Einstein on the Research Program

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Abstract

Einstein was given to writing essays and dropping hints on his personal views on how that the research program is the central concept of how theoretical physics gets down. In this paper we go over how Einstein presented it through his writings, especially through his many essays.

1 Introduction

Relativity is both a research program and a set of four or more major specific theories:

1) Galilean-Newtonian mechanics.

2) Special Relativity (SR)

3) Extended relativity, which includes accelerated reference frames against a flat Minkowski spacetime,

4) Einstein's theory of gravity within general covariance, called General Relativity (GR).

That relativity is a program – or rather a variety of programs – of research, I give, first a hint at how the mode of approaching theoretic physics was in need of change:

> Physics is an attempt conceptually to grasp reality as it is thought independently of its being observed. In this sense one speaks of "physical reality." In pre-quantum physics there was no doubt as to how this was to be understood. In Newton's theory reality was determined by a material point in space and time; in Maxwell's theory, by the field in space and time. In quantum mechanics it is not so easily seen.
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> — Found in: *Albert Einstein Philosopher–Scientist*, "Autobiographical Notes," pp. 81–82.

Abraham Pais describes the effect of Einstein's principle theories within his relativistic research program.

> The phenomena to be explained by a theory of principle have become enormously richer since the days when Einstein made the first beginnings with his program.
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> — Found in: *Subtle is the Lord*, A. Pais, p. 31.

2 The Evidence

And in the midst of all these ways of formulating programs, how does one come up with the physical concepts that inhabit modern theories? They are "free inventions of the human mind":

> The agreement of these considerations with experience together with Planck's determination of the true molecular size from the law of radiation (for high temperatures) convinced the skeptics, who were quite numerous at the time (Ostwald, Mach) of the reality of atoms. The antipathy of these scholars toward atomic theory can indubitably be traced back to their positivistic philosophical attitude. This is an interesting example of the fact the even scholars of audacious spirit and fine instinct can be obstructed in the interpretation of facts by philosophical prejudices. The prejudice—which has by no means died out in the meantime—consists in the faith that facts by themselves can and should yield scientific knowledge without free construction. Such a misconception is possible only because one does not easily became aware of the free choice of such concepts, which, through verification and long usage, appear to be immediately connected with the empirical material.
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> — Found in: *Albert Einstein Philosopher–Scientist*, "Autobiographical Notes," p. 49.

Why the need for the research program in science?

> For even if it should appear that the universe of ideas cannot be deduced from experience, but is, in a sense, a creation of the human mind, without which no science is possible, nevertheless this universe of ideas is just as little independent of the nature of our experiences as clothes are of the form of the human body.
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> — Found in: *The Meaning of Relativity*, p. 2.

The following is one of my favorite quotes from Einstein. It shows how that human reasoning must go well beyond appearances to invent constraints on physical theories, in this case, general covariance.

> What has nature to do with our coordinate systems and their state of motion? If it is necessary for the purpose of describing nature, to make use of a coordinate system arbitrarily introduced by us, then the choice of its state of motion ought to be subject to no

> restriction; the laws ought to be entirely independent of this choice (general principle of relativity).
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> — Found in: *Albert Einstein's General Relativity*, Crown Publication, New York, [First printed in 1919], 1979, p. 63.

The following shows that physical theories benefit, not only from empirical principles, but also by logical ones.

> The general principle of relativity requires that all these [reference] molluscs can be used as reference bodies with equal right and equal success in the formulation of the general laws of nature; the laws themselves must be quite independent of the choice of the mollusc.
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> The great power possessed by the general principle of relativity lies in the comprehensive limitation which is imposed on the laws of nature in consequence of what we have seen.
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> — Found in: *Albert Einstein's Theory of General Relativity*, reprinted Albert Einstein, *Relativity*, p. 91–92.

The general principle of relativity has unlimited scope. (I'm not quoting this to indicate that Einstein was correct, but only that this was his formal point of view on formulating theories.)

> The first observation is that the principle of general relativity imposes exceedingly strong restrictions on the theoretical possibilities. Without this restrictive principle it would be practically impossible for anybody to hit on the gravitational equations, not even by using the principle of special relativity, even though one knows that the field has to be described by a symmetric tensor. No amount of collection of facts could lead to these equations unless the principle of general relativity were used. This is the reason why all attempts to obtain a deeper knowledge of the foundations of physics seem doomed to me unless the basic concepts are in accordance with general relativity from the beginning. This situation makes it difficult to use our empirical knowledge, however comprehensive, in looking for the fundamental concepts and relations of physics, and it forces us to apply **free speculation** to a much greater extent than is presently assumed by most physicists. [emphasis mine]
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> — Found in: *Ideas and Opinions*, Einstein, "On the generalized theory of gravitation," p. 352.

> ...We are thus lead to extend the transformations to arbitrary continuous transformations. This implies the general principle of relativity: Natural laws must be covariant with respect to arbitrary continuous transformations of the coordinates. This requirement (combined with that of the greatest possible logical simplicity of the laws) limits the natural laws concerned incomparably more strongly than the special principle of relativity.

— Found in: Appendix V of *Relativity: the special and general theory*, "Relativity and the problem of space," July 1952.

More here on Einstein's notion of the reference mollusc:

> The general theory of relativity, accordingly, proceeds from the following principle: Natural laws are to be expressed by equations which are covariant under the group of continuous co-ordinate transformations. This group replaces the group of the Lorentz transformations of the special theory of relativity, which forms a sub-group of the former.
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> .....The eminent heuristic significance of the general principles of relativity lies in the fact that it lead us to the search for those systems of equations which are in their general covariant formulation the simplest ones possible; among these we shall have to look for the field equations of physical space. Fields which can be transformed into each other by such transformations described the same real situation.
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> — Found in: *Albert Einstein Philosopher–Scientist*, "Autobiographical Notes," p. 69.

Here, Einstein describes what is today known as the research program of quantum field theory:

> We shall then, I feel sure, have to return to the attempt to carry out the **program** which may be described properly as the Maxwellian—namely, the description of physical reality in terms of fields which satisfy partial differential equation without singularities. [emphasis mine]
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> — Found in: *Ideas and Opinions*, "Maxwell's influence on the idea of physical reality," p. 270.

Once more, Einstein writes of the physicist's need of embracing a **formal point of view** that transcends mere 'deduction of physical laws from empirical data'. By the way, it seems that Einstein has anticipated the Higgs field and mechanism.

> Perhaps the basic property of matter, its inertia, could be explained within the field theory? The question led to the problem of an interpretation of matter in terms of field theory, the solution of which would furnish an explanation of the atomic structure of matter. It was soon realized that Maxwell's theory could not accomplish such a **program**. Since then many scientists have zealously sought to complete the field theory by some generalization that should comprise a theory of matter; but so far such efforts have not been crowned with success. In order to construct a theory, it is not enough to have a clear conception of the goal. One must also have a formal

> point of view which will sufficiently restrict the unlimited variety of possibilities. So far this has not been found; accordingly the field theory has not succeeded in furnishing a foundation for the whole of physics. [emphasis mine]
>
> — Found in: *Ideas and Opinions*, "The fundaments of theoretical physics," p. 328.

According to Einstein, a fundamental heuristic to the invention of good theories in any research program is the generous use of the (vague) concept of simplicity.

> The attempt to comprehend the correlations among the empirical data on the basis of such a highly abstract program may at first appear almost hopeless. The procedure amounts, in fact, to putting the question: what most simple property can be required from what most simple object (field) while preserving the principle of general relativity? Viewed from the standpoint of formal logic, the dual character of the question appears calamitous, quite apart from the vagueness of the concept "simple." Moreover, from the standpoint of physics there is nothing to warrant the assumption that a theory which is "logically simple" should also be "true."
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> — Found in: *Ideas and Opinions*, "On the generalized theory of gravitation," p. 349.

Einstein debunkers are wont to bemoan their perceived 'fact' that Einstein single-handedly destroyed classical 'understanding' in physics in his preference for 'math theories', but this is completely wrong. Einstein tried as hard as anyone else at that time (early 1900s) to successfully extend the mechanical program to electrodynamics, but they all failed. At some point you have to quit beating a dead horse and just move on.

Let's continue:

> Science did not succeed in carrying out the mechanical program convincingly, and today no physicist believes in the possibility of its fulfillment.
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> — Found in: *The Evolution of Physics*, Einstein & Infeld, pp. 121.

Here again, in what follows, Einstein tells us that physical theories are not logically deduced from empirical data, but rather, are the result of adopting a formal point of view that is used creatively to literally build a theory upon the logical foundation of the research program — in this case, by the adoption of the general principle of relativity as a heuristic constraint. To what end, you ask? Well, Einstein's self-appointed mission was to remove all absolute spaces from theoretical physics. And he claimed that he was successful at that.

> Could we build a relativistic physics valid in all CS [coordinate system/s]; a physics in which there would be no place for absolute, but only for relative motion? This is indeed possible!

> We have at least one indication, though a very weak one, of how to build the new physics. Really relativistic physics must apply to all CS and, therefore, also to the special case of the inertial CS. We already know the laws for this CS. The new general laws valid for all CS must, in the special case of the inertial system, reduce to the old, known laws.
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> The problem of formulating physical laws for every CS was solved by the so-called general relativity theory; the previous theory, applying only to inertial systems, is called the special relativity theory. The two theories cannot, of course, contradict each other, since we must always include the old laws of the special relativity theory in the general laws for an inertial system. But just as the inertial CS was previously the only one for which physical laws were formulated, so now it will form the special limiting case, as all CS moving arbitrarily, relative to each other, are permissible.
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> This is the program for the general theory of relativity....
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> — Found in: *The Evolution of Physics*, Einstein & Infeld, pp. 212–213.

In the Einstein relativity programs, the principle of relativity takes on the roles of (1) an implicit definition of a "general law of physics," and (2) has the practical effect of a programmatic heuristic, and is not really a "theoretical postulate." This is really more a semantic issue. Since Einstein modeled the process of building physical theories as first laying a foundation of a research program (and it may be defined by someone else) and having the program defined by its 'formal point of view'. This being the model, just place all heuristic elements into the formal point of view.

> The heuristic method of the special theory of relativity is characterized by the following principle: only those equations are admissible as an expression of natural laws which do not change their form when the coordinates are changed by means of a Lorentz transformation (covariance of equations with respect to Lorentz transformations).
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> — Found in: *Ideas and Opinions*, Einstein, "The problem of space, ether, and the field in physics," p. 283

If we ask what passes for inspiration for developing a formal point of view, Hans Reichenbach tells us what motivated Einstein, at least in one regard.

> When I, on a certain occasion, asked Professor Einstein how he found his theory of relativity, he answered that he found it because he was so strongly convinced of the harmony of the universe.
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> — Found in: *Albert Einstein Philosopher–Scientist.* Autobiographical Notes: Philosophical Significance of Relativity, by Hans Reichenbach (p. 292).

Similar to *harmony*, Einstein included *unity* that must go into his formal point of view.

> The desire to have, for the foundations of the theory, the greatest possible unity has resulted in several attempts to include the gravitational field and the electromagnetic field in one unified formal picture.
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> — Found in: *Ideas and Opinions*, Einstein, "Physics and Reality," p. 311.

Woops, we may as well also include logical economy in one's formal point of view!

> The scientific way of forming concepts differs from that which we use in our daily life, not basically, but merely in the more precise definition of concepts and conclusions; more painstaking and systematic choice of experimental material; and greater logical economy. By this last we mean the effort to reduce all concepts and correlations to as few as possible logically independent basic concepts and axioms.
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> — Found in: *Ideas and Opinions*, Einstein, "The Fundaments of Theoretical Physics," p. 324.

3 Conclusion

To Einstein, the theoretical physicist endeavors to construct successful theories with a particular goal or goals in mind. These theories must conform to certain consciously recognized, or tacitly held to, soft constraints, what he referred to collectively as a 'formal point of view'.

And if the theorist finds him or herself stuck in the effort, maybe the solution is to take a step back and analyze the research program itself, and, if need be, change it.