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Reconciling Technological Progress with the Kuhnian View of Science

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In the lobby of the Stanford University Chemistry Department's Seeley G. Mudd Building is a wall decorated with portraits of the faculty members, past and present. Underneath these photographs of faces, the younger ones smiling, the elder austere, is a framed poster displaying the following inscription: "Those who have the privilege of working in basic research for the advancement of knowledge have a responsibility to see that this knowledge is used for the benefit of society."

Certainly, these words are meant as a warning to prevent scientific advances from being utilized as destructive forces to humanity. Yet they seem to be furthermore proclaiming a certain role for science, namely that of creating beneficial technologies. In other words, not only should scientists ascertain that their efforts will not potentially harm society, but their research should also meet the criterion of benefiting humanity. These words, spoken by Edward Jefferson, chairman of E.I. DuPont, espouse the view that many people hold of science. Scientific endeavors are often seen as building up a greater and greater understanding of nature—formulating more and more accurate models—in order to be able to better "harness" nature through technological advances. Thus, this image of science relies not only on the idea that understanding is cumulative, but also that technologies are cumulative. The very words technological *advances* indicate that there is some progress being made in how we harness our understanding in serving humanity.

However, science, as seen in a Kuhnian light, is not cumulative; thus, the question arises, can the technologies which have emerged from scientific enterprises be seen as useful if they are not seen as cumulative? How can we claim that technologies are useful and progressive if the basic science upon which they are based is not viewed as progressive? To phrase the problem somewhat differently, if paradigms are indeed incommensurable, then how can we feign to believe that the technologies we now formulate are better than before? Technological advances are most easily, and perhaps most often, explained in terms of a progressive view of science. Progress seems to mean building upon past achievements to lead to more and more useful technologies. Can a view such as that summarized in writing in the Chemistry Department foyer be reconciled with the Kuhnian picture of science?

It seems that in order to justify the claim that the new technologies developed are indeed advances and constitute progress, one must in some way treat separately a basic science paradigm and the technologies which emerge from it. If we do not dismiss technologies that came out of the previous paradigm when we move on to the next one, then, contrary to the view that it is intrinsic to science that technologies be produced, these must be seen as two different ends in themselves. I will approach the question of technological progress from two different points of view. For those who approach Kuhn in a more radical manner, there is no way to surmount the incommensurability of different paradigms and of the technologies which emerge from them in order to claim any sort of advancement. Thus, no account of technology, even if separated from basic science, can allow for the notion of progress. However, the less radical interpretation of Kuhn can in fact allow for progress in technology. In separating the exploration of the world which pure science implies from applications (such as models or tools) which do not necessarily accurately represent the world, but do serve society, we can overcome the problem of denying the cumulation of technologies that seems at first to be a necessary conclusion to the denial of cumulation in science. Thus, I will show that technology, while an enterprise intimately linked to science, can in fact be exempt from the incommensurability of the paradigms from which it emerges if treated separately from basic research.

The holist radical standpoint that "when paradigms change, the world itself changes with them" (*The Structure of Scientific Revolutions* 111, hereafter cited as SSR) cannot truly come to terms with the technology issue as presented. If we claim that we need not dismiss technologies as long as they are useful regardless of which theory they rely upon, we are assuming that there is one reality and we are merely finding the best way to deal with it. But according to the radical interpretation, the world changes with a paradigm change, and if that is so then we cannot truly claim that our new technologies are for the better. Instead they serve this new world in a way that the old technologies could not, and furthermore the new technology might have been less capable than the old in serving the previous world view.

Let us examine the following statement in discussing the holist argument: one can only make an observation of an object if one allows it to interact with an outside influence. Furthermore, every interaction, and hence observation, will create a disturbance in the system being observed. We can never in fact make an observation without in some way influencing that which we are observing; further, the way in which we influence the system is determined by our theories. Seen in this light, the theory-ladenness of our observations is an inescapable consequence. "There is, I think, no theory-independent way to reconstruct phrases like 'really there;' the notion of a match between the ontology of a theory and its "real" counterpart in nature now seems to me illusive in principle" (SSR 206). If we influence the system through one paradigm, certain needs may become apparent, whereas if we influence the system through another normal science tradition, other needs are uncovered. Since we have in effect *created* different needs in different world views, the comparison of the technologies applied to alleviate those needs is like comparing apples and oranges and hence inapplicable to this radical view of paradigm changes. As a consequence, the technologies, just like the paradigms in which they function, remain incommensurable.

This insurmountable incommensurability between technologies in the radical view of paradigm change allows us to consider only the more moderate interpretation of Kuhn in dealing with technological progress. To be able to come to terms with a Kuhnian picture of science and still view science as producing technological advances, I start by dividing progress into two categories. First, there is progress *within* a paradigm—different technologies which emerge from the same paradigm can be justly compared; within a paradigm it is fairly easy to pinpoint technological advances. As Kuhn states, "Normal science, the puzzle-solving activity we have just examined, is a highly cumulative enterprise, eminently successful in its aim, the steady extension of the scope and precision of scientific knowledge" (SSR 52). Technological progress thus fits neatly into the normal science realm; technology advances because the concepts upon which it is based have progressed. In other words, the understanding of nature under a certain paradigm has advanced, and it follows that the technologies which have arisen from this paradigm will have advanced as well.

Yet "it is only during periods of normal science that progress seems both obvious and assured" (SSR 163). The more slippery issue pertains to paradigm changes. At first it might seem that the technology coming out of a new paradigm can only be seen as progress in so far as the victors of the revolution pronounce it as such. "Revolutions close with a total victory for one of the two opposing camps. Will that group ever say that the result of its victory has been something less than progress?" (SSR 166). There is, in other words, an agreement that the tools we are now developing are better than before. This seems like rather shaky ground to base our definition of progress on. However, there is another manner in which to view technologies as progressing, and this is by attenuating the bond between technology and the basic science which engendered it when comparing technologies which have emerged from different paradigms. Hence, this is where it becomes apparent that technology and basic science paradigms must be kept separate. While I am not denying the incommensurability of the paradigms from which technologies spring, technologies can, subsequent to paradigm switches, be held separate from the basic science in order to analyze their worth and utility.

I must stress that in treating technology and basic science as separate entities I am not denying that technology is intricately linked to basic science. Indeed, technologies first come about as a product or application of scientific research. It does, however, become important to deemphasize this linkage when paradigms are switched, and technologies may be uprooted from the concepts which gave birth to them. While it may not always be possible for some technologies to survive a paradigm change, there are enough that do survive to make the consequences on our view of technological progress interesting.

In order to support my claim, I will expand on Kuhn's example of Newtonian and Einsteinian dynamics by presenting my own examples of (1) classical mechanics versus quantum mechanics, and (2) synthetic organic chemistry as compared to physical chemistry in modern research and industrial laboratories.

Kuhn brings up the interesting case of Newtonian physics, which is still utilized today despite the paradigm switch to Einstein's theory of relativity. As he says, "Newtonian dynamics is still used with great success by most engineers and, in selected applications, by many physicists" (SSR 99). Indeed, it is the case that many engineering applications are guided by Newton's laws rather than by reference to those of Einstein. Although it has been argued that the reason for this applicability of Newton's laws to technology is because Newton's laws are derivable from Einstein's laws as a special case, Kuhn replies that they merely superficially appear to be a subset. "The variables and parameters that in the Einsteinian Ei's represented spatial position, time, mass, etc., still occur in the Ni's; and they there still represent Einsteinian space, time, and mass. But the physical referents of these Einsteinian concepts are by no means identical with those of the Newtonian concepts that bear the same name" (SSR 102). Nevertheless, he allows that Newton's laws, while conceptually quite different from Einstein's, are in fact useful in their applications. "Our argument has, of course, explained why Newton's Laws ever seemed to work. In doing so it has justified, say, an automobile driver in acting as though he lived in a Newtonian universe. An argument of the same type is used to justify teaching earth-centered astronomy to surveyors" (SSR 102). In making the claim that a considerable amount of technology in use today is based on Newtonian mechanics, one is not, however, denying that a paradigm change has taken place. To recapitulate, the concepts of mechanics have been fundamentally altered through the paradigm switch; yet many of the technologies which were based on the previous Newtonian paradigm are still useful.

> [The argument that Newton's laws can be derived from Einstein's] has not . . . shown Newton's Laws to be a limiting case of Einstein's. For in the passage to the limit it is not only the forms of the laws that have changed. Simultaneously we have had to alter the fundamental structural elements of which the universe to which they apply is composed. . . . Because of its economy, that restatement [of Newton's theory in Einsteinian terms] would have utility, but it could not suffice for the guidance of research. (SSR 102–103)

Thus, we can postulate that it is not the concepts of Newton's *Principia* which have survived the paradigm change, but rather the technological applications of Newton's ideas.

A similar fate has been allotted to technologies based on the classical mechanics paradigm which are still in use today even though quantum mechanics has emerged as the new paradigm in physics. Many scientists see classical mechanics as a special case of quantum mechanics in the limit that the objects being studied are large. (For example, photons hitting a tennis ball will negligibly disturb the system, whereas they will cause a significant disturbance in bombarding a molecule.) Thus, they view it as a subset just as a square is a special case of a rectangle, in the "limit" that all sides are of equal length. Here, again, Kuhn would argue that the point that classical and quantum mechanics belong to fundamentally different paradigms has been missed. One cannot merely relegate classical mechanics to a corner in the quantum mechanical world in which it acts as a special case under certain conditions; classical mechanics describes, if not a different world, a different way of looking at the world. What one mistakes as a similarity in conceptual understanding is rather a similarity in technological applications. Furthermore, this similarity in technological applications allows technologies born of classical mechanics to survive the paradigm switch to quantum mechanics.

To illustrate this point, let us consider a phenomenon described by quantum theory called tunneling which is not present in classical mechanics. According to classical theory, if an object does not have enough energy to surmount a barrier, then it is unable to do so. In the quantum mechanical description of nature, on the other hand, there is a probability, however slight, that an object may tunnel through the energy barrier even though it does not have enough energy to surmount it; thus, the particle is able to penetrate into classically forbidden regions. This phenomenon highlights fundamentally different theories about the way in which particles behave. Nevertheless, technologies developed during the classical era need not be discarded upon transition to the quantum paradigm; in fact, it would often be quite ludicrous to do so. The purpose of walls and doors is to enclose space and keep certain objects either inside or outside the space. If we decided, upon conversion to the new paradigm that building these things are useless, because there is a probability that an object can tunnel through doors and walls, we would be quite foolish. Thus, while in our quantum world particles can penetrate doors without having enough energy to break through them, the utility of a door, which is based on classical fundamentals, is indisputable. The example of walls and doors is an exaggerated instance, but it brings the point home nicely.

Of course, one might argue that it is far from satisfying to utilize tools that are based on concepts that have been overthrown. A response to this rebuttal is given by the somewhat cynical phrase "All models are wrong. Some are useful." It is this utility, as opposed to an accurate representation of the world, which accounts for why some technologies are discarded, while others are retained, even though the paradigms from which they have sprung have been dismissed. "Or think of utility.... It too has figured significantly in scientific development, but far more strongly and steadily for chemists than for, say mathematicians and physicists" (Kourany 205). Kuhn mentions the importance of utility to chemical development, and I illustrate this point through discussion of two areas of modern chemical science, organic and physical chemistry.

Much of physical chemistry research operates under the paradigm of quantum mechanics. Organic chemistry, in so far as it pertains to the synthesis of useful compounds, was in full swing as a paradigmatic area of research well before quantum theory appeared on the scene. Yet despite the paradigm switch in reaction mechanism, bond formation, and atomic composition, to name a few changes, the technology of drug manufacture is principally the same as before the quantum revolution. To the physical chemist it may seem ludicrous to work on chemical problems without considering quantum effects, but this is more a debate about accurate representations of molecules than about technology. The physical chemist will no doubt agree that organic chemists, in focusing on things other than wavefunctions and probability amplitudes, can concentrate more of their energies on making medicinal agents, soaps, and dyes, to name a few applications. Thus, while the organic chemist accepts the quantum theory (and hence is not working under a competing paradigm), the technologies he or she is concerned with are useful regardless of whether one applies quantum or classical physics. The synthetic approach that is used is a model which is useful, regardless of whether the concepts upon which it was initially based have been supplanted by quantum theory.

To emphasize my point that the organic chemist does not work in a different paradigm from the physical chemist, I note that organic chemistry utilizes many forms of spectroscopy in order to determine molecular structure, such as infrared and nuclear magnetic resonance, which are firmly rooted in quantum theory. Furthermore, not all of organic chemistry is devoted to the synthesis of medicinal agents or household products. Indeed, a number of organic chemists do study hydrocarbon-based molecules under the direct influence of quantum chemistry and use quantum mechanical principles to govern the types of experiments they perform. However, the technologies that come out of synthetic organic chemistry overlap the current quantum paradigm and the previous paradigm of classical mechanics.

Consider as an example the case of synthetic dyes. In the late 1800s organic chemistry was already a flourishing field. In 1856 a young British scientist, Sir William Henry Perkin, studying at the Royal College of Chemistry, accidentally made the first synthetic dye, which he called mauve, when oxidizing the compound aniline with potassium dichromate. He subsequently founded his own company in order to reap the financial benefits of his discovery and hence started the first chemical industry. He devised a method to produce aniline on a large scale, and today aniline is made according to a similar procedure: "Dyestuff manufacture is today a thriving and important part of the chemical industry, and many commonly used pigments are derived from aniline" (McMurry 1001).

Perkin's manufacture of synthetic dyes occurred before the switch to the quantum paradigm. Quantum theory explains chemical reactions, such as Perkin's oxidation of aniline, in fundamentally different terms that have supplanted the previous concepts of the nature of atoms and molecular bonding, yet the technology of dye production has not fundamentally changed. The advances that have been made in this industry to make the production of similar dyes more efficient on a large scale are as a consequence commensurable since the technology has not yet undergone a paradigm change. This is a clear instance of how technologies may survive paradigm changes and thus be seen as progressive.

Having established that technologies can be evaluated separately from the scientific traditions from which they emerged, we can consider the implications this separation has on advancement. It has already been mentioned that it is the utility of a technology to society which renders it applicable despite paradigm changes; it will now be stated that it is also this utility which is subject to analysis in determining whether progress has been made.

In Section XIII of *The Structure of Scientific Revolutions* Kuhn describes general scientific progress as the movement away from primitive beginnings rather than movement toward a specific goal. In the process, more and more theories and problems are accrued (but these do not build upon each other!): "Successive stages in that developmental process are marked by an increase in articulation and specialization" (SSR 172). Technologies are also accrued, but we would like to be able to interpret this build-up as a progression. This returns us to the criterion of utility in determining advances: technologies progress in so far as they enable us to expand the domain in which, and the degree to which, they are useful. In terms of the synthetic dye example, the dye industry has advanced in allowing us to make dyes of better and better quality and of many different colors than previously possible. As we have seen, this advancement can occur across paradigm changes. Consequently, the scientific enterprise, while not cumulative in and of itself, paves the way for advances in technology and as such enables "this knowledge [to be] used for the benefit of society."

Works Cited

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