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DECONSTRUCTION IN A
'THINKING' SCIENCE:
THEORETICAL PHYSICISTS AT WORK

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4Martina Merz^{1,2} and Karin Knorr Cetina^{2,3}

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ABSTRACT

In this paper we apply the laboratory study approach of the new sociology of scientific practice to a 'thinking science': theoretical physics. To specify the work and accomplishment of theoretical physicists we choose the notion of deconstruction. Deconstruction involves the expansion of a concrete object such as an equation into a series of other objects upon which the 'hardness' of a problem can be shifted and distributed. In solving an equation, however, the determinate path of a deconstruction method needs to be supplemented by the exploration of clues and guesses, trials and tricks. We go through devices and iterations thereof, which physicists mobilize in dealing with hard problems: formal deconstruction, detours and tricks to identify a working deconstruction, variation, "doing examples", modelling, and, finally, thought alliances between subjects.

1. Theory Division, CERN, 1211 Geneva 23, Switzerland
 2. Institute for Science and Technology Studies, University of Bielefeld, P.O. Box 100131, 33501 Bielefeld, FRG
 3. Faculty of Sociology, University of Bielefeld, P.O. Box 100131, 33501 Bielefeld, FRG
- e-mail: merz@cernvm.cern.ch, knorr@sozjur.uni-bielefeld.de

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1. Deconstruction: The work of theoretical physicists

This paper is a first attempt to apply the laboratory study approach of the new sociology of scientific practice to a ‘thinking science’: theoretical physics.¹ Laboratory studies centrally rely on the direct observation of scientific work. Theoretical sciences, thought of as paper-and-pencil deskwork sciences, do not seem to be easily accessible to an observational approach. The present study overcomes this difficulty by placing a premium on participation: It uses one observer’s capability to interact with theoretical physicists as a member of their culture to explore the intricacies of theoretical work.² The goal of the study underlying the present paper was to explore the theoretical physics’ epistemic culture³: its knowledge practices, its relation to objects and definition of (epistemic) subjects, the meaning and structure of the theoretical in a ‘thinking science’. In this paper, we will attempt to unravel the rhythm, the sequencing, the logic and dynamics of doing a computation in theoretical physics – and the struggle with objects through which this dynamics emerges. This struggle defines theoretical physicists and forces them into a pact with one another. It also specifies the hidden structure of a theoretical physics computation as a curious oscillation between “straightforward” algorithmic practice and “being stuck”.⁴

The focus of the original laboratory studies was the construction of scientific facts. The notion of construction was an attempt on the part of the authors of these studies to come to grips with the instrumental, symbolic, and social processes through which natural objects were observed to be constituted in experimental science. In this paper, we choose the notion of deconstruction to specify the work and accomplishment of theoretical physicists. Deconstruction is a concept much used in postmodern social science and literary criticism to challenge the traditional concepts of the author, of texts, of coherent analysis and interpretation. Deconstruction, in these fields, implements and explores differences – for example the difference between a tribal ethnography and the rhetoric interpretation of this ethnography as a text⁵, between interpretative vocabularies used by participants and analysts and their reflexive and unreflexive uses⁶, or between the voices and meanings of a literary text⁷. Theoretical physics also operates within a regime of deconstruction, at least with respect to some important components of theoretical work. However, deconstruction in physics is built less on difference than on the expansion of a concrete object such as an equation. The object is developed and unfolded into a series of other objects, it is encircled and replaced by them. This object expansion and multiplication deconstructs the original problem; at the same time, it opens up a space for manipulation and inspiration. Within this space, the ‘hardness’ of an equation can be distributed onto new objects; through disassembling the problem, hardness can be shifted between individual components, the value of these components can be graded, the composition of the whole restructured, and the new objects can be called upon to inspire physicists to come up with a “trick” that

assists in finding a solution.

In theoretical physics, the determinate path of a deconstruction method continually needs to be supplemented by non-determinate walks through the dark and uneven terrain of clues and guesses, trials and tricks. These walks are aided by the inexact compass of “experience” and a repertoire of landmark examples (the capital of a field) which point the way. Nonetheless, obstacles never really disappear during these walks. Instead, they vanish from sight in some places, only to pop up again in others. Much like the fiends and noises that accompany an anxious traveller on his or her way through a dark forest, they travel with scientists, troubling them, pinching them, and occasionally blocking the way in unexpected spots. To manage the way out of the forest, other scientists are recruited into these travels – they are asked for guidance on segments of the way, and pressed to walk part of the way on their own when a weary physicist gets stuck. The collaborations that theoretical physicists enter with colleagues have the character of friendships as well as pacts. Pacts strengthen them in their concrete struggle with obdurate objects, and friendships sustain the possibility and recurrence of a pact.

2. Objects and subjects

Objects in theoretical physics are physical states, physical operators, physical quantities and the like – entities which physicists themselves “construct” (native term) and define. Objects pose problems, for example, when they are linked in an equation that has to be solved by a “computation”. Objects and the problems they pose cannot be controlled at will. Despite their human-made character, they confront the human world with obdurateness and ‘hardness’. In experimental high energy physics, a detector is a human-made machine, which not only demands to be designed and constructed, but to be continually observed, measured, and understood. Accordingly, experimental high energy physicists spend much of the lifetime of an experiment trying and learning to understand “the behaviour of a detector”. Like experimentalists, theoretical physicists concern themselves with self-knowledge: with the knowledge of a self-created object world and its consequences. However, in theoretical physics, the obdurateness and ‘hardness’ of a problem seems originally concentrated in a spot – for example, in a single, inconspicuous-looking “cohomology equation”:⁸

$$Ax = 0 .$$

The equation becomes less ‘trivial’ when you consider its elements. The basic objects of a cohomology computation are an “operator” A (the “BRST-operator”) and an infinite number of “states” x as elements of a particular set called “space”. The operator acts on each state and transforms it into another state. For a given operator – which characterizes the underlying theory (as in the observed case various gravity theories) – the problem is

to find a particular subset of the space, namely those states which the operator transforms into zero:

$$x \xrightarrow{A} 0 .$$

The total of all states satisfying this requirement is then called the “cohomology” of the operator, and each state in the cohomology is called a “physical state”.⁹ The requirement that each physical state be transformed by A into zero can be stated in the form of the above equation, $Ax = 0$ (see fig. 1).

(Figure 1 about here)

The problem consists in solving the equation. The solution may appear obvious, but it is in fact not just $x = 0$. To see the obdurateness of the equation, consider A to be a matrix and x to be a vector, both with an infinite number of elements: A does something much more complicated than simply multiplying x by a factor (it transforms the states), and x is not just a number but an object with a complex structure.

The original equation hides more than it shows – the complexity of its components, their differences in kind, and the fact that the equation, by proposing an equality, legislates a requirement that has to be fulfilled. “Understanding”, in this case, is needed for the structure comprising the BRST-operator, the space and the states, a structure that physicists call a “model”. Understanding consists in finding out which states fulfill the requirement of being transformable by A into zero.

The search for an answer to this problem can be seen as an attempt on the part of physicists to conclude a pact with their objects. We call a pact an alignment reached over the time between scientists and objects, which allows scientists to convince themselves that they understand, and which allows objects to retain their independence – the independence to strike back, the independence to suggest and enhance further work, the independence to extricate themselves from any pact. An alignment comes about through an attempt to engage the object, the above equation, in a computation. Engaging an object is not usually a straightforward process. In fact, theoretical physicists continually run up against the hardness and obdurateness of objects: they need to live up to it, work through it, prove themselves against it, extract their own brilliance and sense of self from it. Thus, while the physicists, who are matches for the hardness they choose, work on new theories, the hardness of theoretical problems seems to work on them. Consider for a moment the vocabulary in terms of which physicists talk about computations. Physicists “get stuck” many times while working on a computation. Working toward a solution does not mean simply doing a calculation, but finding ways out of being “stuck”. But not only the physicists get stuck: so does the computation. Physicists and computations are stuck together against the resistance of the equation. In the beginning of a computation, the objects’ independence asserts itself forcefully, and ways must be found for the physicist to

“gain control”. Elsewhere the notion of a reconfiguration of ‘self-other-things’ was used to describe this process.¹⁰ A reconfiguration of self-other-things changes not the subjective field of perception of a scientist, nor features of the world independent of science, but the relationship between scientist and object (or between the underlying social order and the natural order). In the present case, reconfiguring the relationship rather literally means reconfiguring the object. The equation is changed by becoming “reduced”, “converted”, “divided up”, “cut”, “split” or “decomposed”. “Reducing” or “converting” is done by “cutting” or “splitting” the computation into smaller components, which have to be “combined” or “recombined” later to arrive at final results. The concrete meaning of such deconstructions will become clear in subsequent sections. Their accomplishment is that they try to “reduce” an overbearing object to “manageable” size, in order to prevent it from getting “totally out of hand”.

Alignment, then, first requires reconfiguring the entity with which the alignment is sought. But there is also a second means. In theoretical physics, the pact with objects is often extended to a triangular structure: A second theorist (and frequently a third) is brought into the picture. In addition to reconfiguring the object one can reconfigure the side of scientists. To gain control over an equation, physicists collaborate with one another (see fig. 2).

(Figure 2 about here)

The pact with objects, then, requires a pact among subjects. In this paper, we will not focus on the relationships between subjects. Suffice it to say that such collaborations can also be unravelled along the lines of their rhythm, their sequencing, their logic and dynamics. Theoretical physicists seemingly learn how to collaborate in early contacts with their thesis supervisor and with fellow students, as they learn how to handle objects. Like these teacher-student relationships, the thought alliances physicists form later also contain an element of consultation. However, thought alliances are also sustained by and embedded in “friendships” which develop from physicists spending time together in one place. Friendships, too, are marked by the parallelism of alignments – by the conduct of lives mostly spent in physically very different locations (after having stayed at the same institute or department for some time), but continually ‘paralleled’ through electronic mail. Through electronic networks, the exclusive, singular and intense relationships that physicists purchase in their ‘pact with objects’ are extended far beyond their desk – in regard to distances breached and people reached. They are also continued through (and enfolded in) the lighter and more distant understandings of the non-consummated friendships of paralleled lives.

3. Deconstruction and its epistemic profit

Let us focus, in this and the next three sections, on the desk, and start by asking what a working deconstruction of a cohomology equation $Ax = 0$ consists of. When computations and the objects they involve become complex, special techniques can be used to reconfigure an equation. Simple forms of deconstruction are known from school. For example, the calculation of

$$(2 + 3)^2 + (3 + 4)^2 = ?$$

can be solved by first calculating

$$(2 + 3)^2 = 5^2 = 25,$$

then

$$(3 + 4)^2 = 7^2 = 49,$$

and then summing up the results in a third step: $25 + 49 = 74$. The term has been split into two contributions computable independently from each other. When the problem is harder, as in $Ax = 0$, the deconstruction still proceeds through a series of stepwise manipulations, but the steps become more complex. For this purpose physicists use the “spectral sequence technique” (SST), recently taken over from mathematics, where it developed in the 1940s in the field of “homological algebra”. The SST has since become a standard technique; its first step consists in expanding the objects, the second in reshuffling their components, and the third attempts a sequential reordering of them:

1. Deconstruction through expanding the object: The operator A and the states x are thought of as composite objects, which are built up through the multiplication and addition of more elementary operators or states. The first step in deconstructing these objects consists in “expanding” A and x into their components in such a way as to render the objects’ constructedness explicit. For example, A might be:

$$A = \sum_{n \in \mathbb{Z}} c_{-n}(L_n + L'_n) - 1/2 \sum_{m, n \in \mathbb{Z}} (m - n) : c_{-m} c_{-n} b_{m+n} :$$

Here a “mode expansion” has been performed. The modes b_n and c_n – labelled by their energy levels – are common building blocks of both A and the states. Often, the modes L_n and L'_n are themselves composite, and have to be specified in supplementary equations.

To simplify matters (the following procedure holds irrespective of the energy-labels of a mode), we will from now on simply speak of a term bcc instead of, e.g., $b_{m+n}c_{-m}c_{-n}$.

2. Reshuffling components through building in degrees: Deconstruction through expanding A and x is but the first step in dealing with a problematic equation. To ‘simplify’ the equation, another step is needed, one that attaches “weight factors” to each component. A weight factor is just a number (also called a “degree” or a “grading”). Assume, for example, that one of the terms that make up A consists of something like the product

bcc . A degree is now attached to b , and to c (how these degrees are chosen is discussed in 4), say for instance: degree -1 to b and degree 1 to c . Since degrees can be summed up, the assignment of degrees to the basic components results in the attribution of a degree to the whole term bcc , which, in the case discussed, is $(-1) + 1 + 1 = 1$. Each term in A and correspondingly in x , now has a degree attached to it. In a further step, all terms with the same degree are joined together, such that A and x are now made of components of different degrees. The grading ‘reshuffles’ the order of the original components, ‘regroups’ them, and gives each component a weight factor. Through what physicists call “building in discrete parameters”, a preliminary ordering (or a reordering) is achieved.

3. Sequential reordering: The lowest allowed degree attributed to a term in A is zero. A can therefore be rearranged as the sum of components of sequentially increasing order:

$$A = A_0 + A_1 + A_2 + \dots$$

This sum is chosen to have only a finite number of terms, which can vary from problem to problem and from grading to grading. The index attached to the components labels the degree of each particular term. States x are sequentially reordered in the same way. As a result of the grading procedure one has now deconstructed A and x into an ordered sequence of components.

What is the epistemic profit of the above deconstruction and reordering of objects? How does deconstruction, understood as the expansion and re-evaluation of components, transform the problem? Deconstruction distributes and dissimulates the hardness of the attempted computation. If you think of the hardness as of a fixed property encaged in the original equation, then deconstruction sets this hardness loose. It allows the work it requires to be shared by many objects and steps, and it allows it to be moved from one object to another as the calculation proceeds. But not only has the problem been transformed through its decomposition into components: so has the relationship between physicist and object, to the advantage of the physicist.

The obtained rearrangement allows for the sequential input of solutions already achieved, of hardness already conquered. Not only can smaller problems be solved more easily, but each solved component strengthens the physicist for the next step. Instead of the original equation $Ax = 0$, one now has to solve a sequence of equations, which are graded in the sense that the result of the first step – the solution of $A_0x = 0$ – is used as input to the second step – the computation of $A_1x = 0$ – and so forth. When objects are deconstructed through the SST, the computation is not only deconstructed into a sequence of calculations, but the intermediate results are gradually narrowed and brought nearer to the final result in the sense that each step results in a reduction of possible solutions for the next step. For example, the first step might leave you with 6 physical states; the

second step rules out 2, leaving you with 4 remaining states whose explicit expressions were slightly changed in the course of the second step, and the third step no longer changes the number of steps. In general, a finite number of steps is sufficient to solve the problem. The final solution – the cohomology that was looked for – consists of the outcome of the last step. The number of required steps depends on the particular problem (i.e. on the form of the BRST-operator and the choice of the space of states) and the grading chosen. Some problems can be solved by just one step. Physicists say that the sequence “converges”, meaning that successive terms give “finer and finer approximations” of the result they were looking for. The sequence is said to “collapse” when the last required step is reached.

4. First iteration: Heuristic rules for shifting the hardness

With the above deconstruction of problem and object, each step has become easier to handle than the original. However, accomplishing a working deconstruction is itself problematic: the selected components are only willing to cooperate if they are aligned with each other in such a way that every step is manageable. The difficulty can be characterized in terms of a ‘trade off’ process through which amounts of hardness are shifted from one step to another. The shifting has to be done in such a way that all steps remain or become solvable. Thus, the first step in a deconstruction can only be simplified at the expense of the following steps. Since an appropriate distribution of hardness has to do with the grading chosen, several heuristic rules are invoked to help achieve a well-aligned series of steps and a well-balanced distribution:

- Choose a grading such that you need as few steps as possible, since the first step is the easiest, and each further step becomes more complicated.
- Choose a grading such that the lowest term (i.e. the solution of the first step) comes closest to the cohomology you want to calculate.
- If you have several gradings that require the same number of steps, choose the one for which the calculations are simplest.

All these rules sound “fuzzy”, as a physicist said, but this fuzziness represents the complexity of the problem: There is no such thing as a “straightforward” path towards the end result. Without proceeding through variations as one “tries out” different degrees, no “right” way – i.e. no way that “works” – can be found (see also 6.1).

Besides heuristics that help in appropriately distributing the hardness of the problem there are ‘constraints’ which have to be met and which help to achieve a suitable grading. There are, on the one hand, gradings that are “legal” and those that are not, and gradings that are manageable and those that are not:

- “Legal” gradings: The deployment of the mathematical technique requires certain

mathematical properties to be fulfilled, like the above-mentioned rule that the term with the lowest degree in A must have degree zero. No negative degrees are allowed.

– “Manageability”: Other requirements hold for the sake of manageability. For example, one does not know how to deal with a zero-degree term in A that consists of three basic components such as the term bcc discussed before. These terms are not forbidden in a mathematical sense. If however a grading is chosen such that the lowest-order term is of this type, “you are stuck since you don’t know how to do the first step”.

Through physicists’ grading rules, the hardness of a problem can become manageable. Deconstruction, however, does not always work. Certain deconstruction steps may turn out to be impossible, ineffective within a particular problem context, while they had succeeded before, in another context. Other strategies may lead to unprecedented difficulties. In the course of constructing the deconstruction of objects there is no a priori way to avoid “getting stuck”.

5. Second iteration: “Being stuck”, detours, tricks, and an “ansatz”

‘‘I am stuck on computing the BRST of the W-charge -- basically I could not see any way of avoiding the hard work. If you consider looking at such a problem of any relevance, please do so.’’

(e-mail 12; P to N on 24 Sept.)

Theorists expect that new obstacles will ‘pop up’ all along the first road chosen towards a solution as a typical feature of their work; and they do. A further challenge in concluding a pact with objects is to find out how to get around these obstacles, either by clearing the path or by looking for an alternate route. Physicists announce the challenge by declaring themselves “stuck”. How are physicists caused to be “stuck” by objects? By being forced back or by being confronted with an overcomplex situation in which they lose their grip.

“Being stuck” can mean reaching a point where you have to go back, for example to try out degrees through doing a ‘variation’ (see 6.1). But theorists are stuck also when they lose confidence in the path they pursue, when they are not sure which alternative to choose or what the alternatives are. Physicists might lose confidence when they do not see how to “avoid the hard work”. They might be able to proceed with the computation, but “it’s a mess”, they have “no control over it except by writing notebooks full of equations”. Too many steps are required and too many terms have to be included so that “computations really get totally out of hand”. When physicists are stuck, the control promised by a particular avenue is lost and they “run out of ideas” on how to regain it.

“Being stuck” is a description whose application depends on the physicists and on time: on the expected effort required for solving a particular problem, on the effort they

are willing to invest, on the personal style of the researcher – some theorists are more persistent and acknowledge that they are “stuck” later than others. It also depends on predicting the future. Alternative paths sometimes look unmanageable, whereas later they turn out to constitute a way out. “Being stuck” builds reflexivity into hard problems: it forces theorists to reconsider their strategy for solving them. Efficiency, effort and time have to be rethought continually during the course of a computation – unless, of course, one deals with “straightforward” problems which, in theoretical physics, are rare.

Although the SST is used as a standard tool in the course of a cohomology computation, there is no standard recipe for its application. If physicists start from a different BRST-operator, a cohomology computation based on the SST may become impossible to handle. In a case observed, the different grading-requirements (see 4) turned out to be incompatible: Either the zeroth-order term A_0 was of the type *bcc*, and thus not “manageable”, or the lowest degree term “illegally” assumed a negative number. The computation was “stuck”, the “direct analysis”, using the SST as described, did not lead to any result.

Alternative strategies – indirect ways – had to be explored, of which two succeeded independently in resolving the issue. The first was a detour strategy, the second a strategy of exploration by “doing examples” followed by a “trick”. A third way of dealing with the complexity of the problem consists of a reverse strategy: Instead of refining the SST it starts out from the problem in the most direct way and then uses an assumption – an “ansatz” – to map out the structure of a possible solution.

5.1 The detour

‘Go back one or several steps, then try a path to get around the difficulties you could not resolve before’, is the motto of this approach. In the case of ‘our’ cohomology computation, physicists went back to the initial equation as a starting point for a detour. The detour was inspired by a common mathematics approach to solve similar problems: the new path consisted of selecting a different set of states (i.e. a different space) amongst which solutions of the cohomology equation were sought. The computation for the new space again requires applying the SST, while the merit of the detour lies in the possibility of finding a grading that now satisfies all requirements. The actual SST-steps can then be solved with very little effort. However, the new physical states in a detour are not those one is looking for, and hence a problem remains: Can the cohomology of the initial problem be deduced from the result of the intermediate step? If this is possible, the new computation plus the deduction rules can be substituted for the ‘direct’ computation of the cohomology in which one got stuck. Detours simplify the activity of finding a grading and of solving the SST steps. Nonetheless, they do not dissolve the hardness of the problem but continue to shift it from one object to another. The hardness of the initial problem is replaced by other potential difficulties, for example by the difficulties of deriving deduction rules that

require physicists to solve new subtle mathematical problems. These cannot be considered here.

(Figure 3 about here)

Detours are context-dependent: What is considered to be a detour for mathematical physicists might be the “natural way to proceed” for mathematicians, as is the case in the discussed problem.

5.2 Tricks, further expansions, and further work on objects

Up to this point overcoming the obdurateness of physics objects meant expanding them into still hard but more congenial pieces or substituting one kind of obdurateness and hardness by another. In concluding their pacts with objects, however, physicists also resort to tricks – and they have developed strategies that improve their chances of finding a trick. In one of the cases observed, the computation got “stuck” because no suitable grading could be found. The physicists then turned to “doing examples” (see 6.2) to come up with ideas for a practicable path through the computation. These ideas are called “tricks” when their application substantially reduces the hardness and obdurateness of a problem.

In the case analysed, a gloss on the character of the end result – provided by “doing examples” – made physicists recognize that a suitable grading might be found after inserting an intermediate step in the middle of the SST path. The extra step came between ‘expanding the object’ and ‘building in degrees’ and consisted in ‘transforming’ the objects’ components. The transformation mixed the initial components; it folded them into each other in such a way that each new component incorporated pieces of several initial components. After the transformation, the SST worked: a grading had been found, which allowed the remaining steps to be solved without further difficulties. The computation had been stuck for more than a month. Once the extra step was performed, the computation could be completed within a few days.

Physicists called their intermediate step a “trick” since it reduced the complexity and hardness of the calculation by a large amount. With tricks, the hardness of an equation appears to be neither shifted nor redistributed, but dissolved. Tricks are ‘simple’ devices in the sense that they are usually one-step procedures: A single step introduced in the computation managed to (surprisingly) break up the computation. If a newly developed trick turns out to be applicable to advance other computations as well, it might become part of the common trick repertoire shared by the field.

5.3 The explicit construction of solutions

Instead of applying a deconstructive technique (like the SST) to solve the cohomology equation, a computer program can be used to detect physical states starting directly from

the initial ingredients, the BRST-operator and the states. The program can check the states, arranged according to increasing energy levels, and select as solutions those that are “annihilated” by the BRST-operator. In practice, however, the observed problem is of such complexity that only few physical states can be constructed in this way. The number of terms which have to be considered for each check increases dramatically with higher energy levels. Today’s computers are powerful with respect to the amount of information they are able to process; nonetheless they cannot handle such complexity. As a consequence, solutions can only be “constructed explicitly” – by “hand” or computer – after the complexity of the problem is reduced.

How are the hardness and obdurateness of an object attacked to negotiate a computation in this case? Constructing solutions explicitly relies on a ‘guess’, called, in this context, an “ansatz”. An ansatz is (mainly) of instrumental or technical value. It allows the number of potential solutions to be brought down by an assumption about their structure that can be “plugged” in the cohomology equation. The new input is provisional; its goal is to advance the computation by acting as a stepping stone which enables theorists to get on with the work. The result relies on the assumption but is not itself provisional, since a false assumption as ansatz will lead to a contradiction and rule itself out. The ansatz is thus legitimized in retrospect.

Consider an example: the explicit construction of physical states relied on an assumption which was derived from an analogy of the problem with a similar one studied earlier. In the earlier case, the physical states were arranged in a diagram whose pattern was determined by a particular “symmetry” of the problem. When studying the new problem, the BRST-operator changed, and with it the symmetry, so that an adjusted diagram proposed itself as a guideline for the search for physical states. The structure of the diagram could be translated into an ansatz, which served the purpose of prestructuring the desired solutions of the cohomology equation. An ansatz is like a ‘skeleton’ formula, it presumes the form of the solution and some of its properties, leaving space for the particularities of the solution’s ‘body’, the concrete values of the parameters. In this way it allows a reduction of the complexity of an object by provisionally eliminating some of its variables. Thus the problem becomes solvable either by hand or by computer, as in the observed case.

Is there deconstruction in an “explicit construction”? An explicit construction does not rely on a deconstructive technique such as the SST, but the computation is deconstructed by other means. These include the “inspired guess” which is translated into the ansatz. In order to “split the problem into the smallest possible parts” to reduce the complexity of an object, an ansatz must be very specific. It also varies with varying parameters which are related to the energy level. An ansatz can therefore be adapted to certain energy ranges by changing some of its internal structure. In this way a system of 500 equations with

500 unknowns can be transformed in one of 500 equations with only 50 unknowns. Such a system either leads to a contradiction (because of “overdetermination”), in which case the ansatz was wrong. Or it is essentially equivalent to a system of only 50 equations with 50 unknowns, which constitutes a considerable reduction of the hardness and obdurateness of the problem.

With an ansatz approach no solutions can be found which do not have the structure the ansatz proposes. Besides, one never knows whether all solutions have been detected, since infinitely many states have to be “checked” in a cohomology equation. The considered ansatz is therefore likely to catch only a subset of the solutions one is after.

“We construct these (physical) states – of course these are not all of them but some, so to say the most obvious ones – just to show that they exist analogously to those in previous work. ... Since a general proof, I believe, is extremely complicated in this case ... it’s simpler to just construct them explicitly here, as examples.”

6. Third iteration: Three ‘hidden’ procedures

The pact with objects can be attempted through a first-order deconstruction, and, if this is hard to achieve, through a second round of detours and tricks. This section introduces a third category of devices – those which can be deployed toward both first-order difficulties and second-round problems – and which are hidden in publications. In a third run through theorists’ practical work of dealing with computational objects we will focus on three strategies: variation, “doing examples”, and model objects.

6.1 Variation

Techniques like the SST do not specify how some of their requirements are to be met. Variation is used in many contexts in which such a technique has to be deployed to a concrete situation. Take the example of ‘how to find a suitable grading’. This opens the door to the deconstruction of the computation by the SST. Variation, then, provides a strategy to find the right key to the door. It means trying out different keys, making a selection among them, and inserting the chosen one into the keyhole to see whether it will turn. Variation also implies that this process of ‘selection’ and ‘trial’ is repeated until a satisfactory choice can be made.

Successively searching for alternatives seems “straightforward”. In practice, however, the straightforwardness of the ‘selection–try out–repetition’ scheme is broken up by several complications. For example, there might be more than one suitable grading, or there might be none at all. Not all gradings can be explored because not all possible gradings are known, and hence ‘completeness’ is an unresolved issue. The answer to the question whether a particular grading works is itself problematic, since checking tends to cost considerable

time. The effort a physicist is willing to concentrate on a particular grading depends on how promising it seems, which varies over time: giving up on a grading at one point does not imply that you are done with it once and for all. For all these reasons, working through the cycle ‘selection–try out–repetition’ is patchwork, the patchwork that results from pursuing a segment in the cycle, giving up on it, choosing a new starting point, perhaps picking up an older segment later – and never knowing whether all alternatives have been found and explored. In an attempt to minimize the number of cycles, physicists do not make first choices for a grading at random, but based on experience. Having handled a similar problem in the past might help in making a “clever choice”. But if the first choices are not successful, further selections proceed “in the spirit of trying everything once”. Searches become more random, variation turns into ‘blind variation’, and some gradings discarded in the past are reconsidered and explored in more depth.

Which selections are made is up to each physicist. A ‘wrong’ choice discredits itself without causing any harm, since the attempts are carried out in an immaterial world where all actions are reversible and the playgrounds infinite. However, the time and the effort physicists consider appropriate for dealing with a particular grading are a finite resource. Nonetheless, physicists engage in some “playing around” with gradings which are afterwards discarded as a means to increase their experience and to teach them how to efficiently recognize which grading solves a problem.

(Figure 4 about here)

Variation is a ‘direct’ strategy: the cycle of ‘selection–try out–repetition’ fits in the computation at the ‘level’ of the problem (as illustrated in fig. 4) with the ‘right’ grading as the ‘direct’ and necessary ingredient for all further steps of the SST. Variation is not a deconstructive strategy: it does not require or use a deconstruction of the objects. Also the cycle cannot be circumvented by a procedure which systematizes the process of finding a ‘working’ grading, nor can it be refined by a deconstructive procedure. But the grading once found sets off the deconstruction of the computation by means of the SST.

6.2 Examples

Examples turn up in many different contexts in theoretical physics and serve various epistemological purposes. For instance, we showed in 5.3 how examples of physical states could be constructed explicitly in cases where the complete solution was unattainable. Examples are virtually omnipresent in the work of physics computations. In the following we will be concerned only with their potential for advancing a computation by providing a gloss on its outcome. *“At the moment I don’t have a good idea how to make progress, so I’m playing around with examples to see whether I can possibly discover a ‘hidden structure’ ”.*

In “doing examples” the problem is considerably simplified, at a cost: one obtains only

clues and hints instead of the full solution. In contrast to identifying the ‘right’ key to a problem by variation, a key which potentially advances the computation by a ‘real’ step, doing examples can only provide ‘virtual’ progress: a new step might be hinted at but is never already performed. Doing examples transforms the problem into a related simpler one which dwells on a lower level, on a level where the objects are reduced to special cases. Two transitions are necessary: the deconstructive step to the special case, and after examples have been worked out, the step back to the original computation. The latter step is the most problematic part of this heuristic strategy. For its purpose physicists compare several examples from which they “guess” a solution of the general case (see fig. 5).

(Figure 5 about here)

The sketch of “doing examples” in fig. 5 is somewhat similar to the one for taking a detour. With detours, however, the step back to the main level of the computation is a rigorous deduction, so that the detour as a whole can substitute for the part of the computation which could not be solved on the main level. With “doing examples” that step is a guess; it cannot stand on its own and represent the main path.

In general, theoretical physicists grade different steps in a computation as more or less “straightforward”, depending on how “hard” or problematic they are – with a straightforward procedure theorists do not get stuck. However, different steps or parts of the computation can be straightforward or unproblematic in different ways. For example, variation was a straightforward strategy in principle, but not in practice. With “doing examples”, we have to distinguish “straightforwardness” in a technical sense from the epistemological sense. Doing examples can be straightforward in that the deconstruction that provides the objects as input is rather ‘trivial’, and in that no technical intricacies are involved in calculating the examples. However, whether the performed examples are of any relevance for ‘unsticking’ physicists with the general computation (by providing a guess for its outcome) is another matter.

To obtain a guess, physicists usually work out more than one example of a particular kind. Repetition, however, differs from the one in a variation cycle. The variation cycle has to be repeated every time a grading ends in a deadlock until one is found with which the cycle can be moved towards a solution. Working through several examples, on the other hand, has the purpose of building up towards a more and more complex pattern, which increasingly resembles a general solution. Usually three or four examples of each type can provide an idea for the “behaviour” of the general solution.

For obtaining a productive guess it may not be enough to do several examples of only one kind. Physicists may also have to vary the type: they may have to repeat the procedure – ‘deconstruct–solve–guess’ – for different deconstruction grids until they find a productive guess. Although it is not a priori clear which grid can be made productive, some of them

constitute an ‘obvious’ first choice. There is, for instance, the ‘trivial’ deconstruction, which consists of converting a parameter into a number, usually an integer. This deconstruction starts off with rendering the constructedness of the object explicit, and continues by choosing a component to “cut”. Cutting means substituting an abstract quantity by a concrete value, different for each example. This deconstruction is not as elaborate as the deconstruction performed by the SST. When dealing with examples, deconstruction may mean nothing more than the unfolding or fanning out of an object along a certain parameter.

Consider an illustration: an object might be specified by a sum of n terms, where n is an arbitrary integer. The first and most obvious example would consist in choosing $n = 1$ and then performing the computation for this single-component-object instead of doing it for the general sum. The second example would start out from the sum of two components as a new object, etc. Thus the obvious choice for a sequence of examples is to begin with $n = 1$ and to continue by increasing n .

As mentioned in 5.2, the trick that resolved the problem of finding a suitable grading was discovered by doing examples. In this case, the deconstruction grid used for the examples was slightly more elaborate than in the ‘trivial’ deconstruction, since the parameter along which the unfolding took place was not explicitly contained in any of the objects. Doing examples required physicists to go back to the original equation $Ax = 0$, and to try out “the most direct way possible”, i.e. without invoking the SST. To this end, objects had to be expanded in the same way as for the SST, e.g. by doing a mode expansion (see 3.1). Doing the example, then, consisted in writing down the cohomology equation for each energy level separately and solving it, thus searching for physical states of a particular energy at the time. Consider the following component of A :

$$\sum_{m,n \in \mathbb{Z}} (m - n) b_{m+n} c_{-m} c_{-n} = 3b_{-1}c_{-1}c_2 - 3b_1c_1c_{-2} + 5b_{-1}c_{-2}c_3 - 5b_1c_2c_{-3} + \dots$$

Examples for low energy levels are simple to compute. For instance no term of the above sum contributes to the physical states of energy levels 0 and 1, whereas the terms $3b_{-1}c_{-1}c_2$ and $-3b_1c_1c_{-2}$ have to be considered for finding the physical states of energy level 2. Examples for higher levels become more and more complex, since they comprise a growing number of components. For instance 8 more components of the infinite sum are needed to determine physical states of energy level 3. One could say that in every succeeding example a new and broader layer in a pyramidal structure is explored. In this way, physicists hope to get a glimpse of the behaviour of the solution for general energy level.

6.3 Model problems

Examples can be seen as a special case of modelling. When physicists do examples,

they profit from going from the main problem to less complex, deconstructed special cases. When they turn from the main object to models, they choose a model object that has been studied before, with which they have previous experience, an object that is well-explored and understood. Naturally, the model object must contain some of the typical features of the main object, and it must be more accessible (the problem must be solvable). *“When you construct a model you are trying to simplify the situation to something that is computable, ... and which still keeps the flavour of the non-trivial properties of the model you want to study.”*

Accessibility usually also means some simplification, but an important point is the existing experience. A model object, if you wish, has already been won over; the pact with the object exists, and the question is what one can learn from it with respect to a new object.

(Figure 6 about here)

A first answer to this question is that physicists may learn more from modelling than from doing examples. These can provide them with a gloss on the nature of the result they are after. This gloss, however, is but the last step of several in the main computation, and it is not always possible to fill in the missing steps “straightforwardly” in order to rigorously derive from them the glossed result as required. In other words, with the gloss one might have the end result without having all crucial steps leading up to it, a situation not appreciated in theoretical physics. Similarly, when examples are called upon to create the opportunity for physicists to hit upon a “trick” (see 4.2), no trick may materialize. As physicists put it: *“I know the result, but I cannot prove it.”* To some extent, examples can even be used to anticipate a working procedure, by posing not only the question ‘Where do I want to go?’, but ‘How could I get there?’ – all with a simplified version of the problem. This simplified version, however, is not sufficient to explore the question in depth.

Model objects, on the other hand, are related to the main object by analogy. As a consequence, they can be exploited in more flexible ways along the lines of their analogous relationship – as models for the object, for the problem specification, for difficult technical steps, or for possible results. One can take advantage of a suitable analogy by adapting known results to the new context. In addition, one can use the model as a playground for new attempts to deduce old results – for trying out new calculations in a safe and controlled environment. For example, one might try to find a new proof for a solved problem to test a proposal for how to solve the main problem. This work with the model as a laboratory for trying out new calculations is very important and distinguishes physicists’ use of models from pure reasoning by analogy or from doing ‘exemplars’¹¹.

Consider an illustration: the collaborators N, P, and A work on a cohomology computation for a BRST-operator constructed by the colleague G and his three collaborators.

P and A have not yet succeeded in obtaining a result by applying the SST directly. It is then that N sends the following e-mail message, stating some *ad hoc* conjectures for how to solve the computation by adopting the discussed detour strategy. The conjectures are formulated in analogy to a similar problem which they had solved before.

Some very sketchy remarks:

Suppose we are interested in computing the W -cohomology on the Fock space of two scalar fields (BRST operator of F) to prove the results of U et al. One could proceed, in complete analogy with the Virasoro case, as follows.

Probably, in some domain of p (...), F_p is isomorphic to the (dual) Verma module (we derived Shapovalov determinants for W several yrs ago, remember!, so this is something we can check/prove).

Also assume that some version of the reduction theorem is valid (I am aware of the obvious problems in proving/interpreting such a reduction theorem but nevertheless confident that for any reasonable BRST-operator something like this should be true), ... Then we can compute the rhs by means of a resolution of C in terms of W (dual) Verma modules (these we also know!).

Skiping all the details we can at least verify whether H ((the cohomology)) produces anything like the results of U et al. Work in progress.

(e-mail 21; N to P, A on 30 Sept.)

And 10 hours later:

My preliminary analysis of H seems to confirm the results of U et al. Let me give you the results for the $gh = -3$ states ($gh = 0$ operators). There are 9 in total (...) and they occur at energy levels 4, 6, 6, 8, 8, 9, 9, 11, 11. At energy level 4 we have the identity, and at 6 the operators x and y of U et al. The ones at level 8 and 9 are anticipated by U et al in the discussion (sect. 4).

More on this tomorrow.

(e-mail 26; N to P, A on 30 Sept.)

The model problem starts from a BRST-operator constructed by F , which can be deduced as a special case of the operator of G et al. For this BRST-operator U et al had

explicitly constructed physical states using a symbolic manipulation program instead of the SST. The link to the model problem consists of translating the conjectures to the context of the model. N assumes that his conjectures hold, and tries to build up on them. He tries to deduce rigorously the physical states of the model problem in order to first check or test his ideas on a well-known system. The results are then compared with the outcomes obtained by U et al (e-mail 26). The correspondence of the results gives confidence in the approach, and so N starts with an attempt to prove the conjectures for the general case. The results of U et al were known from preprints and publications.

Modelling can be thought of as a device that taps into existing pacts with objects to make the experience available for a new one. In the physicists' fight against the obduracy and hardness of a calculation, they 'virtually' join forces with larger groups of scientists.

7. Fourth iteration: A note on the pact between subjects

In the last section, the pact between subjects – physicists collaborating on a computation – has forced itself back into our text. From physicists' e-mail fragments, one gets a sense of how the real-life interaction between objects and subjects is more detailed, more complicated, and more laborious than we could render it so far. In a sense, we would need a fourth iteration: to delve into the concrete interaction between physicists and see how their 'collaboration' is brought in as a resource that aids in all previous attempts of trying to align theoretical physics objects. Physicists' (e-mail) dialogue is the last – and the most universal – device. It can be brought to bear not only on unpacking the object, but also on finding detours and tricks, or on doing variations, examples and models. It is also a device that recapitulates the dissociating and expansionary character of the previous tools. Theoretical objects and problems, in addition to becoming segmentally deconstructed, expanded, detoured, varied, modelled, and attacked through examples and tricks at the desk, are simultaneously divided up, partitioned, varied and 'paralleled' (worked out separately) between physicists. The structures and the rhythm of this partitioning and paralleling cannot be analysed here. Suffice it to say that like previous methods, the alliances between physicists centre around "getting stuck" – they prepare for it, guard against it, measure the degree of being stuck, and try to overcome it. They may magnify the problems of being stuck – when two or more physicists do not know how to go on. But in centring around the possibility and difficulties of getting stuck, they also 'loosen up' ideas for travels between desks and thought laboratories, the walkable and excitable minds of the thinking sciences: 'It seems we're stuck. I have no earth-moving new ideas, but instead of keeping silent let me just communicate some loose thoughts in the hope that somebody can do something with them.'

Concluding remarks

In this paper we have gone through devices and iterations thereof which theoretical physicists use in their attempts to conclude an agreement with obdurate and “hard” objects: formal deconstruction, detours and tricks to identify a working deconstruction, variation, doing examples and modelling to assist with the first and the second type of procedure, and thought alliances between subjects. The last device not only purchases assistance in the struggle with objects, it also secures physicists’ guidance and trust – trust in the pact once it seems impending, guidance and surveillance along the way, and assurance with respect to the possibility to go on when they are stuck. The pact between subjects, it seems, not only completes the deal with objects, it also supplements individual physicists’ capabilities. In this sense, theoretical physics remains, with its thought alliances, an individuating science.

Epilogue

Sociologist: As a fifth and last iteration I propose that we read the paper together. I would like to encourage you to comment on the paper from your perspective, the perspective of physicists, and to tell me where you do not agree. You should, however, keep it in mind that time is restricted and not all matters can be discussed in depth.

Physicist: Then, let me start. I must say, I have been a bit disappointed that our observer does not seem sufficiently interested in the real sociological questions, like our very fascinating e-mail interaction and our national differences.

Sociologist: We are indeed deeply interested in the ‘virtual’ laboratory you seem to create through your e-mail collaborations. But can we not, for a change, begin with the technical details of your work?

Physicist: One of the ‘details’ of our work is that we construct our objects too, we do not only deconstruct them! We ought to be studied from a constructionist perspective!

Sociologist: You constantly want to tell us what to do! How about if we study the construction of your objects and problems in a next paper? You said yourself that the deconstructionist strategy seemed omnipresent in various disguises, and that I need to understand it if I want to say something about theoretical work. Besides, it interests us that deconstruction in theoretical physics reflects back on our own practice. In a way, it is even similar to it: in the sense in which you physicists not only create a multiplicity of objects, but mobilize in it ‘the other’ (objects different from the original).

Physicist: And we learn from the other. We construct and deconstruct it, and play around with it, and then we learn from it. But what do you actually mean by ‘the other’?

Sociologist: The ‘other’ in physics is close to the self – a physicist’s construction. Are not all deconstructive sciences reflexive sciences? Would it not mean that there is an internal relationship between the possibility of deconstruction in the described sense and the phenomenon that the entity has been constructed before?

Physicist: Hold it, stop before you start fantasizing! Deconstruction in physics does not always proceed along the seams of a construction. Whereas, for example, in literary criticism, deconstruction I imagine might try to unpack the meanings of an author or the possible meanings an audience or culture attribute to a text – thus plucking the system apart precisely where it has been stitched together.

Sociologist: Without wanting to be rude, maybe we should come back to discussing the physics aspects of the paper?

Physicist: Here, where you introduce “physical states”, you are simplifying, and not for the first time! Presumably, to make the stuff as comprehensible as possible for the non-experts?

Sociologist: Actually, I doubt that this is comprehensible to them anyway. But – Couldn’t you please tell me a little more about the reasons for this exercise? I cannot fathom the depth of your search after “states” transformable into “zero”. Where is the physics in this anyway?

Physicist (patiently): First of all, you are not even talking about a cohomology computation. In the context of BRST-quantization, physical states are given by the cohomology of the BRST-operator A . The cohomology is defined by $\text{Ker } A / \text{Im } A$. So, in order to find the cohomology, you do not only have to solve the equation $Ax = 0$, but also identify solutions which differ by an ‘exact’ state, i.e. a state in the image of A . This is essentially the requirement of gauge invariance. Two solutions which differ by an exact state represent the same physical state. The physical states can then in principle be used as input for computing physical quantities relevant to experiment, as for example scattering amplitudes. And if you allow me to make a last remark, maybe you should tell your readers that this problem arises in the field of mathematical physics, and that the notion of ‘computation’ does not *per se* refer to numerical calculations performed on a computer.

Physicist G: Excuse me for interrupting, but I have to point out that symbolic manipulation programs can play an important role in solving cohomology computations. Maybe you could include a section on the physicists’ pact with computers!

Sociologist: Well, why don’t you wait and see (in 5.3)!

Physicist: Actually I do not understand the depth of your interest in ‘pacts’! Don’t you want to tell me how your physicists actually got started on their cohomology computation?

Physicist N: You should read Serres¹². Serres develops the idea of a 'contrat naturel' which has inspired my sociologist friend. As to how the computation began, I can still dig out my initial e-mail conversations. In fact, I have tons of them on this dragging computation.

N to P, A on 25 Sept.:

“Well, one thing this vacation did for me is to provide me with new energy to start some new project. But what? It seems (several people independently pointed this out to me) that the latest ‘hot issue’ (...) is the construction of free field representations for quantum groups. ...”

A to N, P on 28 Sept.:

“I would like to decide over the next few days if we actually can do something on W-brst, or whether we should move on to bigger (?) and better (??) things.

I saw N’s suggestion, although I haven’t looked at these papers -- no doubt they are all $sl(2)$? ...”

P to N, A on 28 Sept.:

“I have printed out the paper of U and comp on BRST for W-gravity. ... I haven’t read what they have in detail, but an extensive use of Mathematica sounds scary. If we want to do anything in this direction we must do it VERY fast. P”

N to P, A on 29 Sept.:

“We should be able to improve considerably on what has so far been written on W-cohom; let’s crack it this week??!! -- N”

Physicist (jokingly): It seems that they were not scared enough, since they actually plunged into it, with tons of optimism. – Actually, what I was really interested in is how they got their grading. It seems that finding a suitable grading can be a tricky business.

Physicist N: Let me quote from some e-mails.

P to N, A on 2 Oct.:

“Should we expect cohomology at finite or infinite number of momenta? There is a term in the BRST which is γ_0 times a third order polynomial in p ’s, which it seems to me can kill almost everything.

Anyhow, there seems to be a convenient grading that splits this operator into manageable pieces. Define a double degree

(p, q) , where $p(\gamma) = 3 = -p(\beta)$ and zero for the rest, while p is 1 for c and α_+ , and 3 for γ , and - that for the other fields. Then $d_{0,0}$ is the old gravity friend, and $d_{3,3}$ is γ_0 term noted above. Things in between are simple. I am sure I should be able to get out the result this way. Of course, this is not too helpful for the real stuff, ie w-gravity + matter...''

A to P on 5 Oct.:

''Perhaps more hopeful is to lift γ , lose the γW and play with Vir type BRST. Then try to bring back W bit by bit. So I'm thinking about that again. Beyond all this I have the W_0 problem lurking around which I don't really handle yet. Somehow it's got to be important though... A''

P to A on 5 Oct.:

''My hope is as follows: grade the BRST by number of γ 's. Then the 0-order is standard Virasoro, the 1st order is γW , and the 2nd is junk. Now γW is nilpotent on the cohomology of the Virasoro. At this stage one can still try to split into W_+ and W_- . If things converge fast enough, maybe one can conclude something, but not me.''

N to P, A on 7 Oct.:

''I'm not too optimistic about the W-cohom derived from the Vir-cohom by SS-ing, but since we cannot do better at the moment it's worth pursuing. (I still have no idea how you intend to impose $W_0 = 0$ explicitly, or maybe you don't want to consider (full) relative cohom?) -- N''

P to N, A on 13 Oct.:

''I have still problems in mapping out a strategy of dealing with the W-algebras. Even if we understand whether these Fock spaces are free or cofree or irreducible, or whatever, there is a fundamental question on how to implement this information. Thus far I have found that the only systematic way is to grade by the number of W-ghosts, but this requires a fairly detailed knowledge of the Virasoro cohomology. So, what are we going to do???? P.''

N to P on 14 Oct.:

“I’m not sure whether it solves the fdeg problem, but I was thinking of trying to do something along the following lines: Grade by W-ghost number so that d_0 becomes Vir-BRST operator. Then use (co)-freeness of $M \otimes M^*$ to compute this guy. Cohom is probably still free over remaining W generators, so that we may possibly be able to also compute next step in SS explicitly. Hopefully after this step we’ve killed everything so that there is no need to face $Tb \gamma\gamma$ term anymore. This might be the advantage of doing $H(M \otimes M^*)$ over $H(F \otimes F)$! N”

Physicist: I really think you are crazy. Do you plan to present these e-mails to your sociology audience? What do you think they will understand? And what do YOU understand? By the way, in 5.1 you describe the detour strategy. Is this what N is talking about on 14 Oct.?

Sociologist: Yes, it is. He wants to convince his two colleagues to join in the detour he proposes.

Physicist N: I am not sure I understand your intention. You are mixing up everything. We have worked on many different cohomology computations in the last two years. They were all problematic in their own way. The detour which you describe does not always make life easier, just in certain cases. And in our last computation, actually, it was unclear for a long time whether the detour would help.

Physicist: I also give up on understanding your concept. What good is your ‘pact’ when we see theorists drown in a sea of equations? Did the objects break the agreement? As we hear in the e-mail, the cohomology is probably still free. Hahaha.

Physicist N: Don’t joke! Our efforts led to a well-received paper¹³, but indeed not to the desperately sought-for grading. Fortunately, the detour turned out to work fine. When I reread our e-mail, I found that we were stuck from beginning to end.

P to N on 6 Oct.:

“The problem with the fdeg is precisely where I have been stuck for few weeks now. The presence of this quartic term is also responsible for not being able to define a nilpotent operator for n_+^W etc. ...”

A to P, N on 22 Oct.:

“As for W I am completely stuck, and everyone else too I guess. ...”

N to sociologist on 7 Jan.:

“‘What else? Ever more obstacles in our cohomology computation (or rather at the point where we have been stuck for a while). ...’”

N to sociologist on 8 Feb.:

“‘.. Yes, we are still stuck at a certain point...the paper will therefore be a collection of (unreadable) partial results. ...’”

Physicist: Stop, I don't want to hear it any more. It reminds me that I am stuck on my computation of next-to-leading order QCD-corrections, and that my friend and collaborator is on vacation.

Physicist N: Just a moment, I would like to ask a question. Do you think your readers will understand the distinction between your made-up dialogue and the 'real' e-mail quotes you insert in it? I am in doubt.

Sociologist: If you insist, let me hereby openly declare that this dialogue is nothing but a sociologists' (de)construction. – Gentlemen, I thank you for the conversation.

Notes and references

1. Mathematics features in E. Livingston's ethnomethodological study *The Ethnomethodological Foundations of Mathematics* (London: Routledge & Kegan Paul, 1986), as well as in S. Restivo's historical works, e.g. *Mathematics in Society and History* (Dordrecht: Kluwer, 1992). Anthropological studies of physics have been published by S. Traweek: *Beamtimes and Lifetimes: The World of High Energy Physics* (Cambridge: Harvard University Press, 1988), and by M.H. Krieger: *Doing physics: how physicists take hold of the world* (Bloomington: Indiana University Press, 1992).
2. The study was conducted at the European Laboratory for Particle Physics, CERN, in Geneva, Switzerland. One of us (M.M.) has been accepted into the ranks of the CERN Theory Division, admitted to its seminars and supplied with desk and terminal, since September 1991.

We want to thank the head of the Theory Division, John Ellis, for his gracious 'admission' of sociologists into physics, and Peter Bouwknecht, Jim McCarthy, Krzysztof Pilch and Wolfgang Lerche for their tolerance and for sharing with us the intimacies of their work.

We also thank the Deutsche Forschungsgemeinschaft for financing and the Institute for Science and Technology Studies in Bielefeld for facilitating this research.
3. K. Knorr Cetina, *Epistemic Cultures. How Science Makes Sense* (forthcoming 1994).
4. Throughout the text " " is used for physicists' language, whereas ' ' denotes our expressions. A typewriter font is used for physicists' e-mail quotes, interview excerpts are printed in italics.
5. J. Clifford, 'Introduction: Partial Truths', in J. Clifford and G.E. Marcus (eds.), *Writing Culture: the Poetics and Politics of Ethnography* (Berkeley and Los Angeles: University of California Press, 1986); C. Geertz, *Works and Lives* (Stanford: Stanford University Press, 1988).
6. M. Mulkay and N. Gilbert, *Opening Pandora's Box: A Sociological Analysis of Scientists' Discourse* (Cambridge: Cambridge University Press, 1984); M. Mulkay, *The Word and the World: explanation in the form of sociological analysis* (London: Allen & Unwin, 1985); S. Woolgar and M. Ashmore, 'The Next Step: An Introduction to the Reflexive Project', in S. Woolgar (ed.), *Knowledge and Reflexivity* (London: Sage, 1988).
7. B. Johnson, *The Critical Difference. Essays in the Contemporary Rhetoric of Reading* (Baltimore: Johns Hopkins Univ. Press, 1988).

8. Theoretical particle physics embraces sub-‘fields’ which differ widely in their closeness to mathematics and in their direct relevance for experiments. The “cohomology computation” on which this paper focuses is an example of a problem typically arising in mathematical physics, the branch close to mathematics with respect to methods and concepts used. The procedures described for handling the problem, however, also apply to most work in the “phenomenology” of particle physics, which is the branch more oriented towards experimental results. Involved computations have to be dealt with in both, mathematical physics and phenomenology.
9. To enhance the readability of the paper, we have simplified the physics ‘language’ as much as possible. A physicist’s definition of “physical states” can be found in the epilogue.
10. K. Knorr Cetina, ‘The Couch, the Cathedral, and the Laboratory: On the Relationship between Experiment and Laboratory in Science’, in A. Pickering (ed.), *Science as Practice and Culture* (Chicago: Chicago University Press, 1992).
11. T.S. Kuhn, *The Structure of Scientific Revolutions* (Chicago: University of Chicago Press, 1962 and 1970).
12. M. Serres, *Le Contrat Naturel* (Paris: Editions François Bourin, 1990).
13. P. Bouwknegt, J. McCarthy and K. Pilch, ‘Semi-infinite cohomology of W-algebras’, *Letters in Mathematical Physics*, Vol. 29 (1993), 91–102.

Figure captions

Figure 1: The operator A transforms an arbitrary state x into Ax . States are called “physical states” when they are transformed into zero. The complete solution, i.e. the cohomology, is given by the set of all physical states.

Figure 2: Schematic rendering of a coalition between collaborating subjects in relation to an object.

Figure 3: If the main problem cannot be solved directly, a detour may be accessed. After solving the new problem of the detour, derivation rules are needed to deduce the wanted result from that obtained.

Figure 4: Variation cycle. A grading is selected, tried out, and if it works, all steps of the SST are completed. If the grading is not manageable, the procedure is repeated and another choice for the grading made.

Figure 5: The results of several examples are compared in order to arrive at a guess for the general result. Physicists hope that the guess will provide them with ideas on how to solve the main problem.

Figure 6: A problem is modelled. The ‘model problem’ has to embrace known results and/or be simpler to work with than the main problem. The model can then be used as a playground where new ideas are tested.

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6