GEO-SPATIAL IMAGERY AND POPULAR PHYSICS

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Abstract This paper is concerned with the ways in which geo-spatial imagery functions in the presentation of modern physics to the general reader. Focusing on metaphorical descriptions of the experiences of both specialists and non-specialists in approaching the subject, it points to a disjunction between the images commonly used within works of popular physics and those used in their promotion. While positive images of journey and exploration characterize the advertising of books about physics aimed at the general reader, negative images of disruption and placelessness are more characteristic within them. The paper suggests that this disjunction reflects and exacerbates a general confusion about the relative 'reality' of the subject matter of modern physics, and it considers in what ways this confusion can be traced to problems of language inherent in the informal discussion of a study of abstract phenomena for which the primary language is mathematical.

Stories of expeditions and quests, plans for tours and maps for journeys have always appealed to the armchair explorer. Tour guides are not always purchased by those planning to make the tour. There do not, on the other hand, seem to be as many people who would describe themselves as armchair physicists. Partly for this reason, travel books seem more likely to sell than physics texts, so it is hardly surprising that many of the books on popular physics to be found in bookstores today present themselves in the guise of explorations, quests and tours. The drawback in this for the reader is that no matter how well the book is sold as a tour guide, it does not and cannot read like one. The language of popular geography describes facts; the language of popular physics creates images.

Patagonia exists--we may never visit it, but we can assume that the writer of a travel guide to Patagonia has. Quarks do not exist in the same simple fashion; it is impossible for the writer of a book about the 'particle zoo,' for example, to have seen one. A 'quark' is neither a place nor a thing but a concept. Geographical images in books about places are helpful; but they are deeply problematic in books about abstract concepts.

Once we have bought our book of popular physics and sat down to read it we are likely to find that its geo-spatial images have the unfortunate double effect of both confusing and intimidating us. They very rarely help us to visualize things, and they should not: 'things', after all, are not finally what we are reading about. Could such images really make physics texts attractive and intelligible? Do they inevitably make them only the more formidable and baffling? Certainly, the ways in which geographically-based images are used in books about modern physics intended for the general reader need to be given serious consideration.

Geo-spatial images proliferate on the covers and the promotional pages of currently available works of popular physics. Most of these images relate in some way to general concepts of exploration or quest. "Laypersons will read this fascinating book with emotions not unlike those felt by Europeans of the Renaissance when they listened with awe to travelers' tales of exotic scenes and wild adventures on strange continents," we are told inside the front cover of one such book; the back jacket of another encourages us to join in its "layperson's tour of [a] strange new world." [1] It sounds exciting. "Everybody," says the physicist Paul Davies, "likes adventure stories." The characters in Superforce, his popular adventure "into the shadowy world of fundamental physics," are scientists involved in a "quest . . . for a prize of unimaginable value--nothing less than the key to the universe."[2] "Odysseys," "guided tours," "plunges into the exotic realms of space," and "voyages of exploration" appear in some form or another on the back of popular physics books all along the shelves.[3] Publisher's advertisements routinely describe their product, the reporting (for a general audience) of advances in physics, in the terms of geographical exploration--John Gribbin's In Search of the Big Bang, for example, is nothing less than "an extraordinary journey across space and time to find the ultimate cosmic truth."[4] More fundamentally, and even more dangerously, these advertisements also talk of the original work of the physicists themselves in the terms of metaphors of 'discovery.' Take the advertisement for Anthony Zee's Fearful Symmetry, for example.[5]

> In the spirit of Einstein's quest, Fearful Symmetry invites us to view physics not merely as a body of theories and facts, but as a dynamic journey to fathom the workings of the universe.

This portrayal of physicists as explorers is dangerous for several reasons. The most obvious is that we tend to think of an explorer as a person who discovers something to do with place--new lands, for example, or the source of a great river. This new land (or spring, or whatever) is not, itself, new. It is new to its discoverer and to the people who then hear about it for the first time, but it pre-existed that discovery. It has been uncovered, but not created. Physicists, in contrast, despite being popularly famous as men and women who push back the frontiers of knowledge and scale vast intellectual heights to achieve new perspectives on theoretical territory, do not in general 'discover' things which have in any clear sense an existence independent from or even previous to their discovery. This is a form of exploration which creates the landscapes it describes: in fact, the description is the creation.

The promotional materials designed to make us buy books about "the baffling and seemingly lawless world of leptons, hadrons, gluons and quarks" or the "exploration of the frontiers of modern science" inevitably imply that there is a world of objective physical reality 'out there' waiting to be discovered.[6] New language (the naming of the quark called 'beauty,' for example) is coined, in this implied interpretation, to give words to newly discovered phenomena, in much the same way as new words might have to be coined to name unfamiliar plants growing on newly discovered islands. This is a confusing misdirection in thought brought about by our image of the physicist as 'discoverer.' We shall consider the problem of mathematical and non-mathematical language (and especially of naming) in the practice of physics in more detail below but we should at least note here a basic distinction between the explorer who finds that new language is demanded by new things and the scientist who formulates new things by the creation of new language. We return to the basic point that explorers who carry tents and backpacks are working on a scale at which Newtonian physics holds: they can see their subject matter, and they can distinguish themselves from it. Modern physicists, in contrast, are working on a scale--the very large or the very small--at which Newtonian 'common sense' physics does not hold. They cannot see their subject matter, they cannot touch it, measure it or even, at times, imagine it and they cannot separate that subject matter from their observation of it.[7] In his book Inventing Reality: Physics as Language Bruce Gregory repeatedly makes the point that physics is a way of talking about the world, not a discovery of the way the world 'really is.'[8] He directs our attention to the words of the physicist Niels Bohr:

> There is no quantum world. There is only an abstract quantum physical description. It is wrong to think that the task of physics is to find out how nature *is*. Physics concerns only what we can *say* about nature.

The image of the physicist as explorer is dangerous, then, because it leads us into making the mistake of thinking that there is a 'quantum world' waiting to be found by intrepid physicists. According to one of the most respected figures of twentieth century physics, such a world does not exist.

Advertisements on the back covers of books designed to be popular naturally tend to present the experience of reading the book in question as a positive, enlightening and exciting one. Nobody is going to advertise a physics book by proclaiming it to be difficult, confusing and scary. For this reason, the exploration/quest metaphors of popular physics advertisements are generally of the adventure story variety. Consider the back cover promotion of another of John Gribbin's popularizations, In Search of Schrödinger's Cat.[9]

> Now John Gribbin tells the complete story of quantum mechanics, a truth far stranger than any fiction. He takes us step-by-step into an ever more bizarre and fascinating place--requiring only that we approach it with an open mind. . . . And in a world full of its own delights, mysteries and surprises, he searches for Schrodinger's Cat--a search for quantum reality--as he brings every reader to a clear understanding of the most important area of scientific study today--quantum physics.

The reader has nothing to worry about. The world of quantum mechanics may be bizarre, mysterious and stranger than science fiction but we are going to be guided through it "step-by-step" until we achieve "a clear understanding" of what it is all about. A good guide makes all the difference. In referring to Bruce Gregory in terms which make him sound like a native scout Lynn Margulis, quoted on the back cover of his book Inventing Reality, stresses the skill of the guide rather than the difficulties of the terrain: Gregory's book, she tells us, "makes for smooth riding over the rough terrain of . . . modern physics."[10] Fred Wolf, in his book Parallel Universes, is another pathfinder.[11] He "deftly guides the reader through the paradoxes of today's physics to explore a realm of scientific speculation" in which black holes are nothing more threatening than "gateways of information between universes. . . ."

There is a major difference, however, between the geo-spatial images that predominate on the covers of books of popular physics and those which appear most often within their pages. While the book covers entice us in with reassuring images of guides and smooth rides, their texts offer us images with much less comfortable connotations. Occasional early hints of these less heartening images do appear on the covers. An "outrageous ride along the frontiers of science" does not sound particularly reassuring, for example, and while John D. Barrow's work on our concepts of natural law, The World within The World, is predictably enough "[a] rewarding journey to the limits of space and time," it is also, more alarmingly, a book whose "result is a certain dizziness that comes of balancing at the crumbling edge of thought."[12] Here we are dealing with a new order of image. The "crumbling edge" and our "dizziness" here relate to a group of images whose conventional connotations are those of placelessness, loss, and disorientation. In contrast with the place-oriented values of journey, exploration and quest these images reflect and inspire feelings of unease and discomfort.

Place is a very comforting concept: it implies meaningful location in a system or order both spatial and temporal. Place implies the interaction of people with environment over time, and the concept of the environment as a network of places provides literal and metaphorical frameworks for events and histories. Place is associated with vision and understanding. Placelessness, in contrast, is conventionally a very disturbing concept. Voids, abysses, labyrinths, deserts, chasms and shadowed landscapes suggest a loss of meaning in the environment; they are associated with disorientation, darkness and confusion. This distinction is critical to a discussion of geo-spatial imagery in popular physics today, because whereas the promotion of such texts relies heavily on the reassuring place-oriented values of images of guided exploration and discovery, the discussion within the texts of a layperson's approach to the 'world' of modern physics relies equally heavily upon the contradictory images of placelessness and disorientation. The transition is sudden, and it is not encouraging.

Let us look again at the "crumbling edge" quotation from the back cover of The World Within The World. "Barrow," we are told, "leads us . . . with wit and grace, making the journey an enjoyable one." This sounds very pleasant--but to what is he leading us? To "that extreme" which is "the crumbling edge of thought." Suddenly we realize that we have been led cheerfully up to a sheer drop, and we come to our senses to find ourselves looking dizzily over the edge. There is a vast difference between a crumbling edge and a frontier. Beyond one there is more land to be discovered; beyond the other--nothing. But if the frontier is the inspiration of the physicist/explorer, then the crumbling edge, it transpires, is what is lying in wait for the layperson stumbling along behind.

One of the earlier popularizations of post-Newtonian physics still readily available today is Banesh Hoffman's "account for the general reader of the growth of the ideas underlining our present atomic knowledge," a Dover reprint. Its prospectus sounds reassuring enough, even if its title, The Strange Story of the Quantum, is a little mysterious. In an "Intermezzo", however, as Hoffman leads into his explanation of the beginnings of modern quantum theory, we find a fully expanded version of the equation of the shift from Newtonian to quantum physics with the full-blown chaos of massed images of placelessness.[13]

> So far, at least, our story has preserved some semblance of orderliness. We have seen the stately rise of classical physics . . . the beginning of the revolution . . . its ominous spread . . . and the unprecedented stalemate to which it degenerated. Meanwhile we have followed the fortunes of the Bohr theory of the atom from its meteoric rise to its swift decline, dragging science down with it into chaotic uncertainty.
>
> If, however, all this has seemed to be the opposite of progress, if it has seemed to be more a headlong succession of patchworks and contradictory theories built upon shifting quicksands than a serious and considered advance in our understanding of nature . . . then indeed will the events to come seem at times utterly grotesque and fanciful.
>
> What happens next is so fast and furious that for a time all continuity is lost and physics becomes a boiling maelstrom of outlandish ideas. . . . Professional

> physicists, swept off their feet by the swift currents, were carried they knew not where, and it was years before the survivors recovered sufficiently to see, with the beginnings of perspective, that what had so overwhelmed their science had been the convulsive birth pangs of a new and greater era.

The shift from Newtonian certainties towards quantum indeterminacy is perceived here as a descent from order to chaos. Images of quicksands and of maelstroms, losses of footing and of perspective animate this history of the destruction of the "stately rise" of classical physics and the appearance of the new "outlandish" ideas. In the introduction to the following chapter Hoffman pictures his scientists "deep in alien land, confused, leaderless, and without inspiration." The association of the reconsideration of Newtonian physics with images of disorientation, earthquakes, broken foundations, and lost footing is still common in popular physics. Also still common is an almost gleeful belief in the inevitable disorientation of the layperson who has been taken in by the publicity of a popularization and has signed on for the tour. Pity the poor reader lulled into a false sense of security by Hoffman's opening words: "This book is designed to serve as a guide to those who would explore the theories by which the scientist seeks to comprehend the mysterious world of the atom."[14] This seems innocuous enough, but he reveals his real evaluation of the endeavour in the Intermezzo:

> If you have read thus far, there is no dignified way of escape left to you. You have paid your fare, and climbed to the highest peak of the roller-coaster. You have therefore let yourself in for the inevitable consequences. It is no use trying to back out. You had warning in the preface of what to expect, and if contemplation of the heights there described now makes you giddy and apprehensive, I cannot accept responsibility. The going will be rough, but I can promise you excitement aplenty. So hold tight to your seat and hope for the best. We are about to push off into vertiginous space.

Once again, we find ourselves perched on a peak, feeling giddy, bracing ourselves for a plunge into nothingness.

The exploration/quest image does not, of course, become completely supplanted by images of chaos and placelessness once we move inside a work of popular physics. It does, however, become markedly less common and is generally presented in much less secure and grandiose terms. One of the common first retreats from the image of the exotic adventure story is the reminder that really the 'quantum world' is all around us, not beyond some visible frontier. The subatomic "realm," we learn, is actually an "invisible universe underlying, embedded in, and forming the fabric of everything around us."[15] K.C. Cole, in Sympathetic Vibrations, does refer to the ""vast new vistas" and "untapped realms of time, space and temperature," and notes that "[t]hroughout the history of science, the most fruitful areas for exploration have hovered at the extremes and fringes--the outer limits," but she also points out that although "people talk about traveling into "outer space" as if it were some strange and exotic landscape . . . *we are living in outer space all the time.*"[16] The territory is becoming, as it must in detail, more explicitly metaphorical, intellectual and in some ways closer to home. We now know where we are going--to find ideas that lie "outside the province of classical physics"--but at last the purely metaphorical nature of the 'journey' is becoming clear and we must ease ourselves away from expectations of actual travel or literal quest.[17] It is an intellectual, not a geographical adventure, and as such it is going to be much harder work for the reader. Unfortunately, in many cases, this movement is not perceived as a shift from general geo-spatial concepts to more detailed but abstract ideas, but is instead reformulated in persistently geo-spatial terms to become a loss of the certainties of a familiar province, now not in an exploration but in a plunge into "vertiginous space."

The shift from Newtonian to post-Newtonian physics is conventionally presented in works of popular physics in the terms of two sets of associated geo-spatial images. The first is the one we have already noted--the leap into space, the loss of footing--and the other is the linked image of the shaking of foundations and the undermining of solid ground. Both sets of images are firmly connected to geo-spatial concepts of placelessness and the void, and both carry with them all the connotations of loss of security and meaning which conventionally belong to those concepts.

The early twentieth century discovery of the limits of Newtonian physics is routinely--in fact, monotonously--described in the terms of a major earthquake. The image was presumably relatively new when Albert Einstein used it.[18]

> All my attempts to adapt the theoretical foundation of physics to this [new type of] knowledge failed completely. 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."

Werner Heisenberg, another important figure at the time, commented that the violent reactions to the developments of early twentieth century physics "can only be understood when one realizes that here the foundations of physics have started moving . . . and . . . this motion has caused the feeling that the ground would be cut from science."[19] In modern popularizations, similar images are obligatory. "The ground had been cut from under the mechanical model," we learn; Einstein's work in 1905 "shook physics to its foundations;" the implications of that work "rattled not only the foundations of the old science . . but also appeared to strip away much of the theoretical ground upon which it rested."[20]

There is an interesting implication to these images of shaken foundations, and it is the view of physics not in terms of exploration but in terms of construction. This picture of physicists as master-builders avoids some of the problems inherent in their portrayal as explorers of patiently waiting lands. It renders more explicit the role of the scientist in creating the 'reality' of quantum 'things.' Physics is thus a construction, not a discovery, and this is in some ways a more accurate picture. But we need to look more closely at the construction images, particularly when they are linked with images of scaffolding. This division of the image into central construct and surrounding framework can very easily move us back again to the same old confusing division of object and observer, central 'thing' and external approach.

If a definition of the word "scaffolding" had to be inferred from its use as an image in works of popular physics a very confusing picture would emerge. Is it a preliminary external framework put up to facilitate the building of an inner construction? Is it a surrounding framework which permanently supports, like an exoskeleton, a floppy inner construction? Or is it, perhaps, an external image of an existing building, put up later to imitate and mirror it? K.C. Cole, for example, uses the image several times, and in different ways.[21] At times, it seems to be the familiar tool for builders at work: "Scaffolding is a great support from which to build and remodel and fine tune." But wait--Cole goes on to remind us that "the trick is remembering that it's not the real thing." Here, she is using 'scaffolding' to mean 'model'--and pointing out that as such it is a "caricature" of a "much more complex reality." Here the scaffolding seems to represent our understanding or formulation of the physical while the inner building is 'reality.' The construct is the scaffolding; the building pre-exists. We are back to a form of exploration--in this case, that of the blind men discovering the elephant. "Scaffolding," Cole tells us, "is only a facade," and eventually "even the strongest scaffolding gets cast aside, and the best models are replaced by newer ones." This comparison is confusing. Scaffolding here is cast aside, as normal, but not because the building within is complete. It is cast aside to be replaced by newer scaffolding. There is an even more confusing scaffolding image a few pages earlier in the book, in Cole's discussion of the familiar orbit model of the atom that many of us were presented with at school. It is, of course, a violently simplified version of recent thinking on the subject. Are such analogies and models wrong? For a moment we are back to explorations: "all of us," says Cole, "begin the journey to the center of the atom with this comfortably familiar image." The abandonment of the 'orbits' and the other complexities came later. "The orbits were a kind of scaffolding that helped people to get their footing while climbing towards a deeper understanding." This is a very difficult image, even if we can cope with the idea that orbits are scaffolding. Here, scaffolding is acting like some kind of mountain pathway, up which we are climbing--towards something deeper. Part of the problem here is the fact that both depth and height have connotations of understanding--but even discounting what at first sight seems to be the paradox of climbing towards something deeper we are left with the image of scaffolding again acting as a guide and support in our exploration of external reality. It is important to realize that Cole is not relating the scaffolding/model to popular understanding and the building/view to that of professional physicists. The distinction is still between the real and the understood; the existing and the discovered. We are still, all of us, explorers and not builders, a distinction supported by Einstein's picture of what a scientific discovery is, quoted in Gary Zukav's The Dancing Wu-Li Masters.[22]

> [C]reating a new theory is not like destroying an old barn and erecting a skyscraper in its place. It is rather like climbing a mountain, gaining new and wider views, discovering unexpected connections between our starting point and its rich environment. But the point from which we started out still exists and can be seen, although it appears smaller and forms a tiny part of our broad view gained by the mastery of the obstacles on our adventurous way up.

In this passage Einstein presents the exploration metaphor in heartening and still place-oriented ways: in our intellectual journey we are seeing how to place our original position in a wider context. However, as we have noted above, the development of post-Newtonian physics is more conventionally presented in popular terms through images associated with a loss of place. While one set of these images was that associated with shifting foundations; the other has to do with what Hoffman characterized as "vertiginous space"--the void, the abyss, the desert. Cole, again, usefully shows how the one leads into the other. Quantum theory, she explains, is revolutionary rather than evolutionary in that while some new ideas "sprang from previously established foundations," quantum theory "broke away completely from those foundations; it dove right off the end." Even though she goes on to claim that the end result of this dive has been "concreteness and clarity" the image is an alarming one.[23] Robert Nadeau, too, makes the connection between the two sets of images. "As notions fundamental to Newtonian science . . . began to dissolve like so many desert mirages, scientists had every right to feel that the 'ground had been pulled from under one.'"[24]

Dives "off the end" and fading mirages are typical void images. These images are used to describe the experience of physicists grappling with quantum theory, and they are used repeatedly to describe the situation of the layperson trying to reach some understanding of what the physicists have done and are doing. Perhaps these images accurately reflect the experiences of both sets of people. But in presenting the consequences of an intellectual effort in such unnerving terms the writers of books about physics are paradoxically reinforcing the popular idea of the subject matter as difficult and intimidating. Surely there is at least the possibility of a self-fulfilling prophecy here. We have seen above how Hoffman presents the quest of the layperson as a hair-raising roller-coaster ride. Gary Zukav, in one of the most famous and widely-read popularizations of quantum physics, does much the same thing. To ask why Einstein objected to quantum physics, Zukav tells us, is "to stand at the edge of an abyss, still on the solid ground of Newtonian physics, but looking into the void. To answer it is to leap boldly into the new physics."[25] This is on the first page of Chapter One. We are being invited to read on and leap into a void.

While it is understandable that physicists should describe their own intellectual difficulties in constructing meaning from their observations of the results of unimaginable processes in the terms of voids and deserts, it is unfortunate that this metaphorical language should live on into the descriptions of a layperson's experience of the physicist's conclusions. The connotative baggage of such language is offputting and intimidating. It implies a message: "quantum physics is a very abstract and difficult science. It can be undertaken in mathematical languages, but the results of that undertaking are untranslatable. Try to understand it in non-mathematical terms and you will feel very dizzy." This is, of course, not what physicists and the writers who are trying to communicate something of quantum physics to non-specialists are consciously saying. They are loudly and publicly saying the opposite. But this is the subliminal effect of much of the geo-spatial imagery which accompanies the communication.

Taken out of the context of an understanding of what physicists can and cannot do with mathematical languages and their subject matter, the physicist Richard Feynman's description of what happens to people who try to "understand" quantum mechanics is very depressing.[26]

> I think I can safely say that no one understands quantum mechanics. . . . Do not keep saying to yourself, if you can possibly can avoid it, 'But how can it be like that?' because you will get 'down the drain', into a blind alley from which nobody has yet escaped. Nobody knows how it can be like that.

Most ordinary people read books about quantum physics precisely because they want to understand what it is all about. They are frustrated to find that even physicists do not 'understand' it--and that simple questions like "how?" and "why?" will send them "down the drain" and into a "blind alley" from which there is no escape. These are images of quite horrible placelessness and confusion.

Faced with a plunge into space, a crumbling edge, an inescapable blind alley, many people would rather shut their books than read on. These images are not enticing. The back page advertisements for thrilling voyages of exploration begin to look rather hollow. But the central problem here is not, finally, one of truth in advertising. It is not the case that while popular physics can be marketed as an adventure into new lands it must necessarily be experienced as a free-fall into nothingness. The real problem is merely reflected in (and exacerbated by) this dislocation of imagery, this sudden transition from cheerful exploration into terrifying free-fall. The real problem lies with the uses of non-mathematical languages in talking about post-Newtonian physics, for example in the informal discussion and simplification of its new ideas.

Most of us tend to think that our way of talking about physical things accurately reflects the way they are. Physicists, however, talk about their subject matter in the language of mathematics, and in so doing are consciously using a language which no longer has any such simple a relationship to reality. "Maths is a particularly useful jargon," explains K.C. Cole, "in that it allows you to describe things beautifully and accurately without even knowing what they are." "The glory of mathematics," she goes on to quote Richard Feynman as having said, "is that *we do not have to say what we are talking about.*"[27] Victor Weisskopf, another physicist, apparently puts it this way: "[t]he magic of quantum mechanics is that we can talk about things we can't visualize."[28] The distinction between the way we commonly use language and the way physicists have to use the mathematical language is vital, and it lies at the centre of many of the linguistic problems of popularization. As Bruce Gregory explains it in Inventing Reality, the apparently simple relationship between words and reality that seems to hold up on the human scale disappears at that of the subatomic.[29]

> Even if we do not observe a marble, we can still say that it has a well-defined path. We can say this because we can use the path to predict outcomes that can be observed. Electrons are not like marbles. When we do not meaure an

> electron's path, we cannot even say that it *has* a path. Position and motion do not seem to be properties of the subatomic world; they seem to be our way of *talking* about the subatomic world.

Physicists, it seems, are not describing facts but creating images--rendering the unimaginable into terms in which it can be usefully manipulated. The metaphorical language of mathematicians does not reflect a reality, it constructs a system. It is a process of radical simplification. As Gregory explains, "physics is really not about making accurate pictures of the world. For a physicist, a realistic picture is far too complex to be useful as a tool, and physics is about fashioning tools."[30] We should remind ourselves of Bohr's dictum: "There is no quantum world. There is only an abstract quantum description."

Physicists, then, use language to make tools. But what do they use these tools for? The answer is that they are used as tools for prediction, because predictions are what physicists are interested in. They are not asking 'how,' and they are certainly not asking 'why;' perhaps they are not even asking 'what'--but rather, 'what next? or even, 'so what?" As Paul Dirac has defined it, "[t]he main object of physical science is not the provision of pictures, but it is the formulation of laws governing phenomena and the application of these laws to the discovery of new phenomena."[31] According to Bruce Gregory, a physicist would define 'understanding' as being able to describe quantitatively how a phenomeon will develop over time. It is the results that are important; prediction is all.

In ordinary daily language, we make clear distinctions between different explanations for things, even if the different explanations lead to identical results. The argument is as important as the conclusion. In physics, this does not hold. If two approaches, no matter how different they are, reach the same conclusions then those approaches are equivalent and are in fact 'saying' the same thing. Consider the case of the Feynman approach to positrons. Richard Feynman successfully integrated the positron into theories of relativity by treating it as an electron which moved backwards through time. Is this actually what it is? The question, it seems, is meaningless, Bruce Gregory explains.[32]

> This question is resolved the way so many similar questions in physics are resolved--by saying that the same results are obtained by treating positrons as electrons moving backward in time as are obtained by using more conventional techniques, and so the ideas are equivalent. In other words, as far as physics is concerned, whether positrons really are electrons moving backward in time is not a useful question.

Electrons and positrons do not, of course, 'actually' exist for us in the same way that a cat or an apple does. They are formulations, what Robert Nadeau might call 'labels for relationships.' The radically different approaches of Schrödinger's wave mechanics and Heisenberg's matrix mechanics provide us with another example of this triumph of the predictive ability of a theory over its particular formulation of reality. Robert Nadeau explains:

> The alternate theory to Schrödingers wave mechanics, developed by Werner Heisenberg, is matrix mechanics, and the two theories, in spite of a dramatic difference in the assumptions about the actual character of subatomic processes, are mathematically equivalent and are still considered alternative formulations of the single theory--quantum mechanics.

These theories are "logically irreconcilable but mathematically equivalent."[33] Bruce Gregory summarizes this situation as follows:

> The only way physicists are willing to discriminate between ways of talking about nature is on the basis of the conclusions to which differing vocabularies lead. If two ways of talking make the same predictions, as do Heisenberg's matrix mechanics and Schrödinger's wave mechanics, physicists say that they are dialects of the same language.

Mathematical language, then, is a set of metaphors valued for their predictive power. K.C. Cole tells us how the theoretical physicist David Politzer describes "the most recent 'inventions' in the physics of the early universe . . .as mathematical theorems."[34]

> "English is just what we use to fill in between the equations," he said. "The language we use to talk to each other doesn't have analogies in nature. But we have greatly extended our mathemetical vocabulary, and we are always looking

> to expand this set of metaphors. That's what it's all about. Understanding is a way of picturing things, and mathematics gives you a way to do it."

The problem with any metaphor or system of metaphors, of course, is that it is so easy to lose sight of its purely symbolic reality. Similes are much less seductive: the critical word "like" helps to prevent us from confusing subject with vehicle. Presented with the statement "love is like a frog" my response would be to ask in what particular ways the two are alike. There is no temptation to think of love as a type of frog. Perhaps this is because I have some experience of both love and frogs and am not likely to confuse them. Metaphors, however, and especially metaphors which relate to abstract concepts less familiar than love, tend to take on a life of their own--and this can and apparently does happen to the metaphors of physicists. This process becomes all the more natural when the concepts become translated into non-mathematical languages, and all the more confusing when the subject matter of the metaphor is unimaginable in its non-metaphorical state. Do physicists talk about things or abstractions?[35] "Physicists can define a gravitational field," Bruce Gregory tells us, "but does a gravitational field have any reality beyond its definition? Is it something physical or is it a mathematical fiction?"[36] The geo-spatial connotations of the word 'field' contribute to the problem. As K.C. Cole points out, "[l]ight waves do not undulate through empty space in the same way as water waves ripple over a still pond [and] a field is not like a hay meadow, but rather a mathematical description of the strength and direction of a force."[37] But words carry pictures, and with them a sense of reality.

Quarks, which were at one time also labelled "aces," take their name from a phrase in Finnegan's Wake. It is a word without many overtones of meaning. But there are strange quarks, up quarks, down quarks, coloured quarks and flavoured quarks, and the quark called 'beauty.' These abstractions begin to take on character. Richard Feynman thinks this is "lousy terminology."[38]

> One quark is no more strange than another quark. Maybe charm is okay because it's so far out you know it isn't really charmed. But people think that up quarks are really turned up somehow, so it's very misleading.

Quarks provide us with a useful example of an abstraction come to life. Physicists tell us that quarks will never be observed; we have no way of knowing whether they do 'really' exist. But as Bruce Gregory shows, we have invented quarks and now we believe in them.[39]

> The existence of a world we cannot see makes sense from a physicists point of view only if this world has observable consequences. Physicists cannot "see" quarks or gluons, but quarks and gluons are elements of physical theory because they lead to predictions that physicists *can* see. Talking as though there are quarks and gluons helps physicists to make sense of the world. . . .
> [T]he most successful ways of talking about nature that physicists have found turn out to require that they speak in terms of fundamentally unobservable elements. Yet most physicists are committed to the reality of quarks.

This problem--the ways in which metaphorical constructs take on apparently independent physical existence--is compounded once the discussion moves outside that small group of people who could be called practicising academic physicists. Surely most ordinary people, seeing books with titles which refer to zoos full of particles, quarks, positrons and gluons, tend to believe that such things, even if they are not exactly visible, do still actually exist.

The physicist Niels Bohr apparently once wrote that when talking about atoms, "language can be used only as in poetry," because both poet and physicist are "not nearly so concerned with describing facts as with creating images." The physics professor Douglas Giancoli has also been quoted as comparing the metaphors of physicists with those of poets.

> When a physicist says 'an electron is like a particle'. . . he is making a metaphorical comparison like the poet who says 'love is like a rose.' In both images a concrete object, a rose or a particle, is used to illuminate an abstract idea, love or electron.

This is reasonable. How often, though, do we read in works of popular physics that "an electron is like a particle?" This formulation of the comparison in the terms of a simile is much less confusing than is the more common, condensed and metaphorical form: "electrons are particles." It is a difficult distinction to make--that an electron is only 'like' a particle in some ways, as love is only 'like' a frog in others--and it is made even more difficult by the more normal metaphorical construction.

Abstract ideas, we may conclude, do not translate well into concrete analogies. They simply do not fit. Worse still, we often don't notice that they don't fit. We all know that love is not actually a rose (or a frog), but there is much greater confusion about whether an electron is really a particle. The essential difficulty of any attempt to simplify and present abstract concepts in the terms of familiar images is clearly indicated by both the message and the implications of a passage from Robert Nadeau's book Readings from the Book of Nature.[40]

> If mathematical language is a system of subjectively based constructs, then truth in mathematical form does not reside, as Pythagoras thought it did, in some supersensible realm of being known to us through reason and contemplation. But as the response to Bell's theorem, which is, after all, a purely mathetmatical construct, attests, the distinction between map and landscape, which is rather easily accepted and endorsed by many contemporary psychologists, linguists, anthropologists, and sociologists, is not recognized, even implicitly, in the work of many contemporary physicists.

Nadeau here is suggesting that physicists do not in general distinguish sufficiently clearly between the formulations of their metaphorical language and 'the other', the something that is not us that we might call 'reality.' It is interesting, though, that he himself displays something of the same habit of thought in defining the separation as being that between 'map' and 'landscape,' because it is clear that landscape is itself a constructed entity, loaded with cultural and historical values, and far from being identifiable with whatever it is that might be 'other' or prior to interpretation. While the map is not the landscape, neither is the landscape the land. There is a hierarchy of metaphorical interpretation at work in these distinctions.

Landscapes are mental constructs, and so it is hardly surprising that the metaphor of 'mental landscape' is used regularly to mean 'way of thinking.' Nadeau uses it this way himself in a passage which usefully summarizes some of the problems inherent in the attempts to translate the concepts of theoretical physics into ordinary language that we have been discussing.[41]

> Time as the fourth dimension in the mental landscape of mathematics does not, of course, translate well into the mental landscape associated with ordinary language, and can perhaps best be described as "a label given to a relationship."
> The mathematical idealization of this reality that yields precise results in relativistic physics may serve to describe the condition of our being, but our world-constructing minds are not yet equipped to fully construct it in nonmathematical terms.

This is the frustrating truth. There is no simple way in which abstract ideas can be mapped out in visual images, geo-spatial or other. The tour we are promised on the back covers of books such as Gribbin's In Search of the Big Bang and Wolf's Taking the Quantum Leap is impossible. Nevertheless, the nasty moment when we find ourselves perched on that crumbling edge should never happen: we should never have believed in the geographical metaphor in the first place, and if we abandon it, we get rid of the cliff-face too. No matter how seductive the metaphor, it is finally counter-productive to see physics as an exploration--and physics for the non-specialist neither needs nor deserves to be presented as a leap into the void. The use of geo-spatial imagery in the presentation of post-Newtonian physics to the general reader needs to be reconsidered. This study has focused on the dislocation between the images of journey and exploration found in the publicity for books about modern physics and the images of placelessness commonly used to characterize the experience of a layperson actually reading them. It has suggested that the issue implicit in this disjunction is that of the 'reality' of the subject matter of modern physics, and it has also suggested that this should be more overtly acknowledged, or at least less disguised in simple images of geographical exploration.

Such an acknowledgment might alleviate some of the confusions experienced by a layperson reading popular physics. It remains to be said that in addition to the further study of these images, used in portraying the general reader's approach to modern physics and their effects, the use of geo-spatial imagery in actual explanation and description within works of popular physics also needs to be studied. If we conclude that geo-spatial images used in the presentation of the experience of reading popular physics tend to oversimplify that experience in one direction or another (exploration or free-fall), then we certainly need to go on to question the extent to which such images used in the presentation of the concepts of modern physics really guide the reader towards a true appreciation of their complexity and to what extent they too either confuse or produce 'understanding' through oversimplification.

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[1] Martin Gardner, quoted on the first page of K.C. Cole, Sympathetic Vibrations: Reflections on Physics as a Way of Life, (New York: Bantam Books, 1985), promotional material on the back jacket of Werner Heisenberg, Physics and Philosophy: The Revolution in Modern Science [1962] (London: Pelican Books, 1989). Dates in square brackets here and elsewhere refer to the original date of publication.

[2] Paul Davies, Superforce: The Search for a Grand Unified Theory of Nature (London: Unwin Paperbacks, 1985), p. 5.

[3] see, for example, the promotional materials for Fritjof Capra, Uncommon Wisdom: Conversations with Remarkable People (London: Fontana Paperbacks, 1989), Paul Davies, Other Worlds: Space, Superspace and the Quantum Universe (London: Penguin, 1988), Stephen W. Hawking, A Brief History of Time: From the Big Bang to Black Holes (New York: Bantam Books, 1988), Robert P. Crease and Charles C. Mann, The Second Creation: Makers of the Revolution in 20th Century Physics (New York: Collier Books, 1986) and Paul Davies, Superforce.

[4] John Gribbin, In Search of the Big Bang: Quantum Physics and Cosmology (New York: Bantam Books, 1986), back cover.

[5] A. Zee, Fearful Symmetry: The Search for Beauty in Modern Physics (New York: Macmillan, 1986). "Einstein's quest" is presumably to be defined according to the quotation from Einstein printed at the top of the back page: "I want to know how God created this world. I am not interested in this or that phenomenon. I want to know His thoughts, the rest are details."

[6] From the back covers of Heinz R. Pagels, The Cosmic Code: Quantum Physics as the Language of Nature (Harmondsworth, Middx: Pelican Books, 1984) and Frank Wilczek and Betsy Devine, Longing for the Harmonies: Themes and Variations from Modern Physics [1987] (New York: W.W. Norton, 1989).

[7] see Cole, p. 158.

[8] Bruce Gregory, Inventing Reality: Phsyics as Language (New York: John Wiley & Sons, Inc., 1990) p. 95.

[9] John Gribbin, In Search of Schrödinger's Cat: Quantum Physics and Reality. (New York: Bantam Books, 1984).

[10] Gregory, back cover.

[11] Fred Alan Wolf, Parallel Universes: The Search for Other Worlds [1988] (New York: Touchstone, 1990).

[12] John D. Barrow, The World within the World (Oxford: Oxford University Press, 1990), front and back covers.

[13] Banesh Hoffman, The Strange Story of the Quantum, 2nd edn (New York: Dover Publications, Inc., 1959).

[14] Hoffman, p. ix.

[15] Gary Zukav, The Dancing Wu Li Masters: An Overview of the New Physics [1979] (New York: Bantam Books, 1980), p.19.

[16] Cole, pp. 53, 123, 23.

[17] Robert Nadeau, Readings from the New Book of Nature: Physics and Metaphysics in the Modern Novel (Amherst: Univ. of Massachusetts Press, 1981) p. 41.

[18] This quotation is taken from Fritjof Capra, The Tao of Physics: An exploration of the parallels between modern physics and Eastern mysticism [1983 edition] (London: Fontana Paperbacks, 1983) pp. 61-2.

[19] Heisenberg, p. 155.

[20] Gregory, pp. 57 and 60, Nadeau, p. 42.

[21] Cole, pp. 171-76.

[22] Zukav, p. 19.

[23] Cole, p. 106.

[24] Nadeau, p. 42.

[25] Zukav, p. 18.

[26] Richard Feynman, The Character of Physical Law (Cambridge: MIT Press, 1967), p. 129.

[27] Cole p. 170.

[28] Cole p. 173.

[29] Gregory p. 94.

[30] Gregory p. 3.

[31] Gregory p. 95.

[32] Gregory pp. 111-112.

[33] Nadeau pp. 51-2

[34] Cole p. 169.

[35] David Bohm and F. David Peat, in their Science, Order & Creativity (London: Routledge, 1989), suggest that the use of informal language to talk about mathematical formulations leads to a breakdown in communication within the discipline, as informal language acquires new meanings for different speakers while the group as a whole continues to think that everyone understands the informal language in the same way. They argue that the ways in which informal language comes to embody

particular world views actually inhibits free thought in mathematically based discplines.

[36] Gregory p. 47.

[37] Cole p. 156.

[38] Cole p. 163.

[39] Gregory pp. 182, 184--5.

[40] Nadeau, p. 61. Bell's theorem, formulated in 1964, proves in mathematical terms that either quantum theory is wrong in its statistical predictions or there are serious gaps in our commonly held ideas about how the world works. Nadeau is referring here to the literal ways in which the scientific community interpreted this proof. For a basic introduction to Bell's theorem, see Zukav p. 290-4 or Fred Alan Wolf, Taking the Quantum Leap: The New Physics for Nonscientists (New York: Harper & Row, 1989) pp. 202-4.

[41] Nadeau p. 47.