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The Mathematical State of the World – Explorations into the Characteristics of Mathematical Descriptions

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Resumo: Neste artigo tentamos analisar as condições para descrever matematicamente o mundo, considerando o papel desempenhado pelos matemáticos ao discutir e analisar 'o estado do mundo'. Nós usamos essa discussão para esclarecer o que significa usar uma descrição matemática e ilustramos porque os conceitos 'descrição matemática' e 'modelo matemático' são inadequados para avaliar o uso da matemática no processo de tomada de decisão. Como resultado desenvolvemos um quadro conceitual que é suficientemente complexo para corresponder ao que ocorre nos cenários envolvendo aplicações da matemática.

Abstract: In this article we try to analyse the conditions for describing the world mathematically. We consider the role played by mathematics in discussing and analysing 'the state of the world'. We use this discussion to clarify what it means to use a mathematical description. We illustrate why the concepts of 'mathematical description' and 'mathematical model' are inadequate to evaluate the use of mathematics in decision-making processes. As a result we develop a conceptual framework that is complex enough to match what goes on in scenarios involving applications of mathematics.

Palavras-chave: matemática, aplicações da matemática, modelagem matemática, tomada de decisão
Key words: Mathematics, application of mathematics, mathematical modelling, decision making

Introduction

Mathematics is a powerful tool. It influences our political decision-making in both process and outcome. A mathematical description of a given situation could, for instance, help us decide whether we should build more kindergartens, whether we should build a bridge in the cheaper way or the more expensive way, how many elderly people per hour an aged care worker should be expected to assist to take a shower, and so on. Therefore, the quality of the mathematical description that is involved in decision making becomes important.

But how do we define "quality" in relation to a mathematical description? One could argue that a good mathematical description is one that is based on a theoretically correct analysis of numerical data, that is, the quality depends on the mathematical treatment of numbers being rigorous, consistent and accurate. Many decisions of political interest and significance are motivated, however, by more than simple mathematical relations between data; for example many economic decisions refer to complex economic models, and environmental policies are founded on models that incorporate interpretations of what an ecological balance of the environment could mean.

This leaves us with the question of whether the concept of quality, such as what we have alluded to above, in relation to mathematically based decision making in today's political environment is an adequate one. It is a very common belief that the application of mathematical descriptions in decision making is pretty much a straight forward matter because mathematics by way of its nature deals with the essential structures of the worlds phenomena. When debating the quality of a mathematically based decision, only questions concerning the rigour of the mathematical description and analysis appear to be open to serious discussions.

But the problem of quality regarding mathematical models and descriptions may need to be considered in other lines of reasoning all together. We could even imagine that there could exist phenomena which a mathematical description would never be able to account for, even when it is elaborated in the most detailed way and complies with all possible demands of mathematical exactitude. For example, environmental issues can generate a wide range of reactions from groups and individuals of different political inclinations. Some of their responses are expressed in technical and scientific terms; some in purely economic terms; still others in socio-cultural terms. If political decisions privilege mathematically rigorous arguments, then those arguments which are not “mathematisable” because of their nature necessarily get dismissed. For example, there may be a sacred site for an indigenous population that is known also to be rich in minerals. It may well be possible to analyse the economic costs and benefits of mining that site through a detailed mathematical description; however, it is both inappropriate and impossible to “mathematise” the cultural significance of the site.

Therefore, one could think of the problem of the quality of a mathematical description in the following way: on the one hand, one could imagine that a mathematical description of some aspect of the real world could depict essential elements of what is being described, and that mathematics in this way could provide a deep insight in the basic structures of a situation which otherwise would not have been identified. In this way mathematics could help to provide a basis for decision making. On the other hand, one could imagine that a mathematical description would be limited and impose a particular perspective on what one is seeing. Thus, a mathematical description turns into a prefabricated construct of what one is seeing. The consequence could be that mathematics-based decisions reflect, not just a particular type of deep insight, but also a certain rationality which is expressed by the mathematical formalism.

In this article we try and analyse the foundation for describing the world mathematically. We set up the task to clarify what it means to describe with mathematics; we aim to illustrate why the concept of a ‘mathematical description’ or ‘mathematical model’ is inadequate to evaluate what goes on in the application of mathematics in decision making processes; and finally we seek to develop a conceptual framework for the application of mathematics that is complex enough to match what goes on in general application scenarios involving mathematics.

1. Primary and secondary sense qualities

During the Renaissance the idea that the phenomena of the world have two distinctly different types of qualities was emphasised. Thus, Galileo Galilei differentiated between primary and secondary sense qualities. We experience the secondary qualities as taste, colour, sound, etc. These qualities depend on the person who perceives the object: the way one tastes some food refers to personal *experiences* of a given thing. To another person these experiences could be rather different. In fact, it can be difficult to define in what way one can even compare experiences of secondary qualities. The implication is that one should be sceptical of any insights about the natural world that is founded on the secondary qualities because there can be no agreed reference points. The primary qualities, on the other hand, refer to properties that can be measured. These qualities include weight, height, volume, position, movement, speed etc. Now the insight of Galileo and many other scientists in early modern science was that the primary qualities were objective qualities – they could be measured and everybody would agree about the measured results. The primary qualities of objects represent the "objective" properties of the world. In contrast to this the secondary are subjective qualities that depend on the perceiving subject.

In many cases the primary qualities, observable through mathematics, are, apart from being "objective" also "hidden" qualities that are unobservable within an everyday personal experience. For instance, it would be impossible for us to argue how many people smoke or how dangerous smoking really is from just wandering around in our everyday environment and not paying attention to the primary qualities of things. Many issues can only be resolved through a mathematical treatment that expresses results in numbers. With the realisation of the primary qualities of things Modern Science discovered a realm of *hidden truths* about the world that could be described without reference to subjective experiences. The secondary qualities of things, on the other hand, were elusive and hard to pin down in a way that could reveal objective, incontestable truths.

This division between primary and secondary qualities therefore carved out a clear territory for science to explore, namely the primary qualities of things. The primary qualities could be measured and thereby expressed through mathematics. This means that mathematics was afforded a particular role in the formulation of insights about the natural world. In Galileo's view, mathematics played a particular role in this formulation. Mathematics became the language of modern science. Mathematical descriptions of the world were in themselves valuable because they dug out yet undiscovered truths about the world that we could not perceive through our everyday experiences. He says:

"Philosophy is written in this grand book, the universe, which stands continually open to our gaze, but the book cannot be understood unless one first learns to comprehend the language and read the letters in which it is composed. It is written in the language of mathematics, and its characters are triangles, circles, and other geometric figures without which it is humanly impossible to understand a single word of it; without these, one wanders about in a dark labyrinth." (GALILEO cited in CROSBY. 1997, p.240).

The related idea that mathematics was a joint language of all sciences has especially been pursued since the end of the 19th century. Gottfried W. Leibniz, however, at an early stage mentions that science should strive for formulating its knowledge through a unified language of logic. Eventually such a language was developed by Gottlob Frege and Bertrand Russell who tried to show that mathematics is exactly this unified language of logic that could be used by all sciences to describe the primary qualities of things. This idea was celebrated and further developed by logical positivism, not least through the work of Rudolf Carnap, who paid much attention to the nature of the mathematical language through which scientific insight should be formulated.

Modern Science has been extremely successful. A strong component of this success is the move away from natural philosophy trying to express the essential qualities of nature by ways of qualitative studies to focusing on the measurable mathematical relations between the phenomena of the world. But in addition to this move Modern Science has relied on the assumption that all knowledge can, and ideally should be, mathematised. If you have a problem to solve you had better start taking measurements because until you have done so you have not really treated it scientifically. This conception of knowledge and science has not only permeated the natural sciences but also the humanities and especially the social sciences. Thus, Emile Durkheim was highly inspired by Auguste Comte's positivism, while people like Otto Neurath, Ernst Nagel, Talcott Parsons and many others argued for establishing the social sciences according to the scientific paradigm exercised in natural science: Science is measuring. Science is the ability to put your problem into a mathematical model.[1]

In what follows we will discuss the special role attributed to mathematics as a pillar of Modern Science. The discussion will be motivated by an important research question, namely the question what is the state of our planet. Is the state of the world gradually improving or are we in fact experiencing a world that is gradually becoming more and more uninhabitable? And what can a mathematical model tell us about this question? And further, what can this example tell us about the

[1] See, for instance, Delanty, G. and P. Strydon (eds.) (2003).

role of mathematics more generally? As mentioned earlier, mathematics can be considered to be the primary language of Modern Science, but what does it mean to formulate problems, ideas and solutions in this language? So we can ask what the mathematical discourse does to the way we *see* the world, and the way we *act* in the world.

2. What is the State of the World?

It appears that "the real state of the world" provides a necessary foundation for all kinds of overall decision making concerning global environmental issues. However, what is the state of the world, and how do we perceive this state? One analysis of the state of the world is provided annually by the World Watch Institute through its *State of the World* publications.[2] These and many other similar publications of whatever political leanings rely heavily on statistical data to argue their case – which sometimes is for radical change in the way we live, sometimes for "do nothing", and sometimes for something in between. We will take a particular example of a state of the world publication to raise some concerns about using a mathematical analysis of the state of the world in an unreflective way.

In 1998, Bjørn Lomborg provoked considerable controversy with his book, *Verdens sande tilstand*, and it was later followed by a revised edition in English, *The Skeptical Environmentalist – Measuring the Real State of the World* (2001), that triggered international attention. The theme of the book is the global environmental debate, which is seen by Lomborg as being dominated by what he calls the "litany" of doom and gloom. The picture that is spread through the news media on the state of the world is, according to Lomborg, one without good news. We are presented with catastrophes of hunger, hurricanes, stories about cases of devastating pollution among many other horror scenarios because of, in Lomborg's view, a basically unfounded belief that the world is going to hell! Lomborg is keen to convey to the public that there is no basis for the view that there is a global environmental crisis, and he wants to convey that on the contrary, the environment is actually getting better all the time.

Lomborg analyses a number of subjects, e.g. hunger, pollution, extinction of species and waste management problems, and applies statistical methods to corroborate his claim that things are going better than what one would believe from the litany of doom. It is an important aspect of Lomborg's work that it is not new numbers that he is working with but the same numbers as those his opponents in the environmental debate have worked with, those data sourced from big international

[2] The Worldwatch Institute has been publishing *State of the World* annually since 1984.

organisations such as the Food and Agriculture Organisation and the World Health Organisation of the United Nations (LOMBORG, 2001, p. 31). The fundamental argument of the book is that any reasonable mathematical analysis of these data shows how the litany of gloom and doom has influenced the minds of people who have used the statistical data in the environmental debate, and as a result they could not help but produce pessimistic foresights.

Lomborg's work is a meta-research study that examines the mathematical quality of the work of other researchers within the field of environmental science, and we should welcome it as such. This is one point to make about *The Skeptical Environmentalist*. Another point to make is, however, that at the same time, it commits the same mistake as the promoters of the litany of doom. Having read the book, one can only put it back on the shelf feeling that the statistical treatment of the data as presented by Lomborg is at the least to some extent convincing. This has been seriously questioned by the UVVU (Udvalget Vedrørende Videnskabelig Uredelighed [DCSD – the Danish Committees on Scientific Dishonesty]) but their critique seems deficient, at least to some degree. If Lomborg's work has a serious flaw scientifically speaking, it is similar to the one he opposes. Lomborg substitutes the litany with the celebration of future development through further technological research. However understandable this may be, if one considers the litany of doomsday scenarios to be deeply rooted and always taken for granted in the media and research on these topics, Lomborg's work is not mathematically reflective on its own enterprise. His book does not thoroughly take up the limitations of the formal approach that has been applied through his analysis. It may be that Lomborg is right about there being a decrease in the number of species that are extinguished, but the numbers hide that, for example, the Bengalian tiger is threatened. This may be an animal of special importance to the self-understanding of humans on this planet, not to mention the ecological systems of which it is a part. And what ethical value is attributed to the hunted animals? What cultural significance do these tigers represent? These are questions about ethics, values – anthropocentric or otherwise – knowledge from many overlapping sciences etc. and the mathematical analyses will always hide and often overlook its engagement with these concerns. Statistical analysis is created in a way that excludes the value of particular events, and can therefore always only be a partial story about the real state of the world. Lomborg knows he has made such preliminary ethical choices, but finds that his starting point is the only reasonable option, and he presents it on one page out of the 352 of the book. Lomborg positions himself in what he calls a human-centered view that, as he explains, focuses on the values attributed by humans to animals, plants, etc.

"This is naturally an approach that is basically selfish on the part of human beings. But in addition to being the most realistic description of the present form of decision-making it seems to me to be the only defensible one. Because what alternatives do we have? Should penguins have the right to vote? If not, who should be allowed to speak on their behalf? […] It is also important to point out that this human-centered view does not automatically result in the neglect or elimination of many non-human life forms. Man is in so many and so obvious ways dependent on other life forms, and for this reason alone they will be preserved and their welfare appreciated." (LOMBORG, 2001, p.12).

Many would disagree with him on exactly these issues and there is no mentioning of the global political, cultural or economical conflicts and interests mentioned in this preliminary standpoint. Developing a well reflected and documented point of departure is where the real scientific debate should be focused and take place, and not exclusively – as has to a large extent been the case – with regard to mathematical technicalities.

What we more generally have in mind can be referred to in the subtitle of Lomborg's book: *Measuring the Real State of the World*. This formulation seems to presuppose that something could be called, not only the state of the world, but the "real state of the world", and that this state could be measured and objectively be decided upon once and for all. Here we find a similar assumption as the one expressed by Galileo, namely, that the essential aspects of the world can adequately be expressed in mathematical terms. In fact the idea is that mathematics is the unique descriptive tool, which captures the essential (physical) aspects of reality. In Galileo's terms what is essential are the primary sense experiences; these are the experiences that mathematics captures, thus leaving aside the secondary ones. Lomborg does not use this formulation, but in his analyses he (as well as those he criticises) concentrates on measurable aspects of the state of the world, and identifies these aspects as the real state of the world. In other words, when mathematics is brought into generate a description, the world is seen in a particular way, and when description becomes the basis for decision making, then mathematics is brought into action.

3. Mathematical transformations

What are we doing when we see the world through mathematics? And what kind of actions is connected to this way of seeing? By mathematics in action we refer to the actions that emerge as a result of taking a mathematical perspective on the world (or parts of it).[3] We can identify several aspects of seeing the world through the lens of mathematics, and how each of these aspects provides us with reasons for reflection.

3.1 Formalisation – cutting off parts of the phenomenon

A troublesome aspect of a mathematical perspective of the world is presented by the Danish philosopher K. E. Løgstrup. In the third part, *Source and Surroundings – Reflections on History and Nature* of his four-volume work *Metaphysics* (first published between 1976 and 1983), Løgstrup suggests that we are always faced with the choice of interpreting the world as a causally governed system or as a phenomenological experience. One could understand this choice as a choice between attending to the primary qualities of objects in the world or the secondary qualities. It is Løgstrup's thesis that if we limit ourselves to studying causal relationships between primary qualities of objects we cut ourselves off from any human understanding of the universe as our source of existence. What is important to consider is to what extent the incompleteness of primary qualities, or the causally governed system as the basis for describing the world, poses a significant limitation to our understanding of the world. According to Galileo and to Modern Science there is no "limitation" connected to this incompleteness; the primary qualities can grasp what is essential to the world, scientifically speaking at least.

Løgstrup on the other hand finds that there are very serious limitations to what can be concluded about the world through studies of causal systems. When we use formal language as a means of describing a certain phenomenon in life, we cut off part of reality, that is, those aspects which cannot be captured within the conception of the primary qualities. We simplify matters within this field of vision *in order to* make causal judgements about it. In fact a formal description of the world will concentrate on those physical aspects of the world which make it appear like a causal system. This is not without reason. Science seeks to find explanation for what has happened or is happening, (that is finding the cause for the effect that is being observed) and use this to project or predict what is likely to happen if the cause remains. With this understanding, science can provide ways of thinking about what could be altered to the causal factors to diminish, increase or in some other way alter the effects in a desirable way. This is what the modern scientific enterprise is all about and it is one very important way for us to gain knowledge about our surroundings. Galileo

[3] For a discussion of mathematics in action or the formatting power of mathematics see also Skovsmose(2007); Skovsmose and Yasukawa (2004); and Skovsmose et al. (forthcoming).

emphasised this and in this way he opened the space for Modern Science. Alternatively one could try to retain the complex, the ambiguous and the paradoxical, as it is done in the extreme in the different forms of art and, to some degree, in the scholarship in the humanities. Although the traditions of Modern Science define science as the pursuit of knowledge through the use of formal language, we must always bear in mind that we have, in Løgstrup's phenomenological conception, cut ourselves off from seeing some of the attributes of a given phenomenon.

The exclusion of parts of reality through a description reflects the linguistic tool used for the description. In order to clarify this one can consider that natural language is the generative basis of formal language. Formal language is a derivative of natural language, which draws attention to certain aspects of natural language. We should not interpret formal language as the opposite of natural language as for instance Frege and Russell had done in their efforts to construct a scientific language separated and secluded from natural language. Instead we should consider formal language as a subset of natural language – natural language can in principle express what formal language can express, but in addition, it can do a whole lot more. Therefore we always have to be aware that formulating a description in a formal language means leaving out parts of the phenomena. A formal description is a highly selective description.

In this formulation, however, we might already have adhered to some assumptions of Modern Science which can be questioned. We talk about *reality*, and of language as *describing* this reality. This might well be a problematic formulation. The word description can be problematic, as this somehow assumes a form of "picture theory" of language, which views language as reproducing a mirror image of aspects of reality. And certainly the notion of reality has to be considered too: what can we assume when we make reference to "reality"? We assume a distinction but also a relationship between reality and its formulation through language. It makes more sense to talk about language and reality as two partly overlapping entities, which can be interacting in much more complex ways than indicated by a notion of description. Language can inscribe values into phenomena; it can form or categorise and restructure reality. And this also is true when the language is mathematics. We therefore need to reconsider the conception of a mathematical description of reality.

3.2 Systematisation and inscription

Let us now assume that mathematics has been applied to describe some aspect of reality. The world is not taken in its phenomenological complexity, but is instead reduced to its primary qualities in the formal language of mathematics. We shall call this process in the sciences *formal reduction*.

What does this formal reduction mean for the way we *see* the world? In fact which world are we seeing? As a first step we can say that one is reducing a perceived phenomenon that involves both primary and secondary qualities into one that only reveals primary qualities.

But the reduction of a phenomenon does not stop here. After deciding upon a formal representation of the world's primary qualities there are still infinitely many possibilities for constructing a mathematical description of the phenomenon. The reduction of the world into measurable primary qualities has to be continued further. There are different mathematical lenses that can be put into use. One is about the size of things you are interested in describing. Are they nano-sized or are they cell-sized or perhaps planet-sized? On top of this come decisions about what causal elements needs to be added to the description. If we are dealing with the movement of a billiard ball we can reduce a description of the phenomenon by claiming that the surface is perfectly flat in some sense (which is never the case in reality), that the ball is perfectly round (which is also not the case), that the billiard table is a closed physical system (which is very far from being the case) etc. In conclusion we have to admit that from the phenomenon we have experienced – which can be far more complex than a billiard ball rolling across the table – we are after the formal reduction and the additional *system reduction* providing a description that has very little to do with the original phenomenon.

Hence, we have illustrated at least to stages of transformation in any mathematical description of a given phenomenon in the world. But yet another type of transformation takes place when we are constructing a mathematical description. It concerns the interests that are implicit in a given description of anything. These interests reflect the purposes that the creator of the description has in producing the description. Do they want to use a differential equation to produce a picture of an idealised physical phenomenon? Do they want to produce a table of numbers to show how prosperous a society is? Do they want to present a graph to highlight the inequities in the workload in an organisational unit? We shall call this third level of transformation an *inscription*, because it refers to the idea that certain decisions, values, intentions, interests, ideologies and priorities are built-in components of any mathematical description of the world (see Skovsmose et al., forthcoming).

We have located three forms of transformations in relation to a mathematical description of a given phenomenon in the world; the formal reduction, the system reduction and the inscription. We may not even after these three forms of transformation have fully constructed a mathematical model as such. To obtain this we would still need to establish causal relations between elements, parameters, variables etc. in our mathematical description. In total we shall in what follows call the entire process of mathematisation the *mathematical transformation*. However, it seems quite clear that we have to be aware that what is normally called a mathematical description of a phenomenon cannot really be taken to be a predetermined map of the relations between things in the world. A mathematical description is something you subscribe to or do not subscribe to on the basis of careful examinations of the values, limitation, priorities etc. of the transformations.

3.3 Mathematically-based prescriptions

We now have an idea about what it could mean to make decisions based on mathematical descriptions, and that such descriptions include extensive transformations of phenomena. Once a mathematical transformation of a real phenomenon is made, then the transformed phenomena itself exists and takes on a life of its own. The formal reduction ensures that only particular aspects of the phenomenon become included in the descriptions and the systemic reduction ensure that a certain type of connections is established between the described entities. Elsewhere, we have introduced the notion of a mathematically scripted world (see Skovsmose et al., forthcoming). In this work we discuss how the mathematical script is used to prescribe certain actions, including decisions. People will then have a “choice” of subscribing to what has been prescribed as actions to take. In many cases, however, the subscription is so pervasive that the script has the appearance of conscripting certain actions. What is often overlooked is that like any scripts, written by mathematics or natural language, mathematical scripts have inscribed in them certain ideologies and values. The level of subscription to the prescriptions may give the illusion that mathematical descriptions are value free, when in fact there is always inscribed into them particular values, interests etc. And very often the most fundamental value relating to our theme here is inscribed in the mathematical script as such – that the world is best understood through its primary mathematisable qualities. But this value is taken for granted and so not a subject of reflection when actions and decisions are prescribed on the basis of mathematical transformations. There may be arguments about the accuracy of the numbers, the number of variables that were used and in what way, but not “why use (only) numbers and quantifiable variables” in the first place.

Decisions turn into actions, and mathematics becomes part of reality. The actions taken as prescribed by a mathematical script is acted out in a complex reality, but they might only be justified within the world of the mathematical transformation of the phenomenon. Through a mathematical script one can for example formulate certain standards, for instance, concerning the "acceptable" degree of pollution of drinking water. Such standards are established through a mathematical modelling process. However, when first established such standards are not only part of a model, and represent certain prescriptions; they in fact create a new reality. The standards make part of the risk structures, which constitutes our life conditions. Our health could be protected behind such standards, companies' interests in selling could also be acknowledged.

4. Conclusions

Mathematics brought into action is a powerful resource for confining the breadth and possibilities of criticisms of decisions. In order to challenge mathematically formulated actions, one is possibly expected to challenge it within the internal world created by mathematics. This is not always possible, particularly when the criticism is about how the mathematically formulated world is interacting with parts of the world that the mathematical transformation left out. But leaving things out, allows for the mathematisation in the first place.

Returning to Lomborg's environmental book, an interesting feature was the measure of attention it received in the public debate. Lomborg is backed by a considerable public consencience, because he is not afraid to talk about what is right and what is wrong in the environmental debate. This attracts the media and influences the public opinion. It displays a feeling of lack in the public debate of science making a clear cut comment on what is right and what is wrong in for example the environmental debate. Science should present a given case to the public as complex, undecided, based on limited knowledge and so on, if this is actually the state of our knowledge in that particular field of investigation. We should be thankful to scientists when this is how they reply to our questions. But Lomborg's crusade against the litany of doomsday very convincingly showed us how mathematical transformations are also embedded in power struggles – in this case about what path to proceed along in environmental issues. The debate was an important illustration of the need for people involved in mathematical modelling to be reflected on the diversity of approaches that can be pursued in the study of a given phenomenon – in this case the state of the world!!

Our intention here has not been to criticize the use of formalisation in science – we cannot do without formalisation and especially not in science as we know it today. Our concern is in the blurring of the (mathematical) model with reality itself. This blurring has a long history, starting at least from the conception of science in modernity that the world can be spanned by our formalism and that this world is the unedited, uncut and entire world. We could go on and talk about the blind spots of mathematical transformations. These blind spots represent what is left out in order to perform a scientific formal representation of a phenomenon, and it is not visible from this formal framework itself. In other words, we shape the world to our mathematical approach in order to talk scientifically about it.

In conclusion it seems important to consider the impact of our life world becoming formed by formal mathematical approaches. We are in the process of formalising our cultural environment – the world as we experience it – so that we increasingly experience our life world as formalised. We are not merely describing the world through mathematics but rather transforming it into categories accessible through and computable in mathematics. Only when we become aware of this transformation produced by a mathematically scripted world, we can retain the possibility of a radical critique. As long as mathematics is churning out consistent answers, there is no easily accessible space for reasonable critique and formalisation measures will continue to dominate the construction of our life world.

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