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# Three Forms of Interpretative Flexibility

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**Abstract**

Interpretative flexibility is a central concept of social constructivism in science and technology studies. We think this concept, as it exists, can and should be elaborated. In this paper, we argue that interpretative flexibility can be traced back to three different forms of infinite regress: the regress of truth, the regress of usefulness, and the regress of relevance. Resulting from this analysis, we observe three different forms of interpretative flexibility. We will show that in controversies or debates concerning the meaning of certain scientific facts, technological artefacts or research approaches, concurrently or consecutively more than one of these different forms of interpretative flexibility may play a part. With this reconceptualisation of interpretative flexibility, we hope to contribute to a more elaborate understanding of the dynamics of the social construction of scientific facts and technological artefacts.

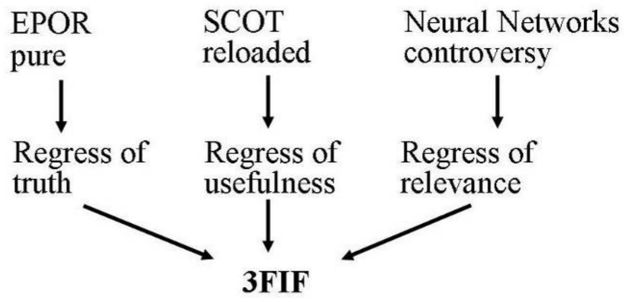
## 1 Introduction

Interpretative flexibility is a central concept of social constructivism in science and technology studies. We think this concept, as it exists, can and should be elaborated. The basic assumption of social constructivism is: The observed phenomenon "X need not have existed, or need not be at all as it is. X, or X as it is at present, is not determined by the nature of things; it is not inevitable" (Hacking 1999: 6). In science and technology studies, this basic assumption is applied to scientific facts and technological artefacts. However, scientists and engineers do refer in a certain way to the "nature of things." They do so by deducing scientific facts from empirical observations or by developing technological artefacts for given purposes. Hence, social constructivist approaches in the study of science and technology rely on an additional assumption: also the empirical observations and the purposes of technology scientists and engineers refer to, allow different interpretations to a certain degree. This is termed "interpretative flexibility." This is not to say that every empirical observation or assumed technological purpose will indeed be interpreted differently. More often than not, as a result of previous processes of social construction, one of the possible interpretations has become widely accepted and will not be questioned by anybody. But where no such consensus has evolved and interpretative flexibility still exists, arguments become circular and lead into an infinite regress. In these cases, the scientific facts are questioned because the underlying empirical observations are subject to interpretative flexibility and the empirical observations are questioned because the related scientific facts are subject to interpretative flexibility. The same holds for the relationship between technological artefacts and the purposes they shall serve.

Our reconceptualisation of interpretative flexibility is based on the observation that this infinite regress is not always of the same kind. To the contrary, we see sufficiently clear-cut differences between three kinds of infinite regress that can be derived from existing social constructivist research in science and technology. We call them the regress of truth, the regress of usefulness and the regress of relevance. Consequently, interpretative flexibility is not always of the same kind, too. In relation to the three different regresses, we will introduce a distinction between three forms of interpretative flexibility (3FiF). Regarding the regress of truth and the interpretative flexibility concerning the truth of scientific findings, we will draw upon the *Empirical Programme of Relativism* (EPOR) by Harry Collins. Trevor Pinch and Wiebe Bijker have applied the notion of interpretative flexibility to the development of technological artefacts. However, in the framework of their *Social Construction of Technology* (SCOT) the concept of interpretative flexibility remains underspecified. In conceiving the underlying regress as a regress of usefulness and interpretative flexibility as concerning the usefulness of technological artefacts, we hope to overcome some of the major problems of this approach. The notion of a regress of relevance and of interpretative flexibility concerning the relevance of evaluation criteria to assess the future potential of scientific or technological approaches has been developed in an analysis of the Neuronal Networks controversy, which one of us has worked on (cf. Meyer 2004).

We will show that the underlying regress affects how interpretative flexibility occurs, how different interpretations are negotiated, and how (if at all) a certain interpretation becomes widely accepted. In each of the three cases, interpretative flexibility constitutes a different situation: either a situation of contested truth or a situation of contested usefulness or a situation of contested relevance. Thus, with our reconceptualisation of interpretative flexibility we hope to contribute to a better understanding of the different meaning of interpretative flexibility within different situations of social construction of scientific facts and technological artefacts.

**Figure 1: Three Forms of Interpretative Flexibility**




In providing a differentiated view on interpretative flexibility, we do not only want to point out differences *between* the social construction of scientific facts and of technological artefacts. Additionally, we assume that this view is useful for analyzing different meanings of interpretative flexibility *within* processes of establishing scientific facts or technological artefacts. This is to say that interpretative flexibility of scientific findings is not only a question of contested truth and interpretative flexibility of technological artefacts is not only a question of contested usefulness. Both can articulate questions of contested relevance. Furthermore, interpretative flexibility of usefulness can influence the social construction of scientific facts and, inversely, controversies about truth can be part of the social construction of technological artefacts. This can already be shown in the "classical" case studies of the EPOR and of the SCOT. We will use the case studies of the gravitational waves controversy and of the development of the bicycle to illustrate our 3FIF concept.

## 2 The Regress of Truth

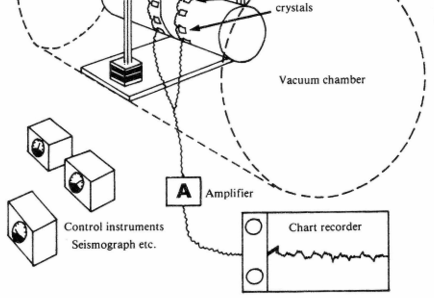
The basic assumption of the *Empirical Programme of Relativism* (EPOR) is that the natural world plays only a small or no role in the construction of scientific knowledge (cf. Collins 1981: 3). The facts upon which scientific statements are based do not possess an inherent meaning. They have to be interpreted to become meaningful. Thus, they can in principal (but not necessarily in the practice of research), be interpreted in different ways. Since Collins' main examples come from the realm of the natural sciences, especially physics, the subjects of possible interpretative flexibility are experiments and the resulting data. However, in most cases, the potential interpretative flexibility of experiments and their results does not occur in research practice, because the established scientific state of the art allows for only one of these interpretations. In such a case, their meaning is undisputable.

Experiments pupils carry out in school provide a simple example: the pupils' task is to produce the proper result but the interpretation is not in question. However, in some cases experimental results cannot be explained with recourse to undisputable knowledge. This is where interpretative flexibility becomes acute. When the results of an experiment and the existing scientific knowledge do not match, this can be explained in two different ways: either the experiment was implemented properly but the actual state of knowledge fails to explain its results; or the experimental design was faulty, thereby producing false results which do not question the actual scientific knowledge. In such a situation it is impossible to decide which one is the right explanation. An experiment is performed competently when it produces proper results. The aforementioned experiments in school illustrate this point: there, the proper results are known because they fit into uncontested scientific knowledge. Thus the teacher has no problem in deciding whether or not a pupil has performed the experiment competently. What is important is that pupils demonstrate their ability to conduct experiments properly by getting the right results. However, when the existing scientific knowledge does not help to decide whether an experimental result is reliable, the attempt to prove scientific claims experimentally leads into an infinite regress: Whether the experiment is implemented in a competent way or not can only be determined by the accuracy of the results. Yet, the decision about the results depends on the experiment and whether it is competently conducted. That is what Collins calls the "experimenter's regress" (Collins 1985: 79).

Scientific results are judged by the criterion of scientific truth. So Collins' experimenter's regress can be described as a *regress of truth*. From the scientist's point of view truth is often seen to mean that a scientific statement corresponds with the reality it describes or from with it draws generalizations. In contrast, from the point of view of the social scientist as observer of science true scientific observations and generalizations are observations and generalizations that are commonly accepted to be true within the respective scientific field – for whatever reason (cf. Bloor 1976). However, the idea of scientific truth implies that contradicting scientific statements cannot be true at the same time. Thus, the occurrence of contradicting scientific claims raises the need to decide between them. For this reason the interpretative flexibility of experiments and experimental results leads to scientific controversies. Solving a scientific controversy means to exclude, over time, all but one of the different interpretations of the initial situation of interpretative flexibility. Since it does not work to refer to experiments as the normal way of scientific decision making in situations of interpretative flexibility and since already established scientific knowledge does not help either, social negotiation is the only way to come to a solution. Collins calls this the process of closure of a scientific controversy. The central actors of this closure processes are the scientists directly involved in the particular research area. Collins calls them the "core set" of the controversy (cf. Collins 1983: 95).

Collins' most elaborate example of a scientific controversy and the underlying interpretative flexibility is the search for gravitational waves. Gravitational wave is the name for a physical phenomenon which could be described as a marginal, short-term shift in the structure of space. This shift is caused by the movement of big masses in the universe and is a theoretical result from Albert Einstein's general theory of relativity. An experimental proof of the existence of gravitational waves would therefore be seen as empirical evidence for Einstein's theory. In 1969 Joseph Weber, Professor at the University of Maryland, claimed that he had detected gravitational waves with a detector he had invented himself.

**Figure 2: Diagram of Weber's Detector (cf. Collins 2004: 53)**



However, there was a significant difference between his interpretation of his experimental results and what, until then, had been inferred theoretically. The amount of gravitational waves he claimed to have detected was too large to fit into the established knowledge about the structure of the universe. In terms of established knowledge this amount of gravitational waves implies a dynamic that would incinerate the universe in a relatively short period of time (cf. Collins/Pinch 1993).

In the following years, groups from different research institutes tried to replicate Weber's experiments. But nobody managed to detect gravitational waves. Weber's critics saw this as proof for errors in Weber's experiment. They concluded that his data was wrong. Weber, on the other side, saw his colleagues' failure to detect gravitational waves as a proof that they did not manage to build a working detector with the same sensitivity as his own.

Several research groups published their results, but their articles simply pointed out that they could not detect anything. They did not conclude that Weber must have been wrong; at least they did not assert this explicitly. As more and more groups failed to detect waves, the climate gradually changed and the scepticism regarding Weber' findings increased. Collins argues that the crucial change in the scientific community's opinion was caused by an article, which lacked new scientific findings. This article was special not because of what it said, but how it was said. The rhetoric was very different to all the articles previously published on this subject. The author directly attacked Weber and his research, claiming Weber to be absolutely wrong. Later, an assistant to Garwin, the author of this article, explained, what had happened: "At that point it was not doing physics any longer. [..] We just wanted to see if it was possible to stop it immediately without having it drag on for twenty years" (Collins/Pinch 1993: 134).

Collins regards this as the central element in the social closure of the interpretative flexibility in Weber's research. At last, in 1975, the scientific community, the core set, agreed that Weber was wrong and his experiments had been incorrect. The controversy had been closed.

## 3 The Regress of Usefulness

Assuming basic similarities between the social construction of scientific facts and the social construction of technological artefacts, Trevor Pinch and Wiebe Bijker have applied the main concepts of the EPOR to the social study of technology (cf. Pinch/Bijker 1984; Pinch/Bijker 1987). In their programme of *Social Construction of Technology* (SCOT), interpretative flexibility denotes that fundamentally different meanings can be attached to the same technological artefact (cf. Pinch 1996: 24). Persons, who share the same interpretation of a certain technological artefact and thereby influence the development of this artefact, are referred to by Pinch and Bijker as a *relevant social group*. In SCOT, these relevant social groups taken together are equivalent to the scientists within the core set of a scientific controversy in EPOR. They build the constellation of actors within which the social negotiation and reduction of interpretative flexibility takes place.

Additionally, SCOT adopts from EPOR the assumption that interpretative flexibility does not persist. "What one observes is that closure and stabilisation occur in such a way that some artefacts appear to have fewer problems and become increasingly the dominant form of the technology. This, it should be noted, may not lead to all rivals vanishing, and often two very different technologies may exist side by side (for example, jet planes and propeller planes)." (Pinch 1996: 25) In

Pinch and Bijker's opinion, the processes of closure have the same structure as in scientific controversies: The proponents of the different interpretations seek to establish their own to be the most convincing view. Some attempts to influence other relevant socials group's interpretations are more successful than others. In this process a certain interpretation becomes accepted by more and more relevant social groups and eventually leads to a certain technological artefact becoming seen as the appropriate solution to a certain problem by most of them. What gravitational waves are to Collins, bicycles are to Pinch and Bijker. They use the history of bicycle development to illustrate their concept: "The high-wheeler had the meaning of the 'macho machine' for young men of means and nerve, but for older people and women it had the radically different meaning of the 'unsafe machine'. Such interpretative flexibility may apply not only to a compound artefact but also to some components of it. For example, when the air-tyre was first introduced, it was for some groups an object of derision, aesthetically unappealing, and a source of endless trouble (punctures). On the other hand, for Dunlop it was the perfect solution to the problem posed by the vibrations of the bicycle." (Pinch 1996: 24-25) In this case, the closure of the debate results from redefining the problem: The high-wheeler literally lost the race, when the air tyres, which were originally developed to make bikes safer, proved to be a crucial factor to high speed in races. Even users of the macho machine preferred safe riding and winning over risky riding and losing.

We feel that the SCOT programme is less convincing than it could be. Its central concepts – interpretative flexibility, relevant social groups and closure – are defined less precisely than the corresponding concepts of the EPOR because they do not reflect phenomena that are specific to the process of technology development. The observation that certain objects or artefacts may have different meanings for different people and that this may lead to disputes about who is right and who is wrong holds for any object or artefact without an already established meaning and is in no way specific to technological artefacts. Defining interpretative flexibility by pointing at the different meanings a technological artefact from the point of view different social groups may have is nothing more than to define interpretative flexibility by referring to interpretative flexibility.

We need a narrower and more specific concept of interpretative flexibility of technological artefacts, one which takes into consideration the particular features of technology. In scientific controversies, the regress of truth is accountable for the specific form of interpretative flexibility of scientific claims. Thus, we have to look for a regress, which in a similar way, is accountable for a specific form of interpretative flexibility of technological artefacts. In our opinion, such a regress indeed exists. We call it the *regress of usefulness*. We reach to this conclusion by referring to the basic characteristic that distinguishes technological artefacts from scientific findings on the one side, and from other cultural artefacts on the other side: The specific technological quality of technological artefacts is that they are meant to produce desired effects sufficiently, reliably, and in a repeatable way, effects which would not be possible or would require more effort without the artefacts (cf. Schulz-Schaeffer 1999: 410). From this, it follows that the criterion for judging technological artefacts is their usefulness for a certain purpose, as truth is the criterion for scientific facts.

Consequently, interpretative flexibility of technological artefacts as far as their specific technological quality is concerned is interpretative flexibility with regard to usefulness. It occurs when there are different possible answers to the question whether a technological artefact with its particular functional features will be useful and how, for whom and, in which context this will or will not be the case. Thus, the reason for interpretative flexibility of technological artefacts to occur is that depending on the respective purposes of different groups of users and depending on the diverse requirements of different contexts of use these questions of usefulness can be answered differently. Interpretative flexibility of this kind also has its roots in an infinite regress: Whether a certain technological artefact possesses useful functional features will become clear only after it has found its users and has been implemented successfully in certain contexts of use. Yet, the decisions regarding the design of the technological artefact and its particular functional features have to be made before it can be used. This is what we the regress of usefulness.

Conceiving interpretative flexibility of technological artefacts as related to usefulness allows us see a similarity and a difference to the interpretive flexibility of scientific facts. As well as in scientific research there are cases of technology development where interpretative flexibility does not play a major part but is limited right from the start. In many cases it is already well known who the users of the artefact in development will be, how and for which purposes they will use it and what the contexts of use will be. Especially, this is the case when the new technological artefact is supposed to become the successor of an already exiting artefact or when the development process aims at enhancing an existing artefact. This is similar to the normal way of scientific research where the already accepted and (for the time being) undisputed scientific knowledge limits the range within which the data can be interpreted differently.

However, when interpretative flexibility becomes relevant, a major difference between scientific research and technology development has to be taken into account, a difference the SCOT lacks to notice: Interpretative flexibility of experiments and experimental results inevitably causes scientific controversies as long as the proponents of the different interpretations agree that contradicting scientific claims cannot be true at the same time. In contrast, for technological artefacts such a basic necessity to discuss divergent interpretations controversially does not exist. In principle, there is no reason why users should agree on what purposes a technological artefact shall serve and no reason why alternative technological solutions serving the same purpose should not be developed. Thus, while interpretative flexibility of truth necessarily evokes controversies, interpretative flexibility of usefulness does not. And while scientific controversies are aimed at closing the debate sooner or later, closure is not a necessary feature of debates concerning different meanings of technological artefacts. Sometimes, however, technological controversies occur that seem to be similar to their scientific counterparts. As we will see later (part 5.1, (3)), this is because the underlying interpretative flexibility, then, is related to truth and not to usefulness.

## 4 The Regress of Relevance

A third form of interpretative flexibility appears in debates about different future directions of scientific research or of technological development. Interpretative flexibility here means that because no undisputed point of view exists, it is possible to take up different positions regarding the question of which research approach or project of technology development is promising and which one will lead to a dead end. Under the condition of limited resources, i.e. under the condition that not each of the possible approaches of research or development can be adopted, questions of this kind lead into controversies which need to be closed. However, under this condition the attempt to answer these questions leads to an infinite regress as well. As a one best way solution, the most promising alternative research or development approaches should get the most resources. But which criterion allows one to judge, which of the research approaches or development projects competing for funding will deliver fruitful results and thus deeming them promising than others?

Since these future events are unknown the interested parties will try to predict them based on contemporary available research and testing results. Sometimes there is little doubt among the actors involved in which direction of future progress the existing state of the art points. But sometimes the contemporary scientific or technological knowledge turns out to be ambiguous in this respect. This is the case when the scientific or technological knowledge available relies on scientific methods or technological tests, which had been developed to specifically evaluate progress in one of the approaches under investigation. Then, it is most likely that the respective methods or tests will show better results for the approach it was originally designed for. –Lines of technological development are usually connected to corresponding modes of testing. And each mode of testing focuses on criteria, which are essential for exactly the line of development, it is supposed to evaluate. As a consequence, certain technologies and the corresponding tests are mutually reinforcing (Constant 1980: 22). The same mechanism can be shown for different scientific approaches and the corresponding experimental methods.

So, for deciding, which of the different approaches is more promising, proponents of a certain approach use tests and the corresponding evaluation criteria, which are consistent with their favoured approach. And of course, each side – by using their own evaluation criteria – will find prove, that the approach, they are advocating is the most promising one. At the same time, each side will question the relevance of the evaluation criteria of the competing approaches for predicting future success. The only possibility way to find out, which of the different criteria are the relevant criteria to predict future success, would be to compare the results of each endeavour. But the reason for identifying the more promising approach is due to resource scarcity, in which only one or a few of them can be funded. Consequently, the attempt to identify promising approaches of future work in science and technology also leads into an infinite regress, which we call the *regress of relevance*. Here, the relevance of available test or research results with respect to the question, whether or not a scientific or technological approach is promising, is subject to interpretative flexibility.

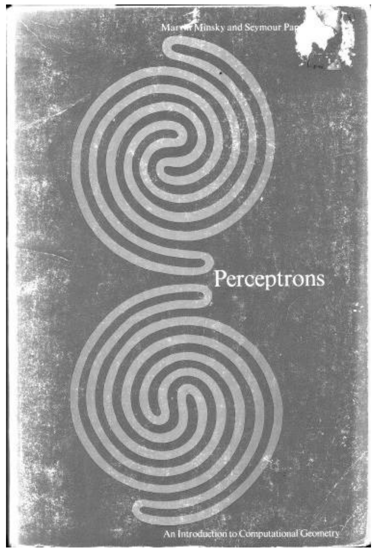
The research on Neural Networks in the 1960's provides an example for a controversy based on interpretative flexibility of relevance. Neural Networks were seen as a way to create intelligent machines by imitating the human brain activities. Researchers who followed this approach tried to build computational structures similar to the basic physiological structure of the brain. In contrast, Symbolic Artificial Intelligence (AI), being the main competing approach at the time, tried to identify the rules humans use when they are thinking. They expected to be able to create intelligent machines by programming knowledge, rules and reasoning procedures. Scientists of the Symbolic AI approach claimed that it would never be possible to create intelligent machines based on Neural Networks. Marvin Minsky and Seymour Papert, the most prominent advocates of Symbolic AI, presented mathematical proofs to support this claim. No scientific controversy took place. The proponents of the Neural Network approach did not contest the truth of Minsky and Papert's proofs. But they questioned the relevance of these results for the question, which of the two different approaches is more promising (cf. Meyer 2004: 75-79). The potential of a future direction of scientific research or technological development is contested by challenging that the scientific facts or technological achievements the proponents or opponents use to support their view are relevant concerning this matter. Contesting the potential of a future path of scientific research or technological development, thus, does not necessarily mean to challenge the truth or the usefulness of the scientific facts or technological achievements used as arguments.

In order to show the structure of a controversy concerning relevance, we shall look more closely at one set of arguments both sides used in the discussion about Neural Networks. In 1969, Minsky and Papert published a book, entitled “Perceptrons”, where they laid down their arguments against the Neural Networks approach (cf. Minsky/Papert 1969). The cover of the book showed two figures, which look nearly identical. One of them consists of one single line and the other one consists of two lines. In their book, the authors presented a mathematical proof saying that Neural Networks would never be able to find out, which one is which.

In addition, they offered a very simple algorithm from the research on Symbolic AI to solve this problem.

Rosenblatt, one of the most prominent proponents of the Neural Networks approach agreed with their interpretation. But he also pointed out, that in his perspective, these results where completely irrelevant for analysing the potential of future research on Neural Networks. His argument was very simple: Neural Networks are supposed to imitate human thinking and recognition. Even with these very simple figures, humans are hardly able to distinguish, which of the two is connected and which is not. If humans are not able to do this, machines which are supposed to imitate humans do not have to be able to do it either (cf. Meyer 2004: 77-78). So the evaluation criteria for the two different approaches varied, depending on which of the two approaches was preferred. Proponents of Neural Networks used evaluation criteria which where consistent with their sub symbolic concept of Artificial Intelligence, proponents of Symbolic AI used criteria, which complied with there concept of rule-based Artificial Intelligence.

**Figure 3: Cover of “Perceptrons” (cf. Minsky/Papert 1969)**




But in spite of Rosenblatt’s criticism on their evaluation criteria, Minsky and Papert successfully established their view concerning the relevance of these facts until the end of the 1960’s. They managed to convince the main funding organisations that supporting the Symbolic AI approach would be much more promising than funding research on Neural Networks. They skilfully used their personal contacts within these funding organisations. They also focused their critique of the Neural Networks approach on problems which could be easily solved by means of Symbolic AI. The problem of connectedness was one of them. In the end of the 1950’s a few hundred groups did research on Neural Networks. Ten years later, this number was reduced to just a few projects. These projects had to ‘hide’ in other research areas, because at this time it was not possible to get direct funding of research on Neural Networks. The controversy was closed.

## 5 The Empirical Relevance of Distinguishing between Three Forms of Interpretative Flexibility

The case of Neural Networks reveals that controversies in science can be based on interpretative flexibility of relevance instead of interpretative flexibility of truth. We will show in the following sections that interpretative flexibility of usefulness can also play an important part in interpreting science. In addition to that, we will also show that all three forms of interpretive flexibility can account for different meanings of technological artefacts. Interpretation processes that started as controversies about the truth of facts can be ended as decisions concerning questions of usefulness or relevance, and vice versa. The proposed distinction between three forms of interpretative flexibility allows for a more detailed analysis of these mixtures and transformations. As we hope to have shown in the previous sections, with each of the three forms, different ways to handle interpretative flexibility are connected. Therefore, it is important to distinguish between them for analysing the social construction of scientific facts and technological artefacts, especially in cases where more than one form of interpretative flexibility occurs.

In the following section, we will elaborate on the thesis that interpretation of scientific facts or technological artefacts may contain different forms of interpretative flexibility at the same time or one after another. First we will present three general observations. After that we will use the classical examples of SCOT and EPOR to show, how our concept allows a more detailed analysis of the processes, which led to the closure of these controversies.

### 5.1 Three General Observations

(1) The concept of paradigm shift, i.e. the replacement of an established paradigm by a new, but not yet very elaborate one, was presented by Thomas S. Kuhn (1962) for the scientific realm and adapted by Giovanni Dosi (1982) for technology. On a very high level of abstraction, these concepts describe a shift from reference to truth or usefulness to reference to relevance. If disputes in science between an established and a new and still evolving paradigm would be controversies related to truth and if the corresponding disputes in technology would refer to usefulness, the established paradigm would always win. If a new paradigm prevails against an old one, it is because of the future scientific or technological innovations it is expected to bring about. A new paradigm cannot prove the truth of its scientific assumptions or the usefulness of its envisioned technological solutions as good as an established paradigm can. This is something that will or will not be demonstrated by “normal science” and “normal technology development” within the frame of reference of this paradigm, work that in contrast to the competing established paradigm still lies ahead. A new paradigm is attractive because it seems to be more promising for solving scientific or technological problems in the future.

(2) Controversies concerning truth can be transformed into questions of usefulness. This can be observed when closure in a scientific controversy is not to be expected in the near future or when a controversy is regarded to be unsolvable. The question whether it is possible to perceive reality in itself or whether every perception of reality depends on the observer’s point of view is an example of a scientific problem many scientists assume to be unsolvable. Thus, in giving reasons for assuming a more epistemologically realistic or constructivist position, scientists tend to shift from truth-related arguments to arguments of usefulness.

This is how Hartmut Esser and Niklas Luhmann support their different point of view. Both agree that the basic epistemological problem is unsolvable (cf. Esser 1993: 53; Luhmann 1990: 531). However, both explicitly argue their position to be the more useful one. Esser's reason for a more realistic position is that epistemological realism is the simpler hypothesis (cf. Esser 1993: 54, 56). According to Luhmann scientific theories, on the contrary, should allow for a high resolution of the observed phenomena (cf. Luhmann 1990: 510). Accordingly, he sees the constructivist position as more useful since it provides a reflexive theory adequate for the complexity of the modern society (cf. Luhmann 1990: 531).

Thus, in transforming scientific controversies into different interpretations concerning the usefulness of scientific positions it becomes a question of purpose and context which position is more adequate.

(3) On the other side, differences in the interpretation of the usefulness of technological artefacts can be transformed into scientific controversies. This can be achieved by transforming the subject of interpretative flexibility – for example the question whether a particular functional feature of a technological artefact is useful within a certain context of use – into a subject of empirical scientific research. Donald MacKenzie (1989: 411) calls this "producing facts about artifacts". The process, which does the magic, is called testing. Testing technology means checking hypotheses about the usefulness of certain properties of an artifact in a scientifically controlled, empirical way (Constant 1980: 21). It transforms differences in the interpretation of usefulness into technological controversies. Technological controversies are controversies about the truth (!) of hypotheses about usefulness. Or to say it in MacKenzie's word again: "all the issues that recent sociology of science has raised about *experiment* in science can be raised about *testing* in technology" (MacKenzie 1989: 411). MacKenzie puts emphasis on the fact, that there is a tester's regress which is analogous to the Collins' experimenter's regress (cf. MacKenzie 1989: 424). He is right because the tester's regress as well as the experimenter's regress is a regress of truth.

### 5.2 Interpretative Flexibility of Relevance and the Controversy of Gravitational Waves

In the 1980's, the gravitational waves controversy was reopened, turning into a controversy related to relevance. In 1982, about seven years after the closure of the controversy described above, Weber published new results. He claimed to have found the explanation as to why his measuring apparatus had been able to detect gravitational waves. Following his argument, he had not detected the huge amount of gravitational waves, which he thought he had and which did not correspond with the scientific consensus. Instead, his apparatus was vastly more sensitive than previously assumed.

**Figure 4: A Weber Bar (cf. Collins 2004)**

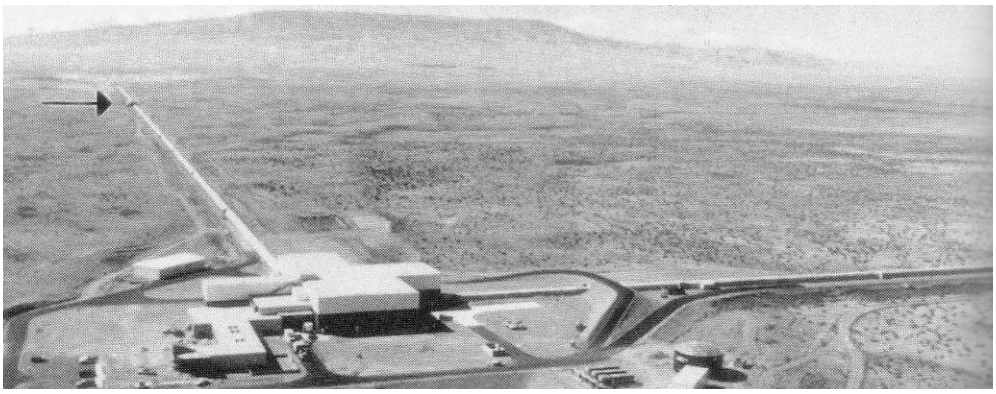
Based on his new theory, Weber calculated the sensitivity of his sensor to be one million to one billion times higher than he had thought. As a consequence, the detected gravitational waves intensity would be a million to a billion times smaller than calculated. This would mean no conflict exists between the data and the established theories regarding the structure of the universe. Weber explained his new estimation of the sensitivity of his with a specific characteristic of the metal bars he uses as detectors He argued that in order to properly describe how the metal bars inner structure responds to gravitational waves, quantum theory must be applied. The quantum-theoretical effects, which Weber assumed to be active in his bars, caused the higher sensitivity to gravitational waves.

Weber published this line of argument at first in 1982 in the journal *Physical Review*. This paper was ignored by the scientific community. After the closure to the controversy in the mid-1970's, this was the usual reaction to Weber's publications. The controversy was closed, further discussion was not necessary. The scientific community's exclusion mechanisms worked well (cf. Collins 2004: 364-366). However, after he had published in 1989 another article on the same topic his line of argument became massively criticized by established researchers in the field. Although this article was published in a smaller journal (*Il Nuovo Cimento*) and contained no new arguments, the scientists reacted to this article. What had happened?

Research Institutes at MIT had developed a new technology for detecting gravitational waves. Based on lasers, this technology was expected to be much more sensitive than the metal bars.

The newly contrived detector consists of two laser measurement sections, which where positioned orthogonally to each other. With the help of the lasers, the exact length of the section is measured at every given moment. If a gravitational wave hits this detector, the lengths of the detector's two "arms" change. This change is different in each of the detector's "arms," depending on the angle in which the gravitational waves hit the detector. This change in the relation of the length can be measured and serves as a proof of gravitational waves. Around the world, a few of these detectors where planned. The biggest two, the Laser Interferometer Gravitational Observatories (LIGO), were planned for construction in the USA. For each of the arms, the laser measurement section measures a length of 4 km.

**Figure 5: LIGO (cf. Collins 2004)**



The costs for building these facilities were an estimated 300 million dollars. The US government was expected to fund this project. At this time, when the negotiations over LIGO funding were taking place, Weber renewed his claims about being able to detect gravitational waves using a much cheaper and more sensitive apparatus than LIGO. In addition to the article from 1989, Weber wrote numerous letters to the decision makers of the funding of LIGO. In these letters he accused the LIGO-Project to be an enormous waste of tax money compared to his own measuring apparatus. (cf. Collins 2004: 360-361). By doing this, he tried to involve actors into the debate which were not part of the core set of the scientific controversy regarding gravity waves. Thus, Weber transformed the controversy about scientific truth which he had already lost into a controversy about the relevance of alternative research directions of detecting gravity waves. This explains the harsh reaction to his paper from 1989. His new arguments and the opponents' responses did not revive the scientific controversy. This controversy remained closed. Weber's findings were not treated as worthy to be discussed scientifically. Weber argued, that, based on his evaluation criteria, his approach was more suitable to measure gravitational waves – because of the quantum-effects within his bars – and much cheaper than laser-based experiments. His opponents did not agree on his criteria. For them, his argument based on quantum theory was pure nonsense. From their point of view Weber's bars where not able to measure gravitational waves at all and – as a consequence – his cost-argument was insignificant.

So, the goal of Weber's opponents was to show the decision makers of the funding organisations that Weber and his work should not be seen as belonging to the core of research on gravity waves, that is view was not shared by anybody within the scientific community and, thus, that his objections concerning the relevance of their new research approach should not be taken seriously.

### 5.3 Interpretative Flexibility of Truth and the Development of the Bicycle

The reconstruction of the bicycle development, as Pinch and Bijker provide it, includes an episode where interpretative flexibility of usefulness becomes transformed into truth-related hypotheses about usefulness. According to Pinch and Bijker, the safety bicycle's victory over the high-wheeler was a victory captured in bicycles races. The success of the safety bicycles in these races were seen as a proof that their air tyres have a better performance with respect to the purpose of riding as fast as possible than the solid tyres of the high-wheeler. Thus, these bicycle races provided a situation of testing the functional feature "air tyre" against alternative solutions to the speed problem. Admittedly, it is not a very scientific sort of testing, but it is testing. According to the reconstruction by Pinch and Bijker, these races resulted in the safety bicycle being superior became widely accepted as true. Scientific controversies occur because of interpretative flexibility of experimental results. In the same way, these testing results could have become the subject of a technological controversy. In both cases the underlying problem is or would be the regress of truth. There would have been plenty of opportunities for the advocates of the high-wheeler to question the validity of the bicycle races as tests. An overview over possible reasons for challenging the results of tests is given by MacKenzie (1989: 413-414). Critics could have argued "that existing cycle races were not appropriate tests for a cycle's 'real' speed (after all, the idealized world of the race track may not match everyday road conditions, any more than the Formula-1 racing car bears on the performance requirements of the average family sedan)" (Pinch/Bijker 1987: 46). They could have argued that it is not the average speed of the race, but the maximum speed which is important or that the race proves the superiority of the air tyres, but does not reflect the superiority of the low-wheeler and so on. Arguments of this kind illustrate that technological controversies are about truth-related issues. McKenzie's analysis of the technological controversy about the accuracy of intercontinental missiles shows this very clearly. According to Pinch and Bijker, the proponents of the high-wheeler forwent the option to start a technological controversy. They simply accepted the test results. The bicycle races transformed a situation of contested usefulness into a situation in which it would be now a question of truth to challenge the claimed superiority of the air tyres. Since nobody started a technological controversy about this issue, the transformation immediately led to a closure of the debate.

### 5.4 Interpretative Flexibility of Usefulness and the Controversy of Neural Networks

The case of Neural Networks serves as an example of a controversy about relevance that revived but took a new direction after questions of usefulness were included. Especially in the 1980's, the discussion about the usefulness of certain methods became crucial for the outcome of the renewed debate. A distinguishing feature of this controversy is that after the debate was closed in the late 1960's, it was reopened at the beginning of the 1980's. Many of the same actors used mostly the same arguments to debate whether Neural Networks or Symbolic AI is the more promising approach. But this time, the result was completely different. The research on Neural Networks, which was announced to be of no avail in the late 1960s, experienced a furious revival. By the end of the 1980's, it became an established and well funded part of the research on artificial intelligence. This is due to more than one reason (cf. Meyer 2004: 97-107). However, one central aspect was that the controversy was enlarged by the question of the usefulness of specific products resulting from the research on Neural Networks compared to research on Symbolic AI.

As indicated above, though having lost the controversy of the 1960's, some Neural Networks research groups were able to survive by "hiding" in other scientific disciplines like biology and physics. Due to the work they conducted there, these groups presented first applications for Neural Networks in the 1980's. In 1987, it was a sensation, when a computer program was presented, completely based on Neural Networks that was able to transform written text in spoken language. Based on successes like this, proponents of Neural Networks tried to shift the focus of the controversy. Instead of a theoretical discussion about the long-term prospects of Neural Networks research, like in the 1960's, they promoted a debate concerning the usefulness of certain existing solutions to problems. Of course, they focused on topics which proved problematic for Symbolic AI, e.g. pattern recognition. As a response to this attempt to reopen the controversy, Minsky and Papert republished their book "Perceptrons." (cf. Minsky/Papert 1988) Because it worked so well then, they just added a new introduction, extended the final chapter, and left the rest of the book as it was. They wanted to show that their mathematical proofs still support their assessment of the nearly non-existing potential of Neural Networks. Thus, Minsky and Papert tried to force the revived controversy into the direction that in the 1960's had proven to be successful in promoting their research approach They argued that all solutions presented by Neural Networks research still rely on overly simplified models which are also subject to the restrictions they claimed to have demonstrated in their book. Applied to the complexity of the real world, they would fail to keep up with the promises of their creators. Because Neural Network research was located in research areas different from computer science and due to the availability of first applications that demonstrated their usefulness, these theoretical arguments could not develop the power they had 20 years before. Minsky and Papert lost the debate concerning the usefulness of the Neural Networks approach because they focused their argumentation on the level of theoretical long term evaluation. Their opponents, on the other side, connected concrete problems with concrete solutions. In doing so, they where able to establish their perspective of the usefulness of Neural Networks. Consequently, research on Neural Networks became an attractive research option for scientists in the field of Artificial Intelligence as well as for funding organisations.

## 6 Conclusion

The concept of three forms of interpretative flexibility (3FiF) as presented here relies on two strands of argumentation. First, by tracing back interpretative flexibility to three different forms of infinite regress, we focus on differences between phenomena related to interpretative flexibility. Second, we wanted to show that in controversies or debates concerning the meaning of a certain scientific fact, technological artefact or research approach, concurrently or consecutively different forms of interpretative flexibility may play a part. Combining and extending previous considerations regarding interpretative flexibility in this way serves two objectives: we hope that in identifying differences in interpretative flexibility and corresponding differences in handling interpretative flexibility, we will contribute to a better theoretical understanding of the dynamics of the social construction of scientific facts and technological artefacts Additionally, we are confident that our approach is useful for empirically analysing the course of development of scientific or technological controversies in a more appropriate way. Shifts between and transformations of the respective reason of interpretative flexibility (contested truth, contested usefulness, contested relevance) become observable as well as situations of their coexistence. This helps to explain why closure in debates about the meaning of technological artefacts occur although there is no inherent need to come to an agreement; why on the other hand scientific controversies remain open although, here, an imperative to closure exists; how scientific controversies become closed for other than truth-related reasons; or why, as in the case of Neural Networks, an already closed controversy becomes reopened again.

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