

## STEERING PROBLEM SOLVING BETWEEN CLIFF INCOHERENCE AND CLIFF SOLITUDE

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### ABSTRACT

Starting from Nickles' constraint-inclusion model, we present five challenges that any rational problem solving model should meet, but that seem to lead to an inextricable riddle. We then introduce the contextual model and show, step by step, that it meets all the challenges and resolves the riddle. This results in a strong argument for the concept of rationality that underlies the model.

### 1. *Aim of this paper*

In discovery matters as in others, we are on the rationalist side. Scientific creativity should be both explained and approached by methodological means. If that is so, discovery and creativity should be tackled in terms of problem solving — this claim can hardly be seen as contentious. And that position naturally leads one to Tom Nickles' constraint-inclusion model. Other models known to us are either too sketchy, too partial, not sufficiently sophisticated, or incapable of handling both descriptive and methodological questions about problem solving.

There are several challenges that any problem solving model should meet. We discuss five of them in section 2, and it turns out that Nickles' model either fails to meet them or resolves them in a rather arbitrary way. In the subsequent sections, we present our own model (that provides a reinterpretation of Nickles' constraints) and show the way in which it

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meets the five challenges. A contextual approach to problem solving was developed by the older author in Batens 1985, 1992a, and 1992b; some applications are discussed in Batens 1984 and Batens and Meheus 1996. The younger author adapted the approach in applying it specifically to creative problem solving — see Meheus 1997 and 199+b. That the approach survived this test, seems comforting in itself. As both authors have some deep disagreements and neither of them considers the theory as finished, the present paper is at some points a compromise. Nevertheless, we hope to have shown that the model meets the challenges and does so in a way that agrees with present insights from the philosophy of science.

The two central challenges seem to be these: a problem solving model should be able to explain why some individual or group, rather than another one, solved a problem in a rational way; it should also enable one to understand why a solution is accepted by the scientific community. Oddly as it may appear, the combination of both requirements causes difficulties provoked by the way in which one locates a problem. To determine the meaning of a problem, one needs a reference point: the views of an individual, a research group, a research tradition, a discipline, the scientific community, or (why not) mankind.<sup>2</sup> Whichever decision one takes here, it either seems impossible to explain why this one rather than that one solved a problem in a *rational* way, or it becomes mysterious how a solution can ever be generally accepted. And further hard difficulties arise, as we shall see.

From section 3 on, we describe the contextual model (which was argued to meet different challenges in other papers) and show step by step that it is able to meet those difficulties in a not *ad hoc* way. While our argumentation proceeds in epistemological terms, we refer to historical examples to underpin the realistic character of the model and its specific application. In the final section, we briefly point to the strength of the concept of rationality that underlies the model.

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<sup>2</sup> Traditional Anglo-Saxon logicians will easily resolve all challenges by invoking propositions. Unfortunately, these objective and human-independent entities resolve no one else's problems.

## 2. *Some background*

Since the origin of the modern sciences, our views on discovery and creativity had a remarkable history. Originally, discovery was seen as an integrating part of methodology and the logic of discovery as algorithmic or nearly so. During the nineteenth century, conceptions in line with romanticism led to the famous opposition between the context of discovery and the context of justification, culminating in a view that banned discovery from methodology.<sup>3</sup> The revival of the methodological investigation of discovery, which started some twenty years ago, derived its major impetus from historical and sociological studies of the sciences and from developments within cognitive psychology and artificial intelligence.<sup>4</sup> An especially promising movement ties discovery and creativity to *problem solving*, and analyzes the activities of scientists as problem solving behaviour.

Various problem models have been developed, by cognitive scientists as well as by logicians and philosophers of science. One of the most elaborated ones is Nickles' constraint-inclusion model (Nickles 1981). As compared to the others, this model has some clear advantages. For instance, it enables us to understand that someone may have a problem without already knowing its solution — remember the so-called *Meno* paradox. It also leaves some room for (and suggests the plausibility of) positive guidance in problem solving processes. Put differently, the model suggests that innovative discoveries result from a complex and highly structured reasoning process, rather than from trial-and-error, whims, genius, or other extra-methodological phenomena.

The constraint-inclusion model has some important characteristics. Presumably the most central one is that a problem consists of two elements: (i) the demand that a goal be attained together with (ii) a set of constraints. "Constraint" is used here in a broad sense to refer to any item of information (experimental result, law, theoretical finding, cog-

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<sup>3</sup> See Laudan 1981 for a study of the reasons for this transition, and Nickles 1980b for some related remarks.

<sup>4</sup> For a historical overview of the changing methodological views on discovery, see Nickles 1980b. These changes seem to be connected to much more general modifications in scientific methodology — compare section 1 of Batens 1992a.

nitive value, heuristic rule, ...) that imposes a condition on the solution of the problem or that narrows down the solution path. Remark that, according to this model, *all* items of information that define a problem belong to the problem itself, or, in other words, are included in it, viz. in its second element. Another characteristic of the model is that problems (as well as constraints) are viewed as *objective* entities. They 'exist', at some historical point, in a knowledge system and related practice. Whether they are or are not discovered by someone is irrelevant to their existence.

On this model, a change in the set of constraints entails a change in the problem. This does not mean, however, that each time a new constraint is discovered we are dealing with a new problem. Nickles indeed distinguishes a problem in the 'agent' sense, and a problem in the 'semantic' sense (Nickles 1981, p. 99). The former depends on a problem solver's conception of the problem. The latter refers to the problem as it 'exists' in a given body of knowledge and related practice. According to Nickles, discovering new constraints leads to a change in the agent sense, but not in the semantic sense. A change of the latter type requires that the relevant body of knowledge is modified in some fundamental way.

Nickles' constraint-inclusion model is certainly promising. It avoids the *Meno* riddle and is able to capture the evolution of a problem during the process that (hopefully) leads to its solution. At the same time, it views a problem as independent of someone's accidental understanding of the problem and hence as an entity that can be discovered. And still, the very features that lead to these strengths result in difficulties. Modifying the model in order to meet these seems to run us into different but equally hard difficulties. We shall list all this in terms of five challenges.

A problem is seen as defined by a knowledge system and related practice. It seems to us that a consistent interpretation of Nickles' writings identifies this knowledge system and related practice with respect to paradigms or research traditions. But why is that so? A researcher belonging to one research tradition may *discover* relevant experimental results, empirical laws, heuristic rules, ... that belong to a different research tradition. In a sense these entities 'exist' (just as much as those from the researcher's own tradition) and are relevant to the problem. So, why define the problem (including the constraints) with respect to a research tradition, rather than to all knowledge and practice available in the discipline (or in the scientific community, or even in the big body of

human knowledge and practice of the days)? And if we find some good reason not to move up from research traditions, why not narrow down further the *locus* of a problem, for example to the knowledge and practice of a research group, or even to that of an individual researcher? Often individual researchers or small research groups have at their disposal powerful heuristic methods that are not shared by their research tradition, or have rather distinctive ontological views. Such peculiarities may enable them to solve problems that cannot be solved by relying on the constraints that are generally accepted within the research tradition.

Both moves involve complications. Let us first consider moving up, say to the discipline, and consider at once the interesting case in which the latter is alive and kicking and the problem does not have a standard solution. How do we define the knowledge and practice of such a discipline? The union of the sets of constraints accepted by all relevant research traditions is often a non-workable bunch: it is too incoherent, often flatly inconsistent. In the same cases, the intersection of those sets of constraints is too weak to lead to a solution of the problem. A mainstream view might offer a way out. But often it is absent, and even if it is present, it will usually be too weak to lead to a solution of the problem. It is well known that interesting discoveries are often produced by dissidents or by individuals or research groups that have very specific views — Newton's mechanics is an obvious example. So, moving up will lead to a problem that contains a set of constraints that is either too incoherent or too weak to lead to a solution. Let us call this the *coherence/strength* challenge.

Connected to that is (what we shall call) the *rationality* challenge. As the problem is defined with respect to the knowledge and practice of the discipline, it will (if interesting) contain either an incoherent or too weak a set of constraints. So, if some research group produces a solution, this is bound to be the result of the *specific* constraints of that research group. Depending on the view one takes, these will be either a selection or an extension, and possibly a replacement, of the constraints contained in the problem. But clearly, on Nickles' model, such selection, extension or replacement cannot be justified: it is not determined by the constraints of the problem. So, the upshot seems to be that, if we move up from research traditions, the solution of interesting problems — those that require creativity — cannot be a rational matter.

Moving down will drastically multiply the number of problems; two

problem solvers will hardly ever deal with the same problem. Individuals solve problems against the background of *their* knowledge system, they may follow 'personal' heuristic rules, they may adhere to unorthodox theoretical principles, they may even differ from each other with respect to accepted experimental results. This move too seems to run us into trouble. If two problem solvers almost never deal with the same (interesting) problem, Mary's solution to her problem can hardly be a solution to John's problem. But if John's acceptance of Mary's solution requires that he first replaces his problem by hers, Feyerabend lurks around the corner. So, moving down we have to confront the *relevance* challenge: how can someone's solution be relevant to the problem of others? And, as a result, how may we ever explain that the others have rationally accepted someone's solution to his problem as a solution to their problem? This we shall label the *acceptance* challenge. Going up, we meet the coherence/strength challenge and the rationality challenge, going down the relevance and acceptance challenges.<sup>5</sup>

All this, however, does not justify the decision to tie up problems to research traditions. Although research traditions are somewhere in the middle — where the Romans mistakenly located virtue — or perhaps precisely because they are in the middle, they are affected by both couples of challenges. If problems are located within research traditions, how shall we warrant *coherence*, respectively *strength*? And how can an individual or research group *rationally* solve a problem in view of its constraints? Why should the solution to the research tradition's problem be *relevant* to the corresponding problem of the discipline? And why should members of the discipline that do not belong to that research tradition *accept* its solution? In principle, there is a quasi-continuous scale from individuals to humanity. Even if, at some point in time, some entities on the scale may be sociologically well delineated, that does not make them immune for either incoherence/weakness or irrelevance.<sup>6</sup>

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<sup>5</sup> In his 1980a, Nickles accounts for individual variation and is able to meet the coherence/strength and rationality challenges; however, the relevance and acceptance challenges are left unanswered in that paper.

<sup>6</sup> This holds even for the two extremes because neither individuals nor mankind can be isolated from their history. An individual's knowledge and related practice cannot sensibly be defined with respect to the (supposedly coherent) contents of his or her consciousness at one point in time. A solution acceptable to mankind today, should in principle be

We still have to mention a fifth challenge. The constraint-inclusion model entails that problems may repeatedly change while being solved, for example because new constraints are added. Nickles tries to cut down on these changes by pointing out that constraints are often (literally) discovered within some knowledge system and related practice. This nicely explains the solution of 'toy problems' (the Tower of Hanoi, the missionaries-and-cannibals puzzle, problems tailored as in Simon's examples, and other puzzles and simple manipulation problems). These problems indeed contain all the information needed for their solution. The solution of more interesting problems, however, requires (amongst other things) that *new* constraints are added; it may be necessary to gather new observational findings, to devise new solution methods, .... Such constraints are not contained in the original problem, nor can they be discovered in a given knowledge system or in the related practice. Moreover, our knowledge system and practice may contain errors that render some problem unsolvable and need to be weeded out.<sup>7</sup> In sum, solving a problem may require that constraints are added, replaced or rejected. On the constraint-inclusion model, any such move entails that we move on to a different problem. If problems change that easily, how then can we ever conclude that a certain result forms a solution to the problem we started from? Let us call this the *identity* challenge.

Of course, one might distinguish problems in the previous sense (defined by a specific set of constraints) from PROBLEMS in the broad sense. PROBLEMS might be seen as trees of problems, changing over time and branching off in different directions as different people attack them. This may be a nice distinction, but it does not in itself clarify the sense in which the solution of a problem at an end-node of some branch of the PROBLEM can be seen as a solution to the PROBLEM to which it belongs. Hence the identity challenge remains.

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acceptable to mankind in the past (if supplied with today's knowledge and practice) and to mankind in the future (if it takes account of today's knowledge and practice). The reference to the future is not trivial. Even if insights on methods and rationality would have changed, the solution should still be acceptable in view of our present knowledge and practice.

<sup>7</sup> We deliberately include the practice here. For example, it may be required that we learn to manipulate some instrument differently, or that we devise a new one and learn to manipulate it rightly.

Let us summarize. We have met five challenges and have seen that the constraint-inclusion model does not seem to meet them in an adequate way. We now turn to our alternative model. We shall present it step by step, referring to the five challenges where appropriate, and we shall return on them in section 8.

### 3. *The contextual model*

The contextual model has many characteristics in common with the constraint-inclusion model. Both models consider new scientific products as *problem solutions*. Both also stress that a problem cannot be disconnected from a set of *constraints* — items of information that provide positive guidance in the search for the solution, provide materials from which the solution (or part of it) may be derived, and enable one to evaluate a proposed solution.

There are also important differences between the two models. We briefly characterize the contextual model in the following paragraphs. We can only discuss some features that are specifically relevant to our present topic.<sup>8</sup>

In the contextual model the notion of a problem is conceived in sufficiently broad a way to include both the demand to answer a question and the demand to realise a certain (external or internal) state. In the former case, we are dealing with an *intellectual problem*, in the latter with an *action problem*. Examples of intellectual problems are explanation problems — “Why does ice float on water?” — and determination problems — “What is the circumference of the earth?” Intellectual problems typically can be construed as *questions*. This is not the case for action problems that include the construction of new scientific instruments (external actions) as well as the realization of mental images (internal

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<sup>8</sup> The model has several features that make it rather realistic. For example, the knowledge system is not supposed to be deductively closed, and whether a knowledge element *A* is *seen* as relevant to some problem is itself determined by a knowledge element (rather than by the logical relations between *A* and the problem). We have to leave all of this out of the discussion.

actions).<sup>9</sup> Although action problems are not explicitly excluded by Nickles, his identifying 'problems' with 'questions' (Nickles 1981, p. 109) implies that action problems may be reduced to intellectual problems.

A context (problem solving situation) is seen as composed of four<sup>10</sup> elements: (i) a problem, (ii) certainties, (iii) relevant statements, and (iv) methodological instructions.<sup>11</sup> These elements are not independent of each other, as will appear in the subsequent paragraphs, but fulfil different functions. Elements (ii)–(iv) are seen as the constraints for (i). As a result, three kinds of constraints are at once distinguished. Only one of them will be viewed as 'constitutive' for (the meaning of) the problem. Let us have a brief look at the elements of a context.

Needless to say, "problem" should be taken here in the narrow sense: the goal that should be attained. How the problem should be interpreted (its logical space, the way and means to tackle it, the adequacy conditions on possible solutions) is determined by elements (ii)–(iv). In view of this distinction, we tend to view problems as concrete entities, for example linguistic entities, or representations of another type.<sup>12</sup> We do not follow Nickles' terminology here — he sees problems as conceptual entities. Nickles' question under what conditions two problems are identical, corresponds in our model to the question under what conditions two problems have the same meaning. We shall not quarrel here about this distinction. For present purposes, it is sufficient to remark that we do not lose any distinctions with respect to Nickles' terminology.

Let us now turn to the elements (ii)–(iv). They all form constraints

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<sup>9</sup> In a broader sense, processes that lead to the solution of an intellectual problem are internal actions (or successions of internal as well as, in some cases, external actions). Our point here; however, is that external action problems and some internal ones cannot be seen as questions.

<sup>10</sup> In the present paper we disregard some complications involved in non-individual problem solving processes.

<sup>11</sup> These may range from recipes or full blown methods to solve the problem (to bake a cake, measure a value, assess the merits of a theory, or perform a calculation) to so-called heuristic rules that merely contain the promise of possibly bringing us closer to the solution. Also, methodological instructions include *does* as well as *don'ts*.

<sup>12</sup> An artist may face the problem to paint a specific landscape that expresses solitude. She may have a vague representation of the landscape in her mind. Nevertheless, this representation is itself concrete and not conceptual (at least not in the traditional sense).

for the problem, but differ from each other as to their *function*.

It is typical for certainties that they are not questioned *within* the context; they are considered as (contextually) *necessarily true*; they specify the logical space. One of their functions is to determine the *meaning* of the entities<sup>13</sup> occurring in the other context-elements. In this sense the certainties limit the *possible* solutions of the problem. When Kepler started working on Mars' orbit, he accepted as evident that planetary orbits are circular. Hence, only circular orbits were considered as possible solutions by Kepler at that time. Similarly, when Fleming set out to find a good antiseptic (one that would kill bacteria, but would not affect the phagocytes), his certainties were such that only chemical substances were seen as possible solutions, not, for instance, moulds.

Certainties fulfil another function as well: they partly determine the *operations* that are considered as justified. Suppose that, in some context, one uses the logical terms of Classical Logic (with the meanings they there have). As a result, specific operations will be justified (for instance, to derive  $B$  from  $A \supset B$  and  $A$ ), whereas others are not. In view of this, the certainties determine the "underlying logic" in a given context.<sup>14</sup> This logic, however, need not be a *deductive* system. In many contexts, it will also contain specific ampliative rules (inductive rules, abductive rules, rules that govern analogical reasoning, ...). The logic may also incorporate inference rules for non-verbal elements such as diagrams.

Relevant statements behave in a quite different way. Typically they are not, in the given context, conceived as necessarily true — their truth is seen as contingent. Where certainties determine the possible solutions to a problem, the relevant statements impose conditions on the *correct* solution. They may allow us, in view of the certainties, to *derive* the correct solution (the correct answer to an intellectual problem), or at least to *eliminate* some possible solutions — the solution should be compatible with them. Thus, observational statements concerning the position of

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<sup>13</sup> These entities may be words, if the other contextual-elements are formulated as sentences. However, they may also be structures of concepts, or representations of schemes or of drawings. In the sequel, we usually refer to verbal entities. However, this drastic simplification is merely meant to keep the paper within bounds; please remember it is a simplification.

<sup>14</sup> See Batens 1985 for an argument that contextual certainties cannot sensibly be distinguished from contextual logical truths.

Mars formed relevant statements in Kepler's attempt to determine the orbit of Mars — they enabled him to eliminate possible solutions and thus to come closer to the correct solution. Similarly, information about the properties of specific chemical substances enabled Fleming to rule out possible solutions.

The methodological instructions specify the operations we should or should not fulfil in order to reach the solution, or at least to come closer to it. They may form an ordered set of instructions that, when applied correctly, should lead to the solution of the problem. As an example one may think here of any explicit problem solving method — for instance, the multiplication procedure taught in primary schools. If the instructions are weaker and an explicit recipe for solving the problem is missing, they may still guide the problem solving process. Means-end-analysis (and similar 'general heuristics') form typical examples. In general, methodological instructions help to determine the path the problem solver will follow.

It is important to note that the context-elements vary from one context to the other. This means, first, that the constraints from one context may be absent in others. It also means that the same items of information may have a different function in different contexts. For instance, a certainty from one context may function as a relevant statement or even as the problem in another. This is obvious if the contexts are consecutive. A well-known example is again Kepler's problem to determine the orbit of Mars. At first, the idea that planets move in circular orbits functioned as a certainty. Later, Kepler *questioned* this idea: the *problem* of the latter contexts consisted in the demand to find out whether planetary orbits are indeed circular. The contexts need not, however, be consecutive. A researcher may solve a mechanical problem by considering relativity theory as certain, and, during the same period of his or her life time, engage research directed at modifying this theory. The same researcher might even consider classical mechanics as certain in a context concerning a different problem.

The Kepler example brought us to a key property of the contextual approach: if a given context does not allow for the solution of its problem, the problem solver (unless when he, she, or it gives up the problem) will move on to a different context in which a derived problem is tackled. The latter might be which elements of the original context are responsible for the failure to solve the problem; or which of those elements may be

justifiedly modified (extended or replaced) in such a way that the problem (or a larger portion of it) becomes solvable; ... A derived problem might also concern a single element from the original context: is it justified? sufficiently specific? sufficiently precise? ... Thus, the solution of a non-trivial problem may be seen as a chain of contexts concerning the problem (in the narrow sense), where the transition from one link to the other may be both explained and justified by a chain of contexts concerning one or more derived problems.

We add three remarks before closing the present section. The first is that we use "problem" in a very broad sense to refer to *any* goal that should be attained. Thus, we do not exclude routine processes (multiplying two numbers, ...). This broad interpretation is common practice in cognitive studies and is also in line with recent trends in the philosophy of science (see Nickles 1990).

The second remark is that, according to the contextual model, problems can be classified into "well-defined" and "ill-defined". We say that a problem is well-defined if and only if, given the set of certainties, the relevant statements and the methodological instructions determine a unique correct solution to the problem. The relevant statements may be incomplete, or they may be inconsistent. In neither case, the problem need to be ill-defined. Even if the relevant statements are incomplete, the methodological instructions may determine the way to complete them. Even if they are inconsistent, the methodological instructions may determine a way to resolve these inconsistencies.

It is worth pointing out that whether a problem is well-defined in this sense is an empirical matter, and by no means *a priori*. Consider the incompleteness case. The methodological instructions may determine a method to complete the relevant statements, but when practised, this method may prove ineffective or it may lead to results that are incoherent or that are, given the available measuring devices, not sufficiently precise. In other words, whether a problem is well-defined does not only depend on the structural properties of the context. It also depends on the world, including the available knowledge and its relation to the aspects of the world it attempts to capture, and also including the available instruments and other action facilities of the problem solver.

Consider a trained physician performing a simple medical diagnosis problem. At the outset, the relevant statements will not allow to derive the solution to the problem "What is this patient suffering from?". By

asking the proper questions and performing the proper tests — all deriving from elements present in the original context — the solution becomes derivable from the gathered data. This is a non-trivial example of a well-defined problem. Remark that the problem is fundamentally different from, for instance, an explanation problem involving a puzzling phenomenon that renders the problem ill-defined. An example of the latter is Galileo's question why, in conflict with the *horror vacui* theory, there is an 'empty space' in water pumps of a certain height. Not only were the original relevant statements inadequate to derive the solution, there also were no instructions determining the way to complete them.

The final remark concerns two features of the contextual model that are not directly relevant to the present paper but are essential for the model and its realistic character. The first is that unconscious mechanisms play an important role in problem solving, but are no impediment for the model's claim on rationality. Many problems are solved in an unconscious way and most contexts are set up in an unconscious way; in practice, all consciously solved problems contain unconscious steps. The second feature is that a knowledge system is considered as containing explicit links between knowledge elements and their function with respect to a problem or type of problems. This entails, for example, that a person's knowledge system may contain relevant information for the solution of a problem, but that this information need not show up in the context in which this person tries to solve the problem. (A more detailed treatment of both features is present in Batens 1992a, 1992b, and several papers in Dutch.)

#### 4. *The role of specific constraints in the definition of problems*

In the present and subsequent sections we consider the way in which the contextual model meets the challenges mentioned in section 2. It is worth mentioning that the contextual model was not devised to meet those challenges. Yet, it leads in a natural way to the suitable results.

A problem and its constraints are defined with respect to a knowl-

edge system and related practice.<sup>15</sup> The difficulty is to decide whose knowledge systems and related practice a problem should be defined by. Possible candidates range from individuals, over research groups, research traditions, and disciplines, to mankind (at some point in time). Any decision in this respect will have effects on the first four challenges. Moreover, the smaller unit we choose, the more difficult it seems to meet the relevance and acceptance challenges; the larger unit we choose, the harder becomes the coherence/strength and rationality challenges.

Notwithstanding all these theoretical considerations, it seems to us that the only reasonable guidance for answering the localization question, are the facts. A problem solver's problem should be defined in terms of the knowledge and practice of this very problem solver. If one wants to understand why some individual or group solved a problem, or if one wants to assess whether the solution was arrived at in a rational way, the problem and its constraints should be defined with respect to this person or group. Exactly the same applies if a problem solver is facing the question how he, she or it should tackle a problem.

It may be desirable that the individual or group tries to collect all available relevant information as well as all available useful techniques for tackling the problem — we mean available (wherever) at that point in time. Whether and to what extent this has to be done is a *derived* problem with respect to the problem the individual or group tries to solve. The derived problem should be answered by assessing whether the problem can be solved in its present context and assessing the price for gathering further information. All this, however, does not change anything to the point made in the previous paragraph.

If we solve a problem, we solve it *as we see it*, and in that sense we solve our problem. Even if you present us a problem to solve, we still solve (in one sense) your problem as we see it — and in that sense it is our problem. We hardly can imagine that someone would disagree with this position.

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<sup>15</sup> We agree with Nickles on this account, except that not the (object level) information contained in a knowledge system determines the problem and its constraints, but the way in which this information is linked to (a function with respect to) problems or kinds of problems. As a result, a problem solver may 'discover' suitable contextual elements for some problem in his or her knowledge system. Such discovery will not only change the context, but also the knowledge system itself.

What exactly does it mean that the way in which “the problem as a problem solver sees a problem” may differ from the problem as seen by other researchers in the domain. There are two main points we have to deal with. The first is that, when a problem is tackled or solved by some specific problem solver, the latter may or may not belong to a larger group that may be considered as a problem solver. In most circumstances the problem solver, whether an individual or research group, will belong to a (or several) research traditions or to a disciplinary community. Whether these groups may be considered as problem solvers will depend on the facts: the extent to which their members display a problem solving activity based on a shared set of constraints. Novel solutions to important problems are often produced by specific problem solvers in periods in which the disciplinary community goes on to solve standard problems (Kuhn’s puzzles) by relying on shared beliefs. However, in some cases, the shared beliefs of the disciplinary community do not allow to solve any problem at all.

The second, more interesting point to be clarified is the relation between a problem solver’s constraints and the constraints shared by larger groups. Referring to a problem solver, we shall oppose specific constraints to general constraints, the latter being shared by all researchers (or all researchers belonging to the mainstream view) in larger collective actors — there may be several such actors and they have to be specified in historical case studies (not in the problem solving theory itself). A problem solver’s constraints will consist of some specific and some general ones. Remark, however, that not *all* general constraints (of a mainstream view) need to be known or accepted by a problem solver.

Needless to say, specific constraints that are typical for a problem solver in the domain, may be shared (possibly in other contexts) with some problem solvers in the same domain or with some or all problem solvers in other (scientific or non-scientific) domains. Joule, for instance, had a remarkable skill for measuring very small differences in temperature. Although this skill was, at that time, rare in the scientific community, it was common among brewers. (Joule worked for some time in his father’s brewery.) Still, were Joule applied the skill for determining the

mechanical equivalent of heat, it formed a specific constraint.<sup>16</sup> Moreover, even if independently working problem solvers share specific constraints for a given problem, this fact does not upgrade them to general constraints.

In some contexts, specific constraints form an *addition* to the general ones. In other contexts, however, they *conflict* with the latter: a problem solver may very well reject one or more general constraints. We refer again to the Kepler example. While solving the problem concerning the orbit of Mars, he replaced the general constraint that the planets move in circular orbits, by the specific constraint that their orbits are elliptical. Or consider Sadi Carnot, who relied on caloric to build thermodynamics at a moment when most people had given up the caloric view on heat.

A traditional and widespread view holds that scientists may differ from each other with respect to metaphysical ideas and heuristics, but not, for instance, with respect to experimental results, theories, and methodological rules. Recent studies show that this is thoroughly mistaken: scientists may be dissident with respect to all kinds of constraints. Sometimes scientists disagree for years on fundamental theoretical assumptions — remember the debate between Newton and his contemporaries about the existence of a mechanical ether (see Dobbs 1988). Precisely the same holds true for experimental results. Newton's results concerning 'primitive' light rays were controversial for several decades (see Schaffer 1989).

Let us now consider three cases in which either the presence of specific constraints or the absence of some general constraints plays a crucial role. What makes the cases interesting is that all of them can be illustrated by examples of creative research at the frontier.

Often a problem is ill-defined (see section 3) with respect to the general beliefs of (the relevant part of) the scientific community. This usually means that the generally accepted relevant statements are incomplete or inconsistent, even if extended or adjusted in view of the generally

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<sup>16</sup> It is well-known that often problems are solved by people who changed disciplines or work simultaneously in several disciplines.

accepted methodological instructions, or that the latter are too weak.<sup>17</sup> If the relevant statements are incomplete, scientists unavoidably will have to rely on specific constraints, either specific relevant statements or specific methodological instructions that allow them to extend the relevant statements. More often than not, different scientists will rely on different constraints — for instance, they may use different analogies. One may think here of Bell, and the way in which his ‘personal’ analogy with the human ear proved helpful in the design of the telephone (see, for instance, Gorman 1992). In interesting cases in which the general relevant statements are inconsistent, different scientists will make different *diagnoses*; in other words, they will localize the *cause* of the inconsistency at different points. As a result, they will question different constraints and present different alternatives. The reactions to the outcome of the solar neutrino experiment form a nice example (see Pinch 1986).

An somewhat odd but interesting case concerns problems that are ill-defined for a problem solver’s, even if they are well-defined with respect to the general constraints. From the point of view of the problem solver, the relevant statements may be incomplete or the methodological instructions deficient (individual researchers may be ignorant of general constraints); alternatively, the relevant statements may be inconsistent (individual researchers may adhere to views that conflict with the general constraints). In both situations, researchers will typically rely on specific constraints in order to solve the problem. Neither situation excludes, however, that the dissident problem solver comes up with a solution that is generally accepted afterwards. This type of example, that some people rely on to ‘demonstrate’ that discovery is an irrational process, comes out perfectly normal and rational on our account. As an example, think of Copernicus’ problem concerning the position and motion of the planets. In view of the general constraints, this problem was well-defined. There was a generally accepted model, and there were generally accepted techniques for resolving anomalies (typically arising with the availability of more precise empirical data). Nevertheless, the model was in conflict with Copernicus’ specific constraints (see, for instance, Kozhamthadam 1994). Precisely because of this, Copernicus looked for a fundamentally

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<sup>17</sup> The remaining possibility is that there is something wrong with the certainties. This case is somewhat more subtle (for reasons that become clear in section 5) and is discussed in subsequent sections.

different solution.

Finally, consider the case where a problem only 'exists' in relation to the beliefs of a specific problem solver. We already referred to Newton's problem to design a 'universal gravitation theory'. This made sense in his specific world view (which included elaborated alchemical beliefs — see, Dobbs 1991), but did not arise or even make sense with respect to the general body of knowledge. In all such cases, specific constraints evidently play a crucial role, and not only in solving the problem. Without them, the problem cannot even be stated.

We produced three types of cases in which research at the frontier depends essentially on specific constraints. Precisely these are the hard nuts for the *rationality challenge*. In our model, however, this challenge simply evaporates. If the problem solver's set of constraints results in a solution of his, her or its problem, then we have a rational explanation why this problem solver arrived at the solution.

Actually, this explanation is the only possible rational explanation that might be produced, precisely because the general constraints are too weak to lead to a solution.<sup>18</sup> In other words, no problem solving model is capable of meeting the rationality challenge, unless it defines problems and their constraints with respect to the actual problem solvers (whether individuals or groups).

The *coherence/strength challenge* equally evaporates, but here the matter is somewhat more subtle. It seems to us that it does not make sense to define a problem with respect to some group, if there is no coherence within that group with respect to the problem. For example, if a disciplinary community is merely a collection of research groups that do not share a common view on a problem, then it seems appropriate to say that the 'problem' is actually a collection of specific, related but different problems that are typical for the different research groups. Sometimes a problem cannot even sensibly be considered to exist within a disciplinary community. To refer to an earlier example, Newton's problem (to find the basic principles and laws that govern the movement of heavenly bodies just as well as the movement of objects near the

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<sup>18</sup> It is possible that the constraints of another problem solver are sufficient to result in a solution of the problem as seen by the latter. The reason why this problem solver did not produce the solution, or did not produce it 'in time' is a factual matter that has to be solved by historical research.

earth's surface) simply did not exist in the mechanics community of his day. Of course, one may define the problem for that community in a reconstructive move — for example along the lines of the Newtonian thought experiment as described in Mach 1917. Depending on the conventions chosen, the problem and its constraints will either be incoherent or too weak to determine a solution.

It seems then, that the coherence/strength challenge is mainly a result of Nickles' approach. This approach is heavily dependent on the (justified) desire to define problems as objective entities, and on the (unjustified) view that problems cannot be objective unless they are defined with respect to larger (and definitely non-individual) social units. We deem this view unjustified because the knowledge system and practice of an individual or of a research group is not in any way less objective than the knowledge and practice of larger social entities.<sup>19</sup>

While our localization of problems answers the coherence/strength and rationality challenges, it renders the relevance and acceptance challenges even harder. But that is no worry for the present section: these challenges have to be met by other means — we shall see in subsequent sections that they can be met by our model.

### 5. *Which constraints identify problems?*

Having localized problems, we now should focus on some questions related to a more fundamental matter. When are two problems identical? Does their identity require that they share all constraints? If not, how do we determine which of the constraints must coincide? If these questions are answered in a different way than in the constraint-inclusion model, then the remaining challenges might not arise or might be less difficult to meet.

Needless to say, the questions do not concern the representations (see section 3) of problems. We are interested here in their meaning. Accor-

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<sup>19</sup> Nickles has a good point where he stresses that a knowledge system and related practice determine a problem in a way that is independent of the understanding of this knowledge system and practice by a specific problem solver. (The latter might be prejudiced, confused, careless, or uninformed.) However, this form of 'objectivity' applies to the knowledge system and related practice of any individual or group.

ding to the contextual model the meaning of a problem in a given context is determined by the *certainties* of that context. If the certainties of contexts  $C$  and  $C'$  are identical and so is the representation of their problems (or if the representations are equivalent in view of those certainties), then the problems have the same meaning — expressed somewhat sloppily: both contexts concern the same problem. Unlike Nickles, we do not require that all constraints are the same. More specifically, we do not require the identity of the relevant statements or of the methodological instructions. This has two important advantages over Nickles' approach.

First, the multiplication of problems is drastically cut down. As a result, the relevance challenge and the acceptance challenge will not arise in many situations. If two contexts differ only from each other with respect to the methodological instructions, their problems are identical (even in meaning). This result certainly is highly desirable: that two problem solvers tackle the problem in a different way should not entail any disagreement about what the problem is or when it is solved. So, if one of them comes up with a solution and is able to produce an argument to the effect that it is correct — see section ? — then the other will recognize it as a (or, if the problem requires a unique solution, the) solution to his or her problem and will accept it as the correct solution if the argument is sufficiently convincing. Exactly the same applies if two problem solvers have different relevant statements in their respective contexts. Even if they might have a quarrel over the question whether these statements are true or whether they are relevant to the problem, this does not entail and should not be taken to entail that they are trying to solve a different problem. If a contemporary of Kepler's was trying to determine the orbit of Mars, but was unaware of Tycho Brahe's data, it is not sensible to conclude that, for that reason alone, he was dealing with a problem different from Kepler's.

Next, not every change in the constraints of a problem leads to a change in (the meaning of) the problem. This too seems an advantage. Adding new relevant statements or new methodological instructions, or replacing some of the old ones, does not influence the meaning of the problem (as long as there is no change in the certainties). If a physician learns more about a patient's symptoms, this will not (usually) cause a change in the meaning of the problem "What is this patient suffering from?" Similarly, if a mathematician decides at some point to follow a different heuristic for a given proof, and changes nothing else, he or she

will still be dealing with the same problem. So, by defining the meaning of a problem solely with respect to the certainties, the identity challenge is greatly defused. Even if the other constraints change drastically, the problem will remain the same. It seems to us that our approach reduces the remaining challenges to their hard core: they confront us only when problems really change or are really different.

Actually, we already are in a position to show that the *identity challenge* is fully met. Consider a problem solver confronting some problem that cannot be solved in its present context. Changes to the relevant statements or to the methodological instructions have no effect on the identity of the problem. So, let us suppose that the problem solver has moreover to add, reject or replace some certainties in order to reach a solution. If the problem solver is proceeding rationally, these modifications will be justified. Indeed, the transition from one context to another can only have three causes: (i) a step that was justified in view of the previous context<sup>20</sup>, (ii) the solution of a derived problem, or (iii) the fact that new knowledge elements were accepted or previously accepted knowledge elements are rejected. As (i) can only affect the relevant statements and methodological instructions, it never changes the problem, whereas (ii) and (iii) might. However, even if the problem was modified in the transition from one context to the other, the problem solver is bound to see the new (meaning of the) problem as an improvement of the old one. Indeed, the modification is justified either by the *solution* of the derived problem or by the *acceptance* or *rejection* of knowledge elements — as the problem solver was supposed to proceed rationally, he, she or it has reasons to regard the solution as correct or the acceptance or rejection as justified. In other words, the problem solver has a justification to believe that the old (meaning of the) problem was a mistaken understanding of what the problem turns out to really be.

Our solution of the identity challenge then comes to this. The problem may indeed be modified over time. Strictly speaking, a problem solver often comes up with a solution to a different problem than the one he (she or it) started from. However, the problem solver has reasons to believe that the solved problem is the 'real' problem behind the vague,

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<sup>20</sup> It is largely a conventional matter whether such a step is considered as leading to a new context. The convention that it does has some theoretical advantages that we cannot discuss here.

ambiguous or confused problem from which the problem solving process started.

Let us return to the constraints that define a problem. We have argued that there are good reasons to restrict these to the certainties. Nevertheless, we need to discuss some objections to this position. A first objection is that we do not 'include' enough in (the meaning of) a problem itself. Indeed, we stated ourselves (in section 3) that the certainties limit the *possible* solutions of the problem, whereas the relevant statements impose conditions on the *correct* solution. Does this not mean that also the relevant statements determine what a problem amounts to? Hence, should they not be included *in* the problem? Consider two detectives investigating a murder case. If they accept the same certainties (including, for instance, that a person cannot murder someone unless by being present at the scene at the time of the crime<sup>21</sup>), but accept different relevant statements (for instance, because only one of them knows that the butler has an alibi), they may consider different outcomes as the correct solution to the "Whodunit?" problem. Two remarks are in order here.

First, the relevant statements are not independent of the certainties. As the latter determine the meaning of the problem, they will also determine that statements are or are not relevant to the problem. So, if two problem solvers share the certainties for a given problem, they will usually agree on the relevance of information. If both detectives deem the presence of the murderer at the scene of the crime as a certainty, they will also agree that the whereabouts of the suspects at the time of the crime is relevant for the problem.

Next, it is indeed possible that two problem solvers agree on the certainties but disagree on the relevant statements because one has information the other lacks. As a result of this, they will arrive at a different solution. But precisely in such cases, it is crucial that the relevant statements are *not* included in the problem itself. If it were, we could not account for the fact that, in such situations, problem solvers view each other's outcomes as *wrong* and start arguing for their own solution. If the

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<sup>21</sup> The fact that this belief is not accepted in all contexts does not entail that it cannot function as a *certainty* in the present ones. In some (interesting) cases, solving a murder may require that precisely this certainty is questioned (in another context) and eventually rejected.

relevant statements are included in the problem, such discussion is pointless: the solution of the other cannot be 'wrong', it simply is the solution to a *different* problem. Such a view would force us to the absurd conclusion that both detectives might be 'right' with respect to *their* problem, even if they identified a different person as the murderer. Obviously enough, the detectives are not dealing with two different problems; one of them is lacking relevant information.<sup>22</sup>

Having argued that we do not leave out necessary constituents of problems, we might have to face the opposite contention: that we 'include' too much in (the meaning of) a problem. It seldom happens that two problem solvers completely agree on the certainties for a given problem: terms rarely have the same connotation for all problem solvers. For instance, different detectives may have different ideas about the typical murderer. It seems then that our model, just as the constraint-inclusion model, discriminates between as many problems as there are problem solvers. If this is so, how can we ever hope to meet the relevance and acceptance challenge? Well, we shall. But in order to do so, we need to describe some aspects of the contextual model that were left out of the picture up to this point.

### 6. *The role of communication in collaboration and acceptance*

For an individual, a context (its problem and constraints) is mainly a mental entity. Possibly, the individual makes some notes and drawings, consults some books, etc. Still, the individual need not 'objectify' all elements of the context. It is not even necessary that the individual is able to express in words (or by drawings or diagrams) all his or her certainties, relevant statements, or methodological instructions.

If an individual functions as a member of a research group, or if he or she wants to present his or her solution to others, and to argue for this solution, *communication* is required. Typically, what is and can be communicated is not dependent on the meaning of the problem for the dif-

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<sup>22</sup> We need to point out that this paragraph does not form an objection to Nickles' position. He would agree that one detective is lacking relevant information. However, he is only able to arrive at this conclusion by connecting problems to research traditions — we criticized this position in section 4.

ferent parties. That individuals assign rather different meanings to (even all) words, need not in any way prevent them from arriving at *perfect communication* about some topic. Meanings are much more sophisticated than anything expressible in any language. If differences in meaning do not surface in communication, they simply go unnoticed to the participants. But even if the participants realize that the meanings of some terms are different, it is still possible that they justly believe that a statement *A* made by one of them refers to a state that is correctly described by *B* in the language of the other participant. So, even then, perfect communication may obtain with respect to specific problems. (For a more detailed and more precise formulation, see Batens 1985 and 1992b.)

Let us consider an example. Suppose, that, in the beginning of the nineteenth century, an adherent of the caloric theory of heat and an adherent of the kinetic theory of heat are trying to determine what will be the temperature of the mixture of two samples that, at the outset, have a different temperature. There can be no doubt that "temperature" has a different meaning for them (and they may or may not be aware of this). For the first, the temperature of the sample refers to the amount of caloric present in it; for the other, the term refers to the kinetic energy of the molecules.<sup>23</sup> Still, with respect to the aforementioned problem, they are perfectly capable of understanding each other. When one of them states that the temperature of the first sample is 34 centigrade, the other will be able to 'translate' this, and will be able to use this result in solving the problem. Moreover, both will perfectly agree on the conditions under which the problem will be solved. On many other topics, they may not only disagree but communication may be rather difficult. Still, all this is no hindrance for communication on the problem under discussion.

As we suggested, communication is essential for understanding the functioning of a research group as well as for the acceptance of solutions by third parties. Let us first consider collective problem solving.

If a research group tackles a problem, the elements of the group's context are restricted to what is communicated among its members. This

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<sup>23</sup> Referring to footnote 2, we note that it makes absolutely no sense to refer in the present context to 'what heat really means'. Even if there is such an entity, it is very well possible that no human ever discovers it. Moreover, that entity is plainly incapable of enabling us to understand any communication between humans that did not yet discover it.

may be studied from their discussions, research notes, drawings and diagrams. The members of the group will not in general (and need not) assign the same meanings to the problem or to its constraints. In this sense, their individual contexts may be different. Nevertheless, it is important to distinguish these contexts (that may explain why one member comes up with an idea rather than another) from the context for the group.

It is equally important to point out that the individual contexts of the members of a research group are highly dependent on the fact that they are tackling the problem *as a group*. The latter presupposes that they (largely) agree on what the problem and its constraints are. This agreement, however, is not an agreement on the meanings of words (drawings, etc.) but an agreement at the level of communication. The members will give up personal views that conflict with the group view, but *only* in as far as such conflicts surface in communication between the group members — other differences in meaning are doomed to go unnoticed.

The limits of communication also play an important role in the acceptance of a solution by others. Here too, the problem, the solution, and the arguments supporting it, are 'objectified'. Not their meaning is communicated, but sentences, drawings, diagrams, and the like. The multiplicity of problems deriving from individual differences in contextual certainties (discussed at the end of the previous section) has only effects for the acceptance and relevance challenges in as far as this multiplicity surfaces in communication. As a result, we did not include too much in the definition of a problem. The full meaning of a problem and its constraints determines whether a solution is reached within the context, but only the 'communicable part' plays a role with respect to the relevance and acceptance challenges.

There is an interesting relation between solving a problem and arguing for the solution, and this relation has effects on the communication of solutions and their acceptance. Consider a problem solver that arrived at a solution — an answer to a question or an object or state of affairs realized. To consider the hardest case, let it be an individual problem solver. When shall a rational problem solver consider the solution as correct? If the problem was an intellectual one, the problem solver needs

an argument<sup>24</sup> leading from the relevant statements to the solution (the answer to the question). If it was an action problem, then, unless the end state was completely determined from the start, the problem solver needs reasons to realize one state rather than another one, and needs an argument that the state realized instantiates the goal.

An example of an intellectual problem is "To whom did Beethoven address his famous letter 'An die unsterbliche Geliebte'?" Here, we are searching for the name of a woman that was *indeed* the addressee of Beethoven's letter. Only when we have an argument to that effect, we can consider the problem as solved. For this reason, putting the names of all possible candidates in a high hat, and drawing one of them, would not count as a solution. So, we either need reasons to eliminate all but one of the possible 'candidates' (for instance, if we know the period in which the letter was written, we can eliminate all women that were not acquainted with Beethoven in that period) or we need a 'positive' argument for one of the possible candidates.

Next consider an action problem. Researchers searching for a new vaccine for some disease will not randomly mix substances and inject mice with the mixtures. Rather, they will try to find out what the composition of the vaccine should look like, and they cannot consider the problem as solved before they have plausible arguments to the effect that the vaccine indeed cures the disease. Sometimes the precise state that has to be realized is fixed from the outset (for example, if the goal is to paint my house). This, however, is just a limit case: it is obvious whether the state produced realizes the goal.

That this relation between solving a problem and arguments for the solution has effects on the communication of solutions and on their acceptance is rather obvious. It is generally accepted, and justly so, that an argument cannot in principle be private. If the problem solver cannot communicate the argument for the solution, or if the argument loses its force (with respect to the problem *as the problem solver sees it*) while being communicated, then a rational problem solver should conclude not

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<sup>24</sup> The arguments need not be *deductive*. Although, we usually prefer arguments in which the premises necessarily entail the conclusion, many problems force us to stay content with a weaker argument.

to possess an argument.<sup>25</sup> In other words, in order to consider a problem as solved, it is necessary that the problem solver is able to phrase an argument that is in principle communicatively effective.<sup>26</sup> This entails that solving a problem requires reconstructing the solution in such a way that it can in principle be communicated.<sup>27</sup>

### 7. *The acceptance of problem solutions*

Differences between problem solvers may have a considerable impact on the acceptance of a new solution. The original problem solver may have relied upon some specific constraints that make acceptance of the result problematic. Moreover, researchers confronted with the solution may accept some constraints that differ from the general constraints as well as from those of the problem solver. In this section, we discuss how a new solution may be accepted by a third party, even if its acceptability and its relevance for the party's corresponding problem is originally very low. But first, we should discuss some characteristics of evaluation processes.

It is typical that scientists do not simply present their solution to the other members of the relevant community, but that they try (and that journals justly require them) to show why the proposed solution is *correct*. For intellectual problems, they offer *arguments* with the proposed solution as the conclusion; for action problems they will describe or point

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<sup>25</sup> We obviously disregard cases in which the problem solver does not speak the native language or is a 'pedagogical' disaster. The point is whether the problem solver has reasons to believe that the argument can in principle be communicated.

<sup>26</sup> Hence, the argument should be convincing if reduced to 'structural' terms: it cannot depend on hidden suppositions or connotations. We surmise that this was one of the reasons why Mach (in his 1917) required that interpretations should be eliminated from scientific theories, although he admitted that they sometimes are essential in the generation of a solution. If this hypothesis is right, we agree with Mach on the requirement for a structural formulation of solutions, but disagree on the boundaries of structural formulations.

<sup>27</sup> In the case of a collective problem solver, such an argument will be produced as a result of the communication within the group, except when all members of the group share some prejudices or specific views that will make the argument ineffective outside of the group.

to the object or state produced and argue that it instantiates the goal.<sup>28</sup> Hence, evaluating the solution of a problem comes down to evaluating specific *arguments*.

The evaluation of an argument involves two activities: one has to examine whether the premises are acceptable *and* one has to check whether the conclusion follows from the premises. Expressed in terms of the contextual model, one has to examine the relevant statements (Are they correct? Are they indeed relevant for the problem? Are they complete? ...) and one moreover has to verify whether the proposed solution follows (with logical necessity or with sufficiently high probability) from the relevant statements. Even the latter activity is not a passive matter. And if the argument is defeasible, then one should examine whether *all* relevant statements have been taken into account, whether a counter-argument or an argument for an alternative solution can be produced, etc.

Although the evaluation process is not identical to the original problem solving process, it is itself a problem solving process and moreover displays certain similarities with the original process. Just like the original problem solvers, rational assessors have to form an articulate idea of the problem, the relevant statements, the way in which the correct solution can be obtained from these, ... The main difference is that they have not to go through all the wanderings that may have been included in the original problem solving process, because they have access to a guiding 'example' of a presumably correct solution.<sup>29</sup>

It is worth pointing out that solutions may be evaluated with different aims. The question may be whether the proposed solution should be viewed as correct with respect to the problem solver's problem (irrespective of the question whether that is important or even sensible). In this case, assessors will have no quarrel with differences in constraints. The question may also be whether the solution should be accepted as a valuable contribution for the domain (a typical question referees are dealing with). Here, assessors will take into account only the general constraints,

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<sup>28</sup> In both cases, they will rely on the arguments they have been constructing during the problem solving process.

<sup>29</sup> The problem to evaluate a given argument may itself be *ill-defined*. Solving this problem may require creativity. For example, someone may consider a premise as unacceptable but lack a suitable refutation. Similarly, constructing a counter-argument for the conclusion may prove to be far from trivial.

and leave room for extensions and *some* variation. A still different question is whether the assessor should accept the solution as correct with respect to his (her or its) 'corresponding' problem. Assessors then will confront the problem and constraints of the problem solver with their own problem and constraints.

We now come to the question when an evaluation process leads to *acceptance*. A first important observation is that not all differences in constraints have effects for the acceptability of the solution. That the problem solver and the assessor differ with regard to methodological instructions, need not prevent the acceptance of the solution. There are numerous examples of logicians (Henkin, Gödel, Church, Craig, ...) that, relying on specific (combinations of) skills, produced metatheorems that no logician of their days could produce (except perhaps by a much larger effort). Nevertheless, most of these results were immediately accepted by the logical community.<sup>30</sup> Similar examples may be produced for other sciences. Of course, some specific methodological instructions may result in the presence of specific relevant statements — this is the topic of the following paragraph. Similarly, some differences in certainties may be immaterial for the acceptability of the solution. Even if these differences surface in the communication of the problem, the solution, and the arguments, it is very well possible that the assessor regards them as inessential or is able to translate them in terms of his or her certainties. When Mendel's laws were rediscovered by evolutionary biologists, they were reinterpreted but the figures were not changed. So, the only differences in constraints that may have an influence on the acceptance of the solution are (i) differences in the relevant statements and (ii) differences in the certainties that prevent the problem, the solution, or the argument from being 'translated'.

Let us first consider differences in the relevant statements. The easy case concerns new observational results that are arrived upon by generally accepted means. Such 'specific constraints' of the problem solver will be easily adopted by the assessor, possibly after the latter repeated the experiments or the measurements. If the assessor lacks the skill to repeat

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<sup>30</sup> Gödel's incompleteness theorem was the main exception. Presumably he combined so uncommon techniques that, for a while, some logicians were convinced he had derived an inconsistency from arithmetic. The few people that still question some of the limitative theorems today presumably belong to the logical fools parade.

the observations — remember Joule's skill to arrive at very precise temperature measurements — he or she might master that skill, recur to the help of someone who masters it, or, in some cases justifiedly, simply accept that those results are reliable. If the assessor rejects some of the observational results (because of conflicting results, or simply because they are considered not worth repeating), or judges that some relevant statements were left out of account, the assessor will reject the solution.<sup>31</sup> However, as we shall discuss below, this need not be the end of the confrontation. The disagreement on the relevant statements is more fundamental than the disagreement on the solution of the problem, and, in principle, the latter is made dependent on the former.

What about differences in certainties that are judged essential or that prevent translation to an acceptable solution? In many cases, these differences will not be eliminated during the evaluation process. Assessors will view the proposed solution as 'impossible' or deem it the solution of a 'wrong' or even nonsensical problem. In Copernicus' days, his solution to the problem concerning the place and motion of the sun and the planets was rejected by many. Given the general certainties for the problem, the solution was beyond the set of possible solutions. Similarly, Newton rejected several problems of Kepler's (for instance, the question what caused the distance between the planets). Given his specific constraints, these problems simply did not make sense.

In sum, an evaluation process leads to acceptance, if and only if, possibly after the assessor adopted some specific constraints of the problem solver, (i) there is no essential difference in certainties (or translation is not prevented), (ii) the relevant statements correspond, and (iii) the assessor established that all relevant statements have been taken into account and that there is an argument leading from the relevant statements to the solution (or, in the case of action problems, to the statement that the solution is correct).

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<sup>31</sup> Occasionally, someone may consider the solution as correct, *but* for different reasons than the problem solver; the problem is considered as solved, but the road along which the solution was arrived at is rejected. In this case, the critic has to produce an alternative argument. One may think here of Clausius who formulated new derivations for almost all the results of Carnot (see Meheus 1993, and 199+a); unlike Carnot's derivations, those of Clausius were compatible with the idea that heat and work can be converted into each other.

As we announced, the fact that most or even all assessors initially reject a solution does not preclude their accepting it at a later time. When a solution is deemed sufficiently interesting, assessors that reject it will do so by presenting *arguments* against it, or by defending an alternative solution. This gives the original problem solver as well as the other members of the community the opportunity to react. The effect of such a (usually written) 'dialogue' is that (on all sides) beliefs are adjusted.

When there are differences about the relevant statements (and no essential differences in the certainties), each party will try to gather supporting evidence for its own 'deviating' constraints and will try to undermine those of the other. If the dialogue is rational, this process will usually<sup>32</sup> result in converging views on the relevant statements, even if there may be reinterpretations on all sides. As a side effect, the dialogue will usually result in new empirical data for all parties. With the growing convergence, the solution may ultimately be accepted or rejected on the basis of general constraints.

Matters are only a bit more complicated when there are essential differences in the certainties. When people learn about such differences, the typical effect is that they become aware of their own prejudices and hence that a wider range of possibilities opens up for them — including a wider set of possible solutions for the problem under consideration. This entails, among other things, that the meaning of the problem becomes more general<sup>33</sup>. Indeed, previous certainties (that act as necessities) are turned into relevant statements about which there are disagreements. Once a more general problem is thus obtained, more participants will be dealing with the same problem (as far as communication is concerned). Disagreements about relevant statements will be attacked as explained in the previous paragraph. As an example, think of the debate between Copernicus and his contemporaries. As a consequence of this debate, the problem concerning the positions and motions of the planets (as seen by the group) became more general: not only geocentric models were regarded as possible solutions but also heliocentric models.

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<sup>32</sup> The main exception is where deep-rooted ontological or methodological differences keep resulting in different interpretations of the observations.

<sup>33</sup> We assume that the meaning of a problem P is more general than the meaning of a problem P', if and only if all possible solutions for P' are possible solutions for P, but not conversely.

An important aid in the acceptance of certainties is the *success* of the solution. Even if a solution is 'impossible' according to the general certainties, its overwhelming empirical successes will cause rational researchers to become more and more critical about their theoretical objections, and eventually to change their certainties. In other words, if a 'revolutionary' solution turns out to have an overwhelming explanatory and predictive power (as compared to its rivals), rational assessors will accept it, even if this forces them to adjust their certainties. Newton's theory forms a nice example. It *was* in conflict with central general certainties (mainly because of the *actio in distans*). Still, the impressive success of the theory led not only to its acceptance but also to a profound revision of some general certainties.<sup>34</sup>

It is also important to note that the acceptance of solutions to complex problems does not necessarily proceed in a global manner: in some cases, assessors accept *parts* of a proposed solution. We know, for instance, that Galileo's acceptance of Copernicus' model involved several steps: gradually he accepted more and more elements of it (see, for instance, Drake, 1987). Another example concerns Harvey's theory. As Mowry (1985) shows, individual researchers adopted specific elements of his theory and combined them with elements of older theories.

All this clarifies how researchers that start off with diverging certainties, may reach a context in which all essential differences in meaning have vanished. Put differently, researchers who speak at first a 'different language' and consequently view each other's solutions as impossible, may arrive at a situation in which they are able to communicate, and sometimes even reach agreement, on the problem under consideration.

The process during which researchers 'tune' their constraints to one another may require a considerable amount of time (especially when there are essential differences in the certainties). Moreover, during this process, the original solution may undergo a serious transformation. (Darwinism is a good example of both the latter claims.) An accurate historical record of such processes may be quite complicated. But it *is* possible, for specific cases, to examine which researchers participated in

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<sup>34</sup> We do not claim that *empirical* successes have precedence over others. Nor do we think that the 'facts' have precedence over theoretical insights. The central issue, we think, is that accounting of the *pro* and *cons* of opposed conceptions of (scientific) knowledge may force scientists, in view of the facts, to give up one of them.

the debate, and how they adjusted their beliefs in function of the debate. In other words, even if we take into account individual differences between researchers, we are able to provide a rational explanation of the way in which, in specific cases, scientists arrive at a consensus.

Did we meet the relevance and acceptance challenges? We think we did. Our goal was not to show that new solutions are always accepted, for they are not. The only challenge was to show that solutions, that derive from the specific set of constraints of some individual or research group, may be accepted by the disciplinary community, even if, originally, the general constraints were very different from the specific ones. This challenge we have amply met. Moreover, we met it by propounding a hypothesis about the circumstances under which this acceptance will (rationally) take place. This hypothesis may be tested by historical case studies.

### 8. *In conclusion*

We have shown that the contextual model meets the challenges of section 2. We moreover hope to have convinced the reader that it is theoretically powerful and that it is realistic with respect to the history of science. All this, however, will not by itself convince the reader of the superiority of the contextual model over alternatives, especially as the model deviates from standard epistemological conceptions in several respects.

Further arguments for the model are advanced in other papers and cannot be reproduced here. Still, we want to point out that it deserves attention because its underlying concept of rationality combines some interesting features. It enables one to do justice to problem solving processes that are specific for individuals and small groups. It enables us to understand the essential controlling role of consensus formation. And it provides the mechanisms that connect problem solving processes with consensus formation. Only by combining these three features, a problem solving model is capable of preventing that either one end of the social spectrum, or the relation between both, is abandoned as irrational.

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