific viewpoints are increasingly in tension and conflict other viewpoints, including theological and religious viewpoints. Science and religion do not always peacefully co-exist. We see both science and religion bent to suit political aims. We see conflicts about the teaching of evolution in public schools. And we see books defending atheism and scientific rationality on best-seller lists.

1.2 Methodism and Science

Historically, Methodism seems not to have been particularly concerned about the larger interplay between science and religion. The Book of Discipline of the United Methodist Church, for example includes the following paragraphs in the Social Principles on the topic of Science and Technology:

> *We recognize science as a legitimate interpretation of Gods natural world. We affirm the validity of the claims of science in describing the natural world, although we preclude science from making authoritative claims about theological issues. We recognize technology as a legitimate use of Gods natural world when such use enhances human life and enables all of Gods children to develop their God-given creative potential without violating our ethical convictions about the relationship of humanity to the natural world.*

> *In acknowledging the important roles of science and technology, however, we also believe that theological understandings of human experience are crucial to a full understanding of the place of humanity in the universe. Science and theology are complementary rather than mutually incompatible. We therefore encourage dialog between the scientific and theological communities and seek the kind of participation that will enable humanity to sustain life on earth and, by Gods grace, increase the quality of our common lives together.*[1]

These words seem to encourage a healthy two-way communication between scientists and theologians, as opposed to conflict. But in recent years it seems that the dialog has been increasingly cacophonous, especially in public circles in the US. And even as science continues to push into increasingly specialized areas, the gap between those who work with and understand science and those who do not seems to be growing. So while science and technology are becoming more and more ubiquitous and important, there seems to be less and less clarity about how science and religion can talk to each other. And this is happening even though at the same time there seems to be an increasing number of "seekers" in our congregations who are actively seeking *both* a faithful understand and relationship with God *and* a working scientific understanding of the world. And, as more and more social and policy questions touch upon scientific issues, the church and its membership who are struggling to find the best ways to serve each other and the world need to rely increasingly on scientific understandings to successfully address today's problems.

As individuals and institutions grapple with both theological and scientific viewpoints, perhaps the church needs to consider how best to foster the interplay between these two perspectives so as to achieve the most desirable result. Perhaps the church needs to become more comfortable with science and more fluent with it's purpose and methods, if it is to be able to contribute directly and effectively address a wide range of human needs in our modern world. Perhaps the church also needs to recognize the relative strengths and weaknesses of scientific and theological approaches to solving different aspects of different kinds of problems. Maybe the church needs to learn to "step back" when science has the answers, and it needs to learn to "step up" when science does not have the answers.

1.3 Our Starting Point

I am gainfully employed as a member of the faculty of a fair-sized university where teach introductory physics and where I maintain an active research program in experimental high energy astrophysics.[1]

As a result of my research, I have the great opportunity to interact with a wide range of colleagues and collaborators who are conducting cutting edge scientific research at places all around the world. I have met all kinds of people from many different cultures.

I also happen to be an active member of a local United Methodist church. Our church is rather deliberately "connectional" and so, again, I have had a great opportunity to meet a wide range of

[1] I have written a brief "appendix" at the end of this document where I give a short personal biography. See Appendix B.

different kinds of people in both the local and regional church who are involved in a wide range of activities which represent their response to faith.

In both of these contexts, I am occasionally engaged in informal conversations with people who find the idea of a physicist who goes to church somewhat surprising. Perhaps the most common question I am asked is "How can you reconcile the notion of being a scientist with being a part of a faith community?" How can one reconcile the ideas of science and religion? This is indeed an important question, perhaps one of the central questions of our age, and it deserves careful consideration and a thoughtful answer.[2]

However, I will not attempt to answer this question, at least not directly. Indeed, I will leave the whole issue of whether science and religion are fundamental and logically compatible with each other for the many other writers and thinkers who have tackled this question in the past and who continue to address it with a depth of scholarship and eloquence that far surpasses my abilities or training.[2]

Instead I will reflect upon a related question, what I would call the implied follow-up question: *What are the consequences of taking both science and religion seriously?*

In other words, we will *start* from the point of agreeing that we can in principle and in practice a person can develop a self-consistent world view that includes both a hard-nosed commitment to the methods of science *and* a deeply held religious perspective. We will take *as given* the assertion that science and religion *can* be made compatible, that it possible for a person to be both scientific and religious, and that doing this does not require some kind of radical contorted logic or major compartmentalization of thought. Given this, we can then ask: What does this world look like in this case? Are there essential features to such a viewpoint? What are the practical, personal, moral and social consequences of such a worldview? In what ways, if any, can our scientific and religious perspectives inform each other? How does taking science seriously impact our interpretation of scripture. How does it impact our perception of being in relationship with God? How does having a scientific world view affect our callings to discipleship as individuals? How does this viewpoint affect our collective denominational calling as heirs of the Wesley?

1.4 A Limited and Practical Approach

My first detailed exposure to many of these kinds of questions came in the context of a "book club" on science and religion that was organized on Saturday mornings at Trinity United Methodist

[2]Here and for the remainder of my essay I will use the term *religion* to have the meaning given by an "imprecise layperson". What I mean by a "religious" viewpoint might sometime more accurately be described as a *"theological"* viewpoint. In other words, in a casual context I might use the word "religion" include for example a wide range of experiences of being in relationship with God, of making theological statements about the nature of God, and of expressing or considering some set of personal beliefs regarding God. But the word might more strictly related to viewpoint that ascribes importance to the relational and connectional aspects between an individual and the members of the faith community. And of course the word religion more generally is used to describe the organizations and connected communities that ascribe to particular beliefs and traditions regarding God. When I use the word "religion" I might be implying some or maybe all of these things depending on the context. I realize that this kind of usage is rather sloppy, but then I am not trained in theology. At least one of my objectives for participating in the Oxford institute, then is to gain some perspective and clarity on these kinds of issues.

Church in Wilmette, Illinois, by Dr. Phil Blackwell, head pastor. At these meetings, a group of between five and fifteen members of the church would get together for about two hours to discuss a wide range of books that were selected based on their relevance to themes in science and religion and the interplay between the two. This "Saturday Morning Science and Religion Reading Group" persisted for several years, and eventually we found that we had tackled a rather large number significant books.[3] At it's best, the group was a wonderful forum for the exchange of many insights by a diverse group of thoughtful people concerned with the topic. I remain greatly indebted to Phil and the members of the reading group for the influence this experience had on my thinking on these ideas.

One of the main things I learned from our book club is the extent to which there are several very thoughtful and well-informed writers who have fruitfully tackled these issues from several directions. I have learned enough from the book club reading to know that I have *not* learned enough to make make much in the way of generally useful pronouncements about the interplay between scientific and theological ideas. I just do not know enough about these subjects and what I have have learned is rather indirect and imprecise. My training as a professional physicist has given me the tools to calibrate a photon detector, to evaluate a scientific paper on cosmic rays, and to explain to a student how must be true that an object moving in a circle is subject to a central force, for example. My training has *not* prepared me to coherently consider or reflect with any authority upon subjects related to either the philosophy of science, theology, or the role of religious viewpoints in society.

Therefore, for this paper I wish to take a limited and practical approach to dealing with certain aspects of these questions. Here, by "practical" I mean "useful to me personally on a day-to-day basis." Specifically, I will reflect on a few particular examples of my thinking on this question which have been informed both by my personal experience as an experimental physicist and as an active member of a dynamic and stimulating faith community. As as a working physicist, I will tend to focus on the science side.

[3] I will leave it to Phil Blackwell to make some remarks about the structure of our reading group and perhaps some details about the books we read.

2 Science and Religion: Realms of Inquiry

Bridgekeeper: Stop. What... is your name?
King Arthur: It is 'Arthur', King of the Britons.
Bridgekeeper: What... is your quest?
King Arthur: To seek the Holy Grail.
Bridgekeeper: What... is the air-speed velocity of an unladen swallow?
King Arthur: What do you mean? An African or European swallow?...

-Monty Python

Before we can dive into the question of the interplay between science and religion, we consider the scope and subject area of each. A "prevailing paradigm" of our times is that science and religion are two different paths to "knowing", complementary, each concerned with a different subject matter. The idea that science and religion each address different and (perhaps) distinct kinds of questions has been discussed for some time. Harvard Biologist Steven J. Gould's notion of "non-overlapping magisteria" has percolated fairly deeply into popular culture[3]. Stated simply, the idea is that science deals with the physical and objective world of "stuff" while religion and theology deal with issues of meaning, morality and the intangible realm of the spirit. Such a view is one that is probably widely (if imprecisely) held by a large fraction of mainline church attenders. In some sense, this simple division of all matters for consideration into one of these two "realms" solves the major dilemma of science vs. religion for many people of faith.

However, this separation of science and religion into two distinct realms is not always seen as satisfactory. This approach leads to a kind of mental "compartmentalization" – a division of the person into scientific and religious persona. This runs counter to a desire for a more "holistic" and wholly unified perspective.[4] What then is the interplay between the two "realms" here? How do we identify those problems which are most properly tackled by the scientific approach vs. those problems where we rely our our faith, where we rely on the church and our relationship with God? For me, personally, this is one of the most practically interesting questions. I've got two "tool kits" for solving real-world problems. One kit is "science" and the other kit is "theology/faith". Every day I am faced with problems that I must deal with. How do I decide which tool kit to use for each problem?

2.1 Well-structured vs. Ill-structured Problems

To begin an exploration of the nature of scientific inquiry and method, we want to consider further this angle on the relative applicability of science and religion that reflects well in the context of physics especially. One idea that I find personally helpful is the idea of considering *well-structured*

[4]Several authors including Wilkinson, Polkinghorne, and Barbour have written on the topic of moving from an "independence" vision of science and religion to a more "integrated" and/or "dialoging" approach. These are very intriguing ideas, but for my purposes I will operate under the assumption that the independence of science and religion is the primary cultural "landscape" that we operate under.

vs. *ill-structured problems*.[5] The world is full of problems. People, churches, governments, and societies face all kinds of problems. And generally speaking most problems can be categorized into two classes as follows:

A *well-structured* problem has certain characteristics:

- A well-structured problem is stated very precisely. The scope and terms of the problem are all clearly defined and desired outcome is unambiguous to both the poser and solver of the problem. All of the important inputs to the problem are clearly stated.
- A well-structured problem typically has one particular established method or recipe for arriving at the solution.
- A well-structured problem usually has exactly one correct answer, and this answer is usually held and identified as correct by a vast majority of problem solvers who are experts on the problem topic.

In contrast an *ill-structured problem* has more or less the opposite characteristics:

- An ill-structured problem is not generally clearly stated. Key terms may be ambiguously or subjectively defined. Some important inputs to the problem may have to be assumed. Sometimes a list of important inputs is not even known.
- An ill-structured problem is not generally solved by any one agreed-upon best method. Indeed, a wide range of very diverse methods may be applied.
- An ill-structured problem often does not have a single solution or answer that is widely agreed upon, even among experts in a particular field.

Let's look at some examples of well-structured problems:

> "If Jane lives ten miles down the road from Julie, and she walks at a pace of exactly 10 miles per hour, how much time will pass during the walk?"
>
> "What is the amount of rocket fuel required to lift a Saturn V rocket from the surface of the earth into orbit? "
>
> "What is the age of the Sun?"
>
> "What is the chemical composition of a sample of sludge taken from the Kalamazoo River?"
>
> "What is one person's share of the current national debt if this is divided among each man, woman, and child in the US?"

[5] In this discussion I very much in debt Patricia King who has presented and writing extensively on this subject [4]. Patricia King has also written more generally about how problems are solved and critical judgments are made in circumstances where we are presented with imperfect information. And her focus is on how these issues come into play especially in the context of classroom learning by students. Good stuff.

We note that these questions have a definite "feel" to them. They are "technical". The usually involve hard numbers. They might required careful measurement or calculations to answer.

In contrast, let us consider some ill-structured questions:

> "Should I get out of bed today?"
>
> "Will a major government investment in solar energy research really help the economy overall?"
>
> "What is the best foreign policy to apply to reduce the probability of war with Iran?"
>
> "Do actions of Vice President Cheney constitute an impeachable offense?"
>
> "How do I find a compatible spouse?"
>
> "What does God want me to do in this situation?"

One of the things I try to teach students is the importance of identifying both well-structured and ill-structured problems. Sometimes there are hidden assumptions or uncontrolled variables that can turn an apparently well-structured problem into a tricky ill-structured problem.[6] Sometimes the statement of a problem appears to be well-structured, but the method of solution is unknown, and so therefore the problem is to this extent ill-structured.

2.2 Science Favors Well-Structured Problems

Once we recognize the difference between well- and ill-structured problems, we notice something right away: *Science is a particularly well-suited for dealing with well-structured problems.* In fact, I will argue that just to the extent that a problem is ill-structured is the extent to which the paradigms corresponding to any particular branch of science are likely to be unable to cleanly solve a given problem.

In particular, when we *teach* science to our students in the classroom, what we are really doing is showing them how to solve a whole classes of well-structured problems using an agreed-upon set of methods. For example, I teach a class in introductory mechanics. The students need to learn Newton's Laws of Motion and they need to master the method for solving problems using these laws.

Interestingly, one of the common misconceptions that students and others have about science is that this application of known methods to solving well-structured problems is what science is mostly about. This is largely true in the classroom, but *scientific research* is conducted at the boundary between well-structured and ill-structured problems. In fact, in my experience, it seems that when we conduct scientific research, we are usually trying to extend our understanding to an area or problem where we do not generally know how to solve the problem in a well-structured way.[7]

[6] The exchange quoted at the start of this section is an amusing example of this.

[7] Popular graduate student T-shirt: "If we knew what we were doing, we wouldn't call it research."

Indeed, a point I like to make with physics students, especially those who are training for research, is this: *When we do scientific research, at some level what we are doing is trying to re-formulate some ill-structured problem in such a way that it can be solved as a well-structured problem.* We do this is several ways. We directly measure important inputs to problems that were previously unknown or poorly known. We take complicated system and represent them by less complicated mathematical abstractions. We make tentative assumptions, deliberately choosing to ignore certain details of a system while operating under the provision assumption that these details are not important. And then, having re-posed the problem in a cleaner, and simpler way, we proceed to develop what we hope will be a well-defined solution to the new, simpler problem.

Of course, new, well-structured problem that we have developed is not the same problem that we original set out to solve. It's a simpler problem, a cleaner problem. And therefore, the solution that we arrive at for the simpler problem may or may not also be a good solution for the original problem. It depends on whether all of our assumptions and simplifications have had a significant impact on the accuracy of our solution.[8] Therefore, once we have developed our solution, we are obligated to *verify* that this solution is valid to a given degree of accuracy In other words, when we do research, we are often trying to apply a well-structured solutions to what started as less-than-well-structured problems, and then checking to see if we somehow got away with doing this.

In my experience as a research physicist, this affinity between science and well-structured problems seems quite central. When a scientist encounters a well-structured problem he or she solves it.[9] When a scientist encounters an ill-structured problem, they modify the problem so that it is well-structured and then present the solution to this well-structured problem.

2.3 Science Struggles with Ill-structured Problems

Of course some ill-structured problems are ill-structured in part because they are large and complicated. Often these problems can be broken down at some level into sub-problems and some of these may be articulated and solved in a well-structured way. And science has a very important role to play in addressing these well-structured components of ill-structured problems.

For example, determining the social value of solar energy research requires an understanding of the current physics and engineering issues regarding technologies for converting sunlight into electricity, since determining the performance and properties of different proposed technologies is a well-structured problem, which – in turn – becomes an input for a larger social policy issue of making a decision about the value of diverting resources to solar energy research.

Therefore we see that a scientific approach can be a powerful problem solving tool for well-structured problems and also for tackling ill-structured problem by either addressing the well-structured components of these problems and/or by restating ill-structured problems into well-structured problems. But despite these successes, there are certain problems that remain ill-structured and that resist attempts to be reduced or reformulated as well-structured problems. And

[8] In the language of experimental science, we worry about whether or not we have understanding and control of systematic uncertainties. See Appendix A.

[9] Or rather, it is better to say that when a scientist encounters a well-structured problem he or she asks a graduate student to solve it.

it is just to this extent that science is a *not* well-suited approach for solving these difficult problems.[10]

Indeed, at this point it worth emphasizing the following: *Just because a problem is ill-structured does not mean that the problem is not important.* Some of the most important problems of our day are stubbornly ill-structured, and yet are problems of life and death. *Will sending troops to war really decrease the likelihood of an terrorist attack at home? Shall we divert resources to support a single-payer health-care system? How do we stop the killing of innocents due to ethnic and sectarian hatreds? How can we bring hope and peace to those who are suffering from hopelessness and violence? What can one person or one church do to make a difference?* These problems cry out for real solutions. And we can certainly look to science to inform our answers to these questions. But it seems to me that even in the present age, science as a whole is not a particular helpful method for tackling these kinds of questions. Thus it seems that at least for the foreseeable future, we are motivated to consider other non-scientific methods to address these kinds of very important problems.

[10] Atheists authors and others have recently argued that a *completely scientific point of view* ought to be applied to the consideration of *every* problem, and that this is the only *rational* approach. From this point of view, the best way to tackle ill-structured problems is to work as hard as possible to re-state ill-structured problems in a well-structured way using various methods of obtaining and weighing evidence, rational argument, and other critical thinking skills, and experimental verification. Here I make no attempt to refute such a “purely rationalist” point of view – indeed there are aspects of it that seem to me quite admirable – but I will say that in my own experience I find there remain many problems that I must contend with every day that remain ill-structured and unsolved despite considerable efforts on my part to apply “rational” problem-solving methods.

3 Experiment vs. Theory in Physics

> *"Science walks forward on two feet, namely theory and experiment. Sometimes it is one foot which is put forward first, sometimes the other, but continuous progress is only made by the use of both - by theorizing and then testing, or by finding new relations in the process of experimenting and then bringing the theoretical foot up and pushing it beyond, and so on in unending alternation."*
>
> -Robert Millikan (Nobel Prize in Physics 1946)

Before moving ahead, we want to look a little deeper into the nature of this "tool box" we call the scientific approach. At this point, we introduce some definitions so that we can take a closer look at what is generally described as the "scientific method". Science can be considered a fundamental interplay between two concepts: *Theory* and *Experiment*. Here, I am taking a very specialized meaning for these two words which is quite different from regular usage in spoken English. Again, from the basis of person experience, I will concentrate on examples in the field of physics and astronomy, although to a greater or lesser degree, these patterns are also manifest in other fields.

Scientists do not really "study nature" in isolation. Rather we develop an *abstraction* of nature. And then, we go out and test the extent to which this abstraction accurately describes nature.

The set of abstractions for any given subject of study is called *Theory*. Here the word *Theory* does not mean some kind of approximate guess or doubtful proposition, the way the word is used in English. Instead the word *Theory* means a set of well-structured rules (in physics, these are usually expressed as mathematical equations). Thus in the sciences when we say "theory" we usually mean our very best representation of the governing rules that apply to a given phenomena.[11]

It's worth emphasizing that at some level, a given *Theory* is mean to represent a well-structured approximation of some aspect of the nature (physical) universe. Theory aims for simplicity and clarity, as far as possible. We can tackle problems and puzzles in the context of a well-stated Theory because these problems are often simpler in comparison to nature itself which is uncontrolled, complicated, and therefore ill-structured to the extent that we generally cannot take into account all of the factors that in principle might have an impact on the object of study.

A central tenet of the scientific method is that any Theory that one can propose and express should be subject to reasonably extensive experimental verification before being widely accepted as an accurate and useful description of the Universe. In other words, in science we develop a Theory and then we go and we check exactly how good this Theory is in describing the aspect of nature we are studying. We need to test the Theory by making a set of careful, *numerical measurements*. This is testing process is called *Experiment*. Experiment is what tells us whether

[11] Sometimes, especially for well-tested Theories we use instead the word "Law". In fact, in many fields of research, the words "Theory" and "Law" are used interchangeable. Sometimes the word "Law" seems to imply a particular well-tested and accurate Theory but this kind of usage is not universal. For example, historically we present "Newton's Laws" of mechanics in the classroom, and then later we talk about "Einstein's Theories" of relativity. But in fact, the Theories of Einstein are demonstrably more accurate than the Laws of Newton.

or not our abstraction, our Theory gives predicted results that are sufficiently close enough to the actual measurements. If the measurements from Experiment are consistent with the prediction of Theory, then we provisionally accept the Theory as an operationally useful representation of reality. In other words, we assume that the Theory is "true". If, on the other hand, the data do not support the Theory to the desired precision, then the Theory is rejected (or at least it is disfavored relative to alternate Theories that might more accurately predict the results of Experiment.)[12] This is how science – especially physics – works then in the ideal.

3.1 A Schematic Representation

In my experience, if one puts a bunch of physicists together in one room, they will generally agree on a single explanation for what they are doing as scientists and how the whole process works from a practical matter. Most physicists will describe the process in terms of this central idea of progress in research as the interplay between Theory and Experiment.

But beyond this agreement, if you ask physicists to explain the underlying philosophy of this interplay, how it works and why it works in detail, you will get a surprising range of different ideas and different explanations.

There are a number one might think of for this divergence. The first is the fact that having a firm foundation in articulating the underlying philosophy of the scientific method is surprisingly irrelevant to the ultimate success of a conducting scientific research. We do not teach our students the philosophy of science. We teach them to do science. If scientists can generally agree on what constitutes a valid scientific method and a valid scientific argument, then a deep understanding of the underlying "meta-physics" and social/psychological issues of how and why these methods actually work is not essential. As Richard Feynman (apparently) once said, "Philosophy of science is about as useful to scientists as ornithology is to birds."

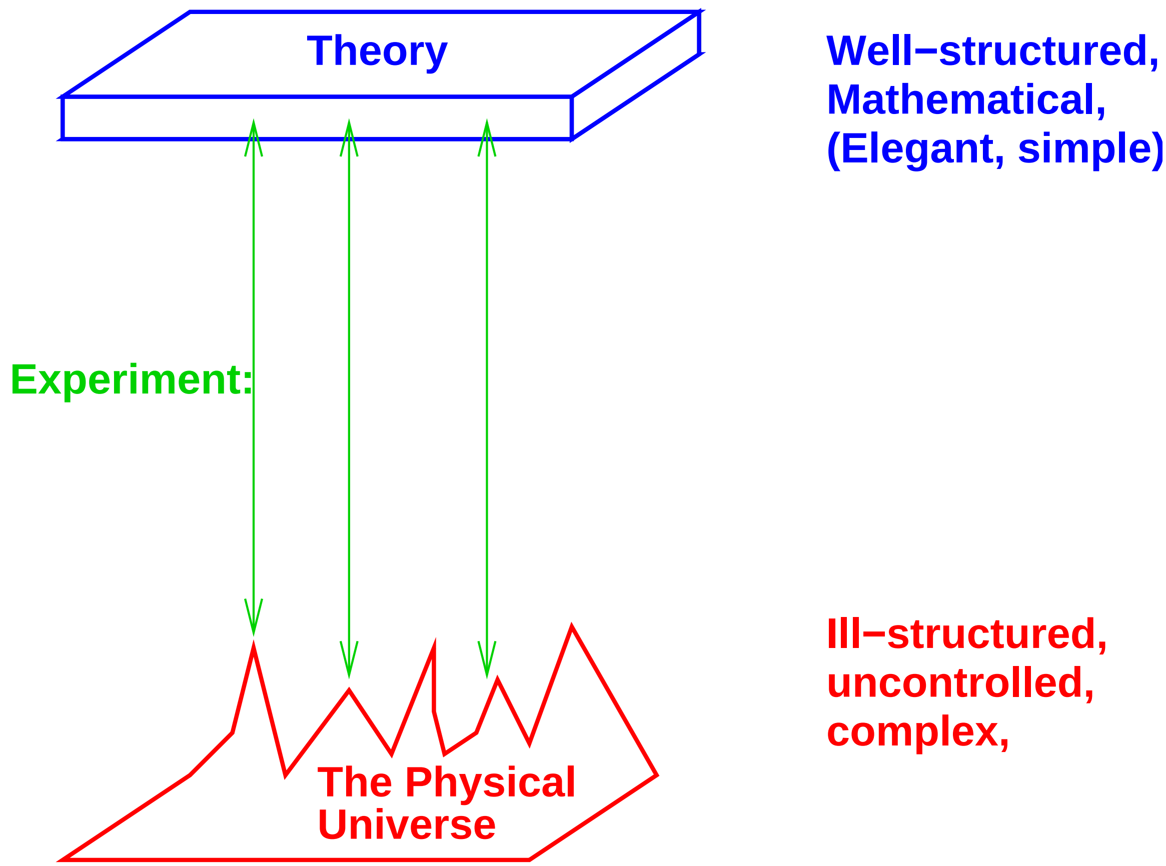
A second reason for the divergence, I think, is that, in trying to explain the interplay between theory and experiment, most scientists will introduce (or rather invent) an additional level of abstraction – that is to say they will refer to some kind of schematic or conceptual representation of the process, and for a variety of reasons different scientists will tend to chose different approaches to such a symbolic or schematic representation.

For example, the figure below shows a schematic that I usually draw on the chalk board during the first class in any introductory course I might be teaching. As far as I know, this schematic is entirely of my own invention: another physicist might draw something different, but it seems to be effective at trying to convey the same essential qualities of the process.

In particular, in my schematic, I represent the idea of "Theory" as an clean abstraction. Theory is a intellectual *construct* that exists in the form of a set of one or more mathematical equations, the terms of which are defined in a well-structured way. Here the word *Theory* means all of the definitions and mathematical details required to describe some general class of physical phenomena. As a construct, Theory represents an over-simplified but well-structured representation (or isomorphism) of the real universe.

[12] See Appendix A for a technical example how Experiment is used to check Theory.

Below the abstraction of Theory exists the "real world" of the Physical Universe. The real world can be observed, but for most interesting problems, simply "looking" at the real world is not enough to determine the extent to which the Theory is correct and accurate. To properly check a Theory, we generally need to design and conduct one or more *Experiments*. The idea is that Experiment allows us to check particular predictions of the Theory against the actual reality of the physical universe. We note that even the most difficult and complex experiments cannot hope to address *every* aspect of a given Theory. Instead we design experiments to checking some key subset of the Theory against some accessible subset of the Physical Universe that is amenable to direct numerical measurement via Experiment.[13]



This figure gives one schematic representation to illustrate the role of Theory *and* Experiment *in the physical sciences.*

[13]The terms Theory and Experiment are generally applied to consideration of a wide range of phenomena within some general field of study. When we design a *particular* instrument to make a specific set of measurement to check one specific prediction of the Theory, then the particular subset of the Theory is often called a "Model" and the results of the particular measurements are called "Data". In this manner the larger interplay of "Theory" vs. "Experiment" is manifest in a particular measurement as the interplay of a particular "Model" vs. some specific "Data".

3.2 Teaching Introductory Physics: Lectures vs. Labs

One arena where these ideas of Theory vs. Experiment are directly applied is in the teaching of undergraduate lab courses in physics. In my department undergraduates are introduced to the subject of physics by attending a regular set of lectures during which the material is presented and problem-solving approaches are discussed. In the idea case, the students in the lecture are actively engaged with the “paradigm” or methods of the discipline. They learn how to solve the (extremely) well-structured problems (which definitely have “right” and “wrong” answers). Hopefully this learning also translates into a generally deeper understanding of how the physical world actually works and the knowledge and techniques can then be applied to further study. However, for this lecture part of the course, we are almost always exclusively concerned with presenting the *Theory*, we in practice we almost never discuss or confront the application of *Experiment* to the given theoretical structures presented.

Therefore our department also requires that the students participate in a *laboratory component* to the course that supplements the lectures. *The primary purpose of the physics labs is to reinforce the central notion that physics is a Theoretical discipline that depends entirely on Experimental verification*. In other words, it does not matter how clever or beautiful our concepts or theories of physics are. If they do not actually match what is measured in the lab, they must be discarded.

3.3 The Central Question of Experimental Physics

More specifically, everything we deal with in physics is based on representing physics systems as mathematical *theories*. which we are typically represented as equations that allow us to describe reality and predict phenomena in a well-structured way.

In the laboratory (student labs as well as cutting edge research labs) experiments are conducted to actually measure the behavior of physical systems. Our aim is to determine if that behavior is well-described by the mathematical predictions from our Theories we want to test. In every Experiment there is one *central* question that we want to address:

> **Do the results of Experimental support the underlying physics Theory to within the uncertainties associated with the measurement?**

This is the “big question” that we address each time we consider the meaning of the result of an *Experiment*, each time we take these results and we consider how they reflect on some *Theory*.

Usually, in the physical sciences, we address this central question not with words but with *graphically* with a mathematical plot. The plot allows us to examine in graphical form both the prediction of the Theory and the data from the Experiment. We can directly compare Theory vs. Experiment.

These kinds of plots are very powerful for getting at this central question. If one attends any kind of scientific conference in physics, one sees these kinds of plots presented over and over in papers and talks. Interpreting such plots is not a difficult skill to acquire: In Appendix A we describe how this works in some detail with some particular examples of plots showing Theory and Experiment. As described in this appendix, a very important component of the comparison is an accurate determination of the measurement uncertainties associated with any particular experiment. As experiments improve with small measurement uncertainties, results from particular experiments must match ever more precisely the predictions of Theory. If the results do not match with enough accuracy, the Theory is liable to be discarded and replaced with a better, more accurate Theory. This is how science move ahead and progresses, with the result that we have Theory that allows us to predict what will happen in any physical situation with increasing accuracy. And just exactly to this extent can it be claimed that Science seeks the truth. What science does is to provide a means of moving towards Theory that can to a given precision describe some aspect of the real physical universe. And while any given Theory presented at any given time in history is subject to being replaced in the future, the process of Experiment ensures that the replacement Theory will be a more accurate representation of the physical truth than the prior Theory. In other words, science moves inexorably closer and closer to the truth.

3.4 The Experimentalist vs. the Theorist

At this point it is worth remarking that central importance of the interplay between Theory and Experiment in the physical sciences is difficult to overstate. Indeed, students who are trained in modern physics are invariably asked to consider specializing in *either* theoretical *or* experimental research. Generally speaking, young physicists are trained as *theorists* or *experimentalists*. The operational motivation for this is that either discipline is sufficiently challenging and requires such a degree of specialized training that it is impractical to be trained and effective as both. In particular, the theorist is usually given special training in the application of mathematical techniques and/or computer modeling, and is encouraged to develop an aptitude for developing new theories and extending old ones with the aim of predicting and explaining new the experimental results that might be obtained. In contrast, the experimentalist is usually given extra training in instrumentation and/or the statistical interpretation of data, and is encouraged to develop an aptitude for designing, developing, and fabricating and interpreting results from sophisticated experiments in order to test the theories.

Here also, I reflecting on the somewhat paradoxical nature of the relationship between the Theorist and the Experimentalist. By construction, they “need each other” in order to make science move ahead. The Experimentalist needs guidance from the Theorist to design experiments that make relevant measurements. The Theorist in turn needs the Experimentalist to provide the data to check the models and to extend with confidence to consider new models and theories.

On the other hand it is also true that at a certain level the relationship between the Theorist and the Experimentalist is somewhat adversarial. If the Theorist makes a prediction, then it is the job of the Experimentalist to build an experiment that will either support or refute the Theorist’s ideas. Many brilliant ideas from Theorists have been proved inaccurate by Experimenter’s measurements.

4 Answering Questions in Science and Religion

"I conceive that the great part of the miseries of mankind are brought upon them by false estimates they have made of the value of things."

-Benjamin Franklin

Having belabored these two characteristics of experimental science, namely the push toward solving well-structured problems and the central importance of the interplay between Theory and Experiment, we now turn to looking at some general classes of problems that can be addressed either scientifically or theologically.

4.1 The Power of Science: Approaching Physical Truths

So when does science work best? What kinds of questions and problems can science address most effectively?

As we have seen, the problems that can be most effectively solved by science are the *well-structured* problems. One class of well-structured problems that science might address is whether something physically exists, and if so, what are the values of its measurable properties? Any such "measurements of existence" can only be conducted and interpreted within the context of Theory.

For example, we can ask a question, "What is the charge on the electron?" In order to design and conduct an experiment to determine this, we need to apply a clear articulation of the Theory of electromagnetism. We use the Theory which allows us to predict the behavior of our apparatus and to interpret the results of our measurement. And at the end of the day the fruit of our labors is clear: we know something specific about the physical universe that we now can apply to solving other problems, developing technologies, etc.

In other words, when we ask the question "What good is Science?" at least one answer is that it allows us to determine (to a given precision) whether certain assertions about the physical universe are physically true – or not.

4.2 The Problem of Religious Claims

In contrast to science, when we ask the question "What good is Religion?" or "What good is theology?", we are not presented with any particularly obvious answers. Indeed, these theological and religious questions have the hallmarks of stubbornly ill-structured questions, especially insofar as there is no generally answers to these questions that are generally agreed upon by experts. Furthermore, in my opinion, it seems like the nature of the answers to these questions depend upon whether this value is sought by individual or collectively in groups, organizations and society as a whole.

One particular difficult subset of questions, it seems to me, relate to questions about the actual nature of God, questions that deal with God's existence and properties. These are just the kinds of questions that science is very good at dealing with in the realm of the physical universe. But in the realm of theological questions, we cannot simply adapt a scientific method to obtain a clear answer.

And these are important questions: Does God exist? How can we know this? What is the Nature of God. What are the properties of God?

These are stubbornly ill-structured questions for many reasons not the least of which is the fact that the question “What is God?” is itself a very ill-structured question. There is certainly no “widely agreed-upon” method for obtaining an answer to this question. There is no generally shared understanding of a “definition of God”.

This is not to say that we cannot address these questions systematically or rationally. Just as with scientific questions, we can start by making certain assumptions as given. We can agree to the definition and meaning of certain “inputs” – everything from the authority of Scripture to the experience of revelation and the emotional impact of creation and human relationships. But in contrast to science questions, here we have no mechanism for objectively and systematically checking that our assumptions hold out. We have no objective way to determine if our reasoning is valid.

In other words, we can put forth a “Theory” about the existence and/or properties of God, and we can even develop a set of predictions or conclusions that can be drawn from this Theory, but there is no method for devising an “Experiment” to check and correct our Theory. Indeed, it seems to be that the inability to apply objective Experiment to religious claims – and not an inability to develop a coherent Theory – that prevents us from applying “scientific principles” to theological problems.

4.3 The Value of Religion

In my experience, then, a central aim of the application of science to the physical universe is the understanding of the underlying nature of physical reality – that is to determine what is and is not objectively true. But this approach breaks down when we try to stretch this method from the scientific to the theological. This is significant because when it comes to addressing questions of what is physically real and what is not real, there is nothing like science.

Indeed, given the measurable certainty and confidence with which we can make statements about the “nature of physical reality” using science, it is dismaying that we seem to have no such measurable certainty and confidence about the “nature of God” using theology.

It is this experience that inclines me toward one conclusion regarding claims made on theological and/or religious grounds: *There is not much value in considering the truth about certain theological assertions regarding the existence of God and/or the properties of God, especially to the extent that the consequences of such claims cannot be physically measured.* In other words, there is not much point in arguing whether or not God exists, if we are faced with the fact that there is no way to prove or disprove God’s existence in an kind of empirical and objective way. There is not much point in arguing whether or not God is male or female. There is not much point in arguing whether or not God is omniscient or omnipotent. Because at the end of the day, none of these assertions can be checked experimentally.

Having said this, I think that there are clearly important theological problems that have solutions that can be motivated and argued by considerations that have nothing specifically to do with whether something is objectively true or not. There are theological "truths" worth contemplating that are not automatically related to whether God has particular properties. There theological and religious considerations that have value beyond whether or not we make particular claims about whether something is actually true or not.

Indeed, I suspect that this issue of what is true and what is not true is less important than other considerations for many religious people. I suspect that many people adapt religious or theological perspective not because of the plausibility for arguments supporting the existence of God, or because of any kind of particular physical evidence supporting one view of God or another, but instead because of the experiential value that adopting such a perspective provides. This is a value that is emotional and social. In other words, adopting theological positions are often a personal choice that is based on the attractiveness of the experience rather than on whether some particular claims are are compellingly argued as true or not.

On the other side of the coin, I worry in particular that the implicit values associated with scientific investigations have inappropriately leaked into our theological considerations. At present there is quite a bit of heat surrounding all kinds of various religious "claims", and within certain religious viewpoints, there seems to be great importance placed on making statements of belief about what is true. It seems to me that there is an inappropriate emphasis on the value of making and defending such "faith statements" – statements that sound like testable truths but are in fact not subject to experimental verification. I worry that such an approach inappropriately implies that the value of religious claims are qualitatively the same as the value of scientific claims, namely that these are useful "facts" that can be reliably and directly applied to solving practical problems.

Indeed, it seems to me that if we inappropriately assign such "truth value" to religious or theological claims, we risk losing the *real* value that religious and theological perspectives can provide: namely the emotional and social (and transcendent) value – value that contributes to our finding meaning and purpose in life.

Indeed, it is somewhat puzzling to me that so much energy seems to be invested in attempting to assign this scientific "truth value" to religious claims when in fact there are many other instances of perspectives where we do not make such a demands on in order to obtain the value.

For example, a few nights ago I went to a baseball game. I had a great time (despite the fact that the home team lost) and I would go again. But I cannot see any way to justify my attendance at the game from a scientific "reality based" point of view. Why did I go? Because I found it emotionally appealing to go. Why did I cheer for the home team? Certainly not because I have some illusion that they are objectively more deserving of my support and praise relative to their opponents. Rather, I cheered the home team because the ritual of sport is constructed this way and because by investing myself in the outcome I become more engaged in the game and find it more rewarding. When the game ends, and the home team loses, however, I am quite content to put aside the ritual and recognize that the value of ritual is simply the emotional reward of the game itself.[14]

[14]Note, in this example, I do not carry my emotional investment in the home team around with me from day-to-day

Similarly, suppose we consider a student who is contemplating an important decision of whether or not to pursuit of a career as a concert musician. I am thinking that such a decision would be difficult to defend in one direction or the other on the basis of a scientific argument. The basis for making such a decision is not whether or not something objectively exists (except perhaps, musical ability). The issue is whether the pursuit of such a career is seen as *worthwhile*.

It is further worth remarking that just because neither baseball nor a career in music can be justified scientifically does not mean that either of these enterprises is intellectually valueless. Further, even though these values correspond to an "emotional appeal", this does not automatically invalidate demean the significance of the value.

Nor are these activities free to operate in a way that contradicts or ignores the constraints imposed by science and reality. Physics governs baseballs and oboes. But physics does not define the home-run. Physics does not define an "impressive" concerto. People do this.

In the same way, then, I think, that there can be particular religious perspectives, certain theological viewpoints, where the value of the perspective is based not on assertions of belief regarding the existence of God, or that some particular quality of God must be true, but on the value that these religious perspectives can provide – a value that is more comparable to the value of a game of baseball or the value of a life committed to musical excellence than it is to the value of determining the age of a rock or the charge on a quark. In my opinion, such a religion perspective can be defended as "worthy" and valuable. In my opinion these kinds of theological perspectives are a natural consequence of taking both science and theology seriously.

once I have left the game. I am not inclined to make absolute assertions about what "ought" to have happened. I am not a "sports fundamentalist".

5 A Few Personal and Practical Consequences

> *"Out of 5.8 billion people in the world, the majority of them are certainly not believers in Buddhism. We can't argue with them, tell them they should be believers. No! Impossible! And, realistically speaking, if the majority of humanity remain nonbelievers, it doesn't matter. No problem! The problem is that the majority have lost, or ignore, the deeper human values - compassion, a sense of responsibility. That is our big concern.*
>
> -The Dalai Lama in *Time*, December 1997

So where are we? We have argued that the scientific approach is very effective at dealing with well-structured problems and also with ill-structured problems that can be re-stated as well-structured. We argued that the interplay between Theory and Experiment is central to the progress of science and that this approach allows us to determine what is physically true. We argued that statements about what is theologically true cannot be experimentally verified and that the value of adopting any given theological perspective has less to do with the value associated with asserting a truth and the more to do with the emotional and social value associated with adopting the perspective. This leads to the general conclusion that, in the present age, it is less important to consider whether a theological claim is really *true* and more important to consider whether a theological position provides some other kind of *value*.[15]

What does this mean practically? How do these conclusions come into play regarding my own personal religious and theological perspectives?

5.1 A Metaphorical/Narrative Approach to Scripture and Doctrine

The first, and most obvious conclusion for me, personally, is that sources of theological authority should be interpreted metaphorically and/or poetically and not literally. There is no empirical evidence to suggest that the authors of the Bible had some special knowledge regarding the nature of physical universe when were written. This implies to me that the writers of the Bible also had no special "absolute" knowledge about the metaphysical theological reality. This means that regardless of the nature of the inspiration, we cannot take any passages from the Bible to be authoritative regarding any aspect of physical reality. As Galileo said, "The Bible tells us how to go to heaven, not how the heavens go." Even to the extent that Scripture presents a historical narrative, the value lies in the artistic and literary interpretation of the narrative and not on their historical accuracy.

To my mind, this frees us from many difficulties associated with to hold the Scripture literal and paramount, as is done in some more fundamentalist traditions. If the Bible is interpreted as poetry, then we no longer need to "worry" about whether we "believe" in miracles. The question changes

[15] It is my personal view, this notion of de-emphasising religious truth claims extends even to the most "sacred" of theological truths associated with the Christian tradition, such as the reality of the salvation by confession of faith, the Resurrection, and Christian afterlife. I realize that for some, such a perspective puts me on the borders of agnosticism, but I would contend that the theological power of these concepts derives not from blindly asserting that these things must be factually true but from the profound meaning that these concepts provide any contemplation of our relationship with God and with others.

from whether or not a miraculous event actually happened to the question of what does is mean that this event is included in this story? What does this story tell us about the relationship between God and humankind? Indeed, I will argue that for the faithful, the theological truths conveyed metaphorically in the narrative of the scriptures are deeper and more profound in the context of the human experience than would be any literal truths that we might try to infer. We move away from questions about whether some claim is literally true into a viewpoint where a scriptural "truth" is more akin to the "truth" that is conveyed in the reading of a great novel or listening to a moving opera. We are changed by these kinds of truth, our lives are different.

5.2 Granting unto Cesar: Science Wins for Physical Reality

A closely related point is that since science is so very good at tackling questions about the nature of physical reality, the person who takes science and religion seriously needs to concede to *science* the authority to deal with such issues. If we take both science and religion seriously we cannot proceed on a basis of accepting scientific results only the proviso that they do not contradict some deeply cherished religious notion about what is or is not true about God.

This is worth emphasizing because in the present age, many important human problems and issue are firmly rooted in scientific contexts. I believe that must be quite careful to avoid the application of theology to arenas where science is well-positioned to address the central problems. Religious arguments have no place in discussions of the origins and evolution of the universe and of life and of humanity, at least insofar as these discussions related to assertions about how things happened and what the measurable consequences of these might be.

This applies not only to the interpretation of Scripture, but other theological authorities as well. In my view, we do religion and theology a major disservice by looking for "scientific evidence" of intelligent design, the efficacy's of prayer, or "faith healing". If we are relying on scientific approaches to verify our theological inclinations, then we are setting ourselves up for failure.

Conversely, since human beings are physical creatures, religion and theology should be increasingly aware of developments in human sciences, medicine, biology, psychology and brain science that can inform the human experience even in a religious context. For example, as we learn more and more about how the brain works, and how our emotional and intellectual words are connected neurologically, it makes sense to consider how this new information can inform our theological perspectives.[16]

5.3 Liberal Doctrine, Evangelism, and the Ecumenical Spirit

Just as these conclusions lead us to de-emphasize the literal truth value of Scripture, so also do they also de-value the importance of doctrinal standards. In other words, we conclude that the *relationship* is more important than the *rules*. Since the value of the theological perspective is an emotional

[16] Some care should be taken here, however. I am very skeptical of almost any idea that we take some result from science and "stretch" this result into the theological arena. For example, several authors have written how the new quantum mechanical view of nature informs our interpretation of mind and soul, or how the indeterminacy of chaos theory and/or quantum mechanics connects some theological mechanism in support of the concept of free will. In my view almost all such claimed connections are very misleading.

and social value, and since this manifests in different way for different people in different cultures, there is not one single “best” perspective that is ideal for all people. This mean congregations and denominations need to foster a attitude of tolerance and an acceptance of diversity on doctrinal issues. This viewpoint implies we should be wary of holding up any kind of doctrinal litmus tests.

A similar perspective relates to the issue of evangelism and the question of ecumenical cooperation. Such a viewpoint rather explicitly recognizes that the narratives from one tradition may be more or less attractive and worthwhile, varying from person-to-person and from culture-to-culture. In other words, the liberal tradition embraces an ecumenical perspective where a diversity of religious viewpoints and traditions by others are accepted and even celebrated.

6 Conclusions: an Experimentalist Approach

> *"Thus the yeoman work in any science, and especially physics, is done by the experimentalist, who must keep the theoreticians honest."*
> -Michio Kak

Finally, then we wish to return once more to the the role of Experiment in science and ask if there is anything analogous to this role for theological and religious questions.

My background is as an experimental/observational astrophysicist. The distinction between theorist and experimentalist in the physical sciences is not widely recognized in the general public but it does have a distinctive impact on ones training and, to some degree, on ones "world-view". It is the job of theorists to develop theories of the physical universe – the detailed mathematical models that govern physically how things happen. It is also the job of the theorist to consider the application of these theories to a variety of physical phenomena so as to explain the phenomena and – ideally – to predict what might be measured in the future. In contrast, it is the role of the experimentalist to apply a practical knowledge of instrumentation to develop experiments and to conduct a careful set of measurements to verify or refute the predictions of the theorists.

I find it intriguing that most of the physicists who are making contributions to the public discussion on physics and the interplay between physics and religion are theorists. For example Wilkinson, Hawking, Polkinghorne, and my departmental colleagues Lawrence Krauss and Mano Singham are all theorists, and not experimentalists.

It is hard to resist the temptation to speculate why it should be that those who are motivated to write on this topic come predominantly from the Theory side. One idea is that Theorists are by temperament and training encouraged to "...put their ideas out there." Another possibility is that there is a natural correspondence between the notions of Theoretical Science and Theology being conceptual constructs. In contrast, as I have mentioned previously, there is not really such a clear cut analog for Experiment that acts as a "checker" for what might be called "Theoretical Theology".

Certainly the main difficulty is that there are no "measurable properties" that can be predicted from Theological consideration and objectively reported. So we will never get the factual verification the way we do in the sciences. But does this mean that there is absolutely nothing we can learn from observation? Is there nothing at all analogous to Experiment that we can apply in even a limited way within the context of Theology?

One idea is that at least the skilled experimentalist has developed a good intuition as to whether an instrument is "working" or not. In the laboratory or in the field, we sometimes notice that "something is wrong" even if we do not have direct access to the data as it comes in. Sometimes a piece of equipment is making a noise. Sometimes, a meter is reading an unusual value. Sometimes there is a faint odor of overheating electronics. Although these are not conclusive indicators of a particular problem, they can indicate that a change is needed, that things need to be looked over more carefully before moving ahead.

The good experimentalist understands the limits of Theory. He values Theory but does not completely trust it. The experimentalist checks and cross-checks. She makes sure that she understands how her equipment works and that it is functioning as expected. The good experimentalist is honest. He reports his findings as measured even if the result appears surprising or disappointing. The effective experimentalist is cautious and does not fear doubt. She recognizes that there is an element of uncertainty in every measurement.

I think that similar ideas can be applied in an analogous way to religious or theological issues. If a situation does not “feel right”, this can be an indication of a possibly inconsistent or improperly adopted theological view. If one of the overriding theological principles is peace, and we find ourselves at war due in part to religious issues, then this is an indication that we have more to learn about the theology of peace. If we profess a faith that claims God’s saving grace is available to all persons regardless of culture, race, or economic status and then then find ourselves in a congregation of people who look and act just like us, perhaps we do not really have the right understanding of the theology of grace. If we quote scripture that warns us to take the “stick out of our eye” and yet we stand in opposition to the full inclusion of members based on sexual orientation, perhaps we do not understand our role as disciples. If we are called to look for the face of Christ in ever person but we do not act to feed the hungry and shelter the homeless, then perhaps our theology is just an intellectual exercise and not a basis for real connection with others. Perhaps we do not really understand the great commandment as articulated by Jesus.

A First Appendix: The Central Question of Experimental Physics

In this appendix I have presented a slightly modified version of materials that are included in the first section of the laboratory manual we have written for students taking our introductory physics courses. This section discusses the interplay between Theory and Experiment with a particular graphical example...

Everything we deal with in physics is based on Theory vs. Experiment. We take the Theory, we apply the theory to some particular phenomena we with to consider and we determine the consequences of the Theory. This particular representation of the Theory applied to some particular phenomenon is called a *Model*. In physics, the model is generally represented by some over all equations. These equations that allow us to describe reality and predict phenomena.

In the laboratory (student labs as well as cutting edge research labs) experiments are conducted to actually measure the behavior of physical systems to determine if that behavior is well-described by the mathematical model or theory we want to test. In every lab experiment in our course there is one (and only one) central question that we want to address:

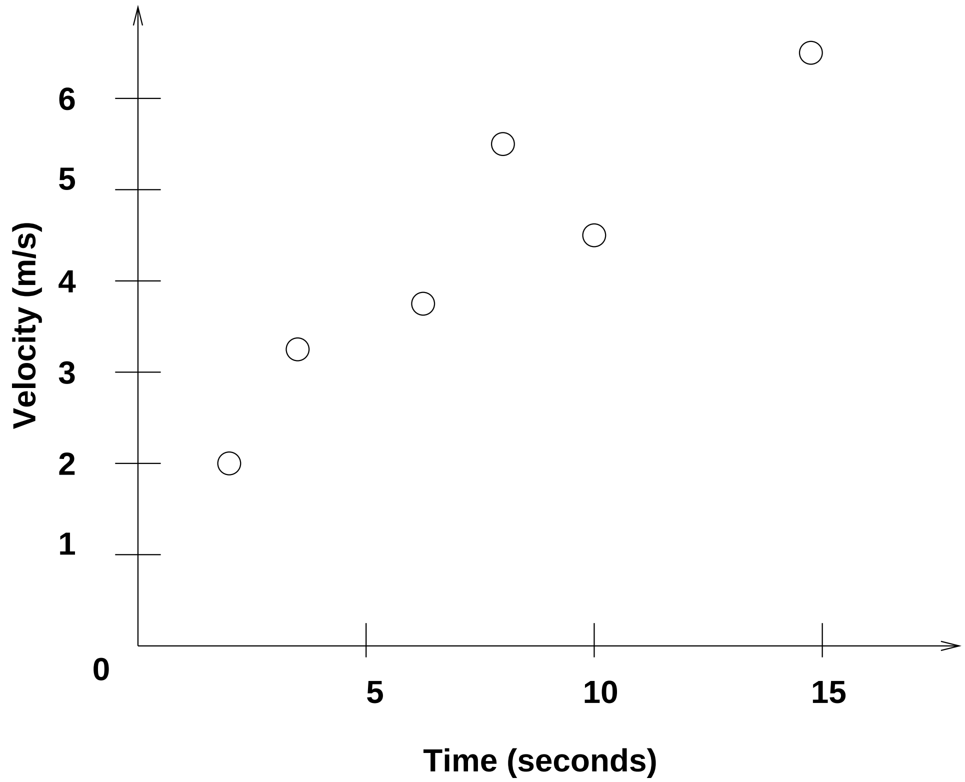
Do the experimental measurements support the underlying physics theory to within the uncertainties associated with the measurement?

In other words, do the *data* support the *model* to within the *measurement uncertainties*? This is the central question we ask our students to address and answer on every lab. Compared to this question, everything else in the lab is merely for “enrichment”.

The reason we need to do this in the lab are (1) because seeing is believing, (2) because experimental verification is generally completely ignored in the context of introducing theoretical and problem solving techniques in the lectures, and (3) because going through the process will provide students with a wide range of experimental approaches, techniques, and mathematical methods that are widely applicable in a variety of technical disciplines.

A.1 Plotting the data

Okay, in practice how does this work? In most labs, students will themselves be taking data and plotting something vs. something else on a graph. For example, suppose a student finds him or herself plotting speed vs. time for a moving cart on a track. Maybe the data plot looks like this:



Well that's nice. It looks like the trend in the data are sort of *linear*. But this data was not taken in an intellectual vacuum. The student takes the data so as to compare it to a particular *model*. It's very important that each time we collect data, we consider what the model that we are trying to verify or test. For example, in this example, perhaps the student is trying to explore a model that predicts that the velocity should be changing according to what we expect for constant acceleration due to a constant applied force. In this case, our model would be represent in mathematical form as a symbolic equation for velocity in constant acceleration:

$$v = v_0 + at$$

Note that the issue is not determining the value of the variables v_0 and a. The issue is determining whether this *model* can be supported by the data. In general, if we are plotting velocity v as a function of time t the model predicts that v will vary *linearly* with t. So this is what we want to know: *Do the data fall into a straight line?* If yes, then the model is verified. If no, the model is refuted.

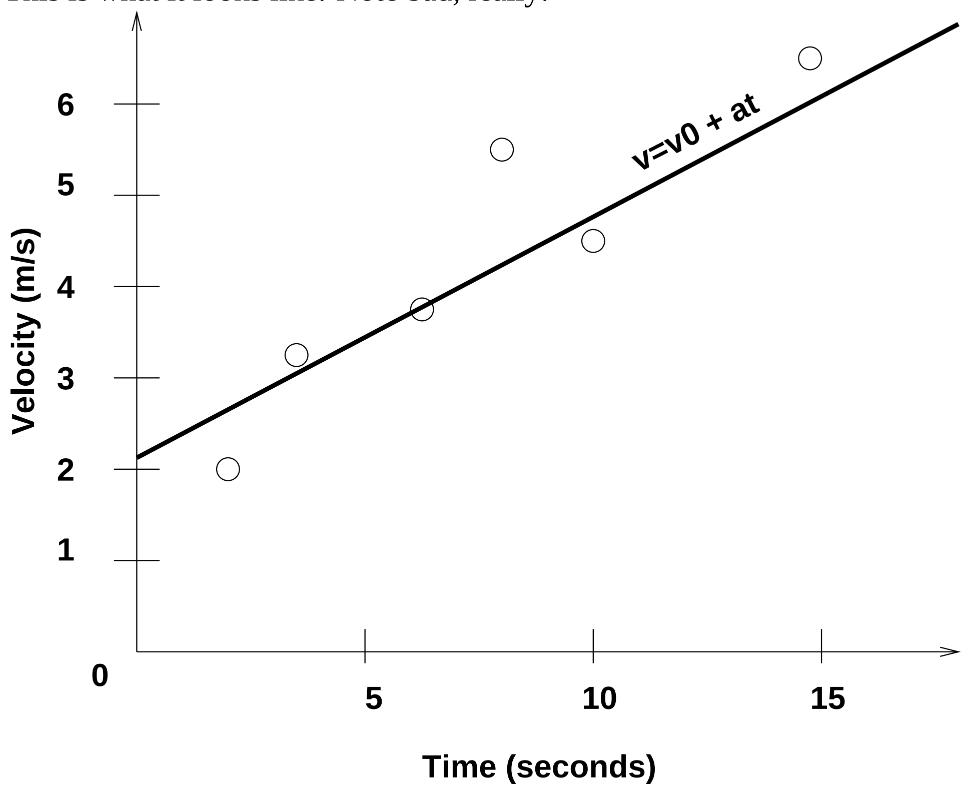
A.2 Graphically representing a model

Okay, so we look at the data and perhaps we can say that it looks like it might be close to falling in a line. What we want to do next is to put down a *model* on our plot. In other words, if we say the data are supposed to represent a line, we want to *fit* a "best line" to the data.

In fact, there are several mathematical and technical descriptions of the best way to fit a line (such as a linear regression). But the details of the technique are not important.[17]

[17] For these labs, it is perfectly acceptable to simply place a ruler on the plot and "eyeball" the best line to the data.

Okay, now students have taken the data and have fit a "best" line using the ruler and eyeball technique. This is what it looks like: Note bad, really:

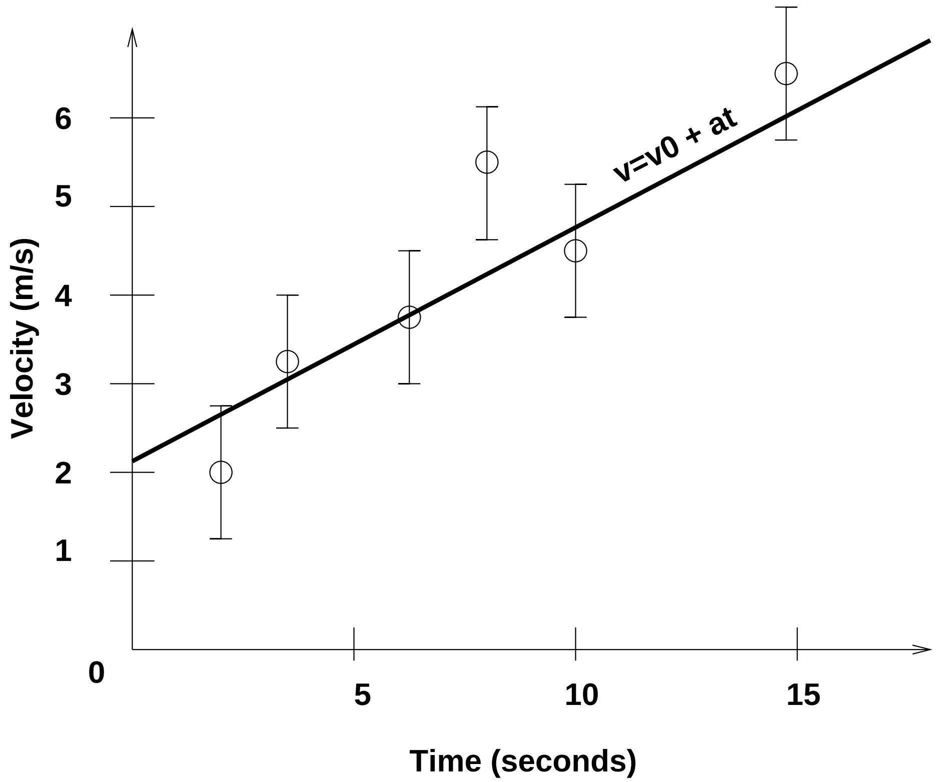


A.3 The importance of measurement uncertainties

Okay, so now we have data and mode as shown in the figure above. Are we ready to answer the main question of the lab: *Do the data support or refute the model?* Well unfortunately the answer is not yet clear. The data indeed line up *close* to the model, but the data do not fall exactly on a single line. There is that annoying point at $x =$ about 8 seconds that is kinda high above the line. Is this okay? Or is this a problem? Simply guessing just won't cut it. *We cannot address our central question until we add a critical missing piece to the plot: "error bars"*.

What are error bars? These are graphical indication of the approximate uncertainty in the individual measurement value of each point. The error bars on each point graphically represent the range of possible actual values for each measurement. There is generally no such thing as a "perfectly measured" quantity in the lab. Every measurement of position, speed, acceleration or mass is only good to a certain level of precision. This level is generally represented in plots by experimental scientists with these "error bars".

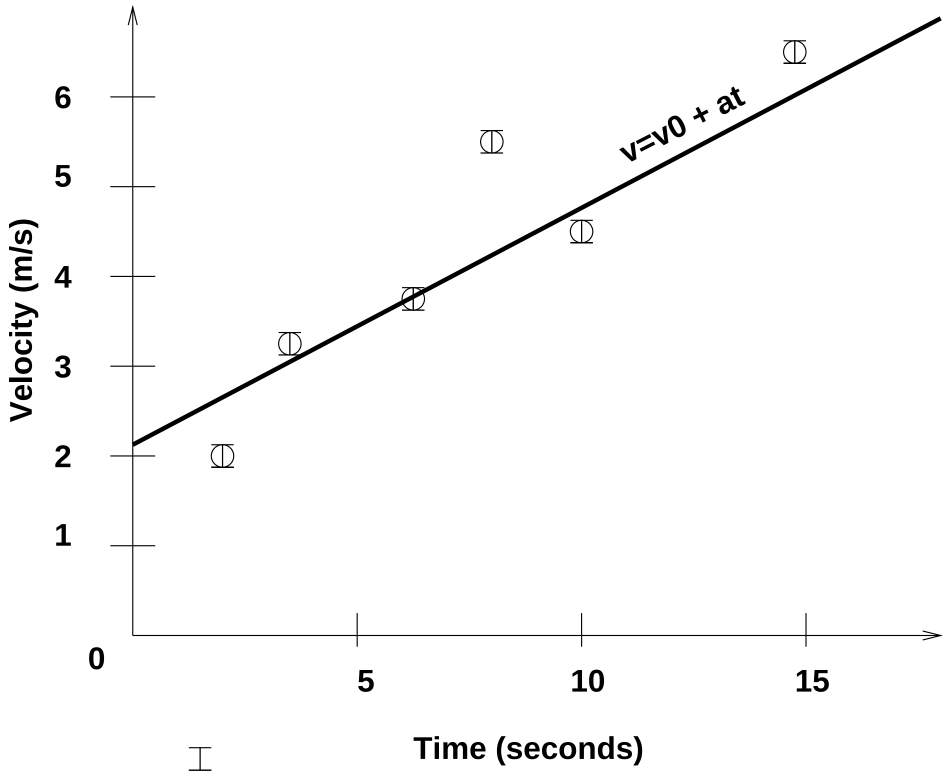
So in a nutshell, the answer to the central question depends entirely on the size of error bars. If we determine that the error bars look like this next plot below, then it's pretty clear that the data support the model *to within the approximate errors on the measurements* for most of the data points:



Note that in the above plot, the error bars "catch" the line at nearly every point.[18] When nearly all of the points match within Therefore we can answer the *Central Question* and we can say that the answer to the central question is this: *"Yes, the data do support the model to within the measurement uncertainties.* This is what it means to experimentally verify a scientific claim.

On the other hand, if the error bars look like this plot below, then it is pretty clear that the experimental data are in rather harsh disagreement with the model.

[18]For statistical reasons, if one or two of the points miss by a relatively small amount this is okay too.



In the above plot, at least three our of the six points do not catch the line in the error bars. The point at 8 seconds is several error bars away from the line – clearly inconsistent with the model. If you were to calculate the chi-square per degree of freedom you would get a number that is rather larger than 1.0. In this case we can also answer the Central Question and we can say that the answer to the central question is "No, the data do not support the model. The data are inconsistent with the model given the specified uncertainties."

Note that the actual values of the data have not changed between the two plots. Only the values of the uncertainties have changed, as reflected in the size of the error bars.

So a central an important task for each student in each lab is to determine an estimate of the errors on each measurement because they *need* this to have this in order to determine if the model is supported or refuted by the experiment. The lab is graded as a success if the student can unambiguously indicate a "yes" or "no" answer to the Central Question.

Note that in general when we do a physics experiment, we try to use *methods* to make the error bars as small as possible. The smaller the error bars, the more precise and meaningful the experiment is. If the error bars are small and the data are supported, this means that the model is shown to be accurate to a high precision. If the error bars are small, the experiment is able to detect small but real deviations between the real physical world from the physics theory. Such deviations are typically the stepping stones to more sophisticated and more accurate physical theories. For example, when the motion of the planet Mercury was measured carefully with precision instruments (which yielded very small errors bars) a tiny but significant deviation from the orbit predicted by Newton was measured. This deviation cannot be explained by Newton's classical physics and can only be explained by the Einstein's theory of Relativity. Ultimately, the new theory supplanted the old one as being "more accurate" and to this extent "more true".

A.4 Estimating Error Bars

There are many fine points for determining errors on measurements and propagating these errors in calculations. Indeed, as an research experimentalist, I spend a rather larger fraction of my time trying to determine and adjust measurement uncertainties than I do actually making the measurements directly. Some measurements are dominated by what is know as "statical uncertainties" – that is the tendency for a measurement to jump around. Other measurements are dominated by what are called "systematic uncertainties" – these are imperfections and miscalculations inherent in your measuring device and/or important deviations from our simplifying assumptions that impact the result.

B Second Appendix: Some Biographical Information

People sometimes want to know some of the details about someone who is writing something. It allows the reader to understand a little bit where that person is coming from.

First, an important disclaimer: *I have precisely no formal training in theology or religious studies.* The closest I have ever gotten to this is proofreading my wife's term papers for seminary. Furthermore I have never attempted any kind of systematic study of writing on the question of science and religion. This means that in writing on some of these topics I will certainly use 'non-standard' terms, will make unwarranted assumptions, and will be enormously ignorant of important and germane work that others have already done on this subject. My apologies to the well-informed reader who might find this very irritating.

I live in Cleveland Heights, Ohio, and teach at Case Western Reserve University, located in urban Cleveland. I'm 45 years old, white, and male.

I was born and grew up near southeastern Michigan. I went to college at the Massachusetts Institute of Technology and then ended up getting a doctoral degree in physics from Harvard. I've worked at the University of Chicago before coming to my present position in Cleveland.

As an associate professor at a university, I divide my time between teaching and research.

Most of my teaching involves undergraduate students, typically first year students taking introductory courses.

My research is in the field of experimental particle astrophysics. My main effort involves experiments to detect cosmic rays, which are very energetic particles that arrive at the top of the Earth's atmosphere from all directions. I work on the Pierre Auger Cosmic Ray Observatory[5], which is a new large experiment, recently deployed in Argentina, designed to detect the highest energy cosmic rays. The Auger experiment is run by an international group of many physicists working together. What is interesting is that although these cosmic rays are very energetic, we do not know where they originate from in the Universe. We do not know the sources of these cosmic rays. We are hoping that our new experimental will give us important new measurements that will provide new clues as to the origin of these cosmic rays. We want to know where they come from and how they end up with so much energy. This is "pure research" in that we are trying to solve a problem that has been puzzling scientists for decades, but as far we know whatever solution we find is not likely to have any immediate practical applications.

I did not grow up in the church, and instead came to this very gradually, largely though my wife, who I met in college at MIT. I'm married to Dianne Covault who after working for years as an environmental engineer, went to seminary at Garrett-Evangelical Theological Seminary in Evanston, Illinois. She now works in two different United Methodist churches in the Cleveland area. We have three beautiful and strikingly intelligent daughters: Linnea (8), Glennis (6) and Estelle (3).

I am by temperament and training a skeptic. I am particularly concerned about the issue of claims that seem to "take on the clothing" of scientific arguments but which in fact are not based on a scientific evidence.

I am politically liberal, and very concerned about the negative impact of war on human rights. I am often embarrassed by the leadership of my country and my denomination.

I usually have a tendency to keep my mouth shut regarding topics that I know very little or nothing about. This generally keeps me out of too much trouble. Not always, though.

References

[1] United Methodist Social Principles, The Book of Discipline, 2004.

[2] See for example writings of Ian Barbour, Kitty Ferguson, David Wilkinson, etc.

[3] Stephen Jay Gould, "Nonoverlapping Magisteria," *Natural History*, **106**, (March 1997): pp. 16-22; also in *Leonardo's Mountain of Clams and the Diet of Worms*, New York: Harmony Books, 1998, pp. 269-283, and available online at: `http://www.stephenjaygould.org/library/gould_noma.html`.

[4] Patricia King, "Learning to Make Reflective Judgments", *Liberal Education*, Vol 78, No. 1, 1992 and reprinted online at `http://dhc.ucdavis.edu/fh/aa/king.html`.

[5] For more information on the Pierre Auger Cosmic Ray Observatory, see online website at: `http://auger.org`