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Dissemination of science and communicative efficiency of texts

Is the level of explanatory ambition a relevant diagnostic tool?

Abstract

In this paper, focus is upon introducing and testing the concept of *level of explanatory ambition* as a tool for assessing the communicative efficiency of attempts of disseminating scientific knowledge. Following a brief introduction to relevant aspects of the concept of communicative efficiency of Roelcke (2002a), the central concepts of *level of explanatory ambition* and *level of explanatory depth* are presented. The basic idea is that it is possible through textual analysis to assess the quality of causal explanations, distinguishing between explanations presenting the system relations underlying the explanations and explanations merely presenting the causal relations on which the explanation is based. The distinction and its effect on the assumed level of explanatory ambition of the explainer are presented, and subsequently the tool is applied to analyse dialogical exchanges in a disseminating science show, *In Our Time* from BBC Radio 4. By way of conclusion, a possible explanation of the analysed behaviour of the participants is ventured through the categories of the tool.

1 Introductory remarks – concept of communicative efficiency

In a non-technical and broad sense, a central goal especially in professional communication is to create texts that are as communicatively efficient as possible, in order to avoid unnecessary efforts on all sides of the communicative situation. In this chapter, I want to focus on a specific type of professional communication, i. e., the dissemination of scientific knowledge. I depart from the uncontroversial assumption that communicative efficiency plays a major role in order to reach the goals in such dissemination settings. Although, or maybe especially because dissemination of science in the form to be studied here, i. e., a radio program, often has a clear character of entertainment, it is important to use the proper amount of text and present the proper amount of content in order to keep the listeners interested and at the same time give them the intended insights into the scientific topic.

A central aspect in this context is the level of explanations chosen in the texts. By this I mean that experts in dissemination situations must always choose to reduce the complexity not only of their formulations (*Kompliziertheit*, cf. Lutz 2017: 299), but also of the disseminated content (*Komplexität*, cf. Lutz 2017: 296–298). In this chapter, I will present and exemplify a way of assessing the chosen level of complexity in the form of what I call *level of explanatory ambition* by assessing the chosen *level of explanatory depth* (cf. section 2.3 below). By way of this assessment, I claim that it is possible to make some predictions about the communicative efficiency of a dissemination text.

In order to move further from the non-technical sense of communicative efficiency used above, I will in this chapter use the approach by Roelcke as my basic framework:

> Sprachliche Ökonomie bzw. kommunikative Effizienz ist dem kognitionslinguistischen Funktionsmodell zufolge also weder an dem lexikalischen Inventar einer Sprache und deren syntaktischen Regeln noch an dem Kon- und Kotext ihrer Texte allein zu messen, sondern ist insbesondere im Hinblick auf die **kommunikative Bereitschaft und das kommunikative Vermögen** zu der Produktion und Rezeption von Texten zu bestimmen.
>
> (Roelcke 2002b: 51)

This means that communicative efficiency has something to do with having the relevant disciplinary and linguistic competence to produce as well as receive texts. Texts are communicatively efficient depending upon the concrete communicative setting. In this context, Roelcke works with four basic factors that have to be in balance in order to achieve communicative efficiency, viz., *extension, intension, concentration* and *competence* (cf. Roelcke 2002b: 66 and figure 1).

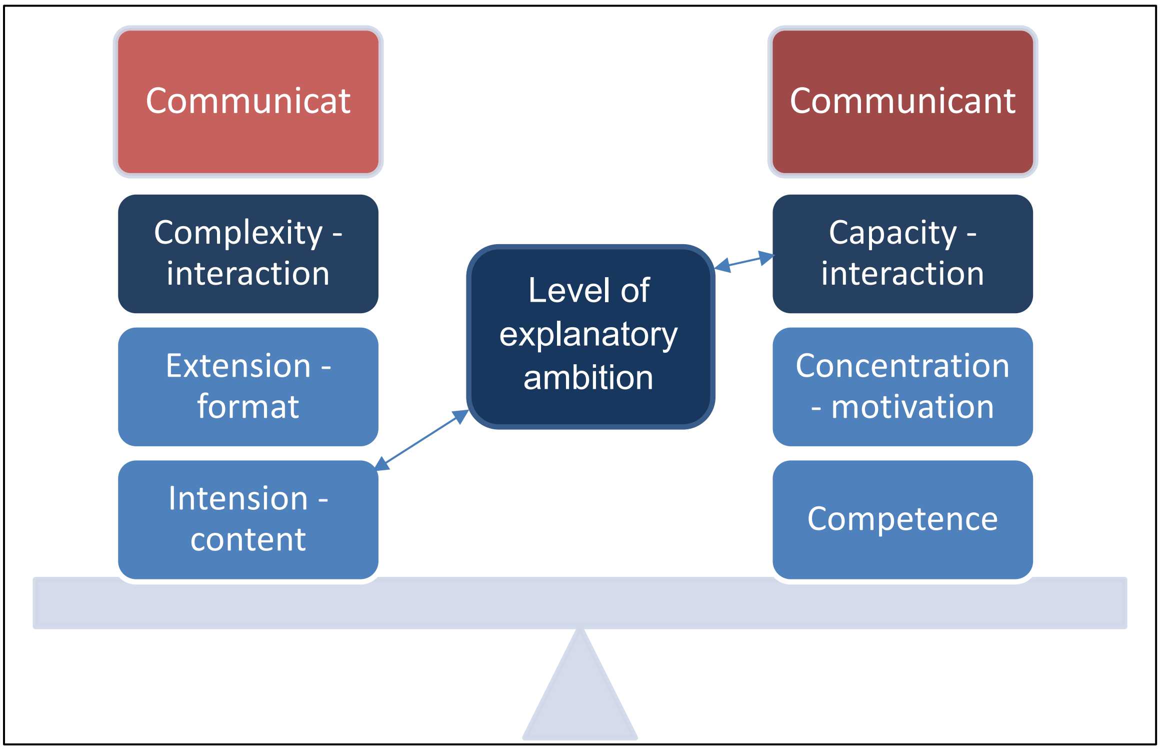

Figure 1: Factors in communicative efficiency connected through level of explanatory ambition; terms according to (Roelcke 2002a)

The approach works with two overarching factors with relevance for assessing efficiency: *Communicat*, i. e., a situated text, on the one hand, and *Communicant*, i. e., the participants in the communication, on the other. The idea is that these two overarching factors have to be balanced in order to achieve efficiency. The same applies within each of the two overarching factors: *extension* and *intension* have to be balanced in their interaction in order to reach a relevant level of *complexity* of the communicat; *competence* and *concentration* have to be balanced in interaction in the form of *capacity* on the side of the communicants.

The concept developed and tested in this chapter, the level of explanatory ambition, is a proposal for an object of analysis that may describe the potential efficiency of communicats in relation to intended communicants in the context of dissemination of scientific knowledge. It especially connects the factor *intension* with the factor *capacity* (= the interaction between *competence* and *concentration*) in order to assess the intended relation between communicative partners signalled through the chosen content.

Before I will demonstrate the application of the concept of level of explanatory ambition in an analysis of communicative interactions in a radio program disseminating a scientific topic from the field of mathematics in section 3, I will present in section 2 some of the central concepts behind the concept. The chapter ends in section 4 with a conclusion and an outlook to further developments.

2 Some conceptual specifications

This section lays the ground for assessing the efficiency of a radio program as dissemination. Central for that is the concept of level of explanatory ambition, which is an overall dimension for assessing the efficiency (2.2). In the analysis to be carried out, the most important input for this assessment is delivered by the analysis of the level of explanatory depth in different explanations contained in the radio program (2.3). In this perspective, I look at how complex different explanations of central concepts presented in the program are. I am interested in the degree of complexity chosen for the presentation by the speakers. This concept, on the other hand, relies upon the idea that a concept from for instance science can be represented at different levels of complexity by different holders of the concept, depending on their acquired theoretical knowledge and/or their practical experience with the concept. Knowledge held about the same concept may thus be placed at different points of a scale reaching from basic everyday knowledge to highly specialized expert knowledge (Kalverkämper 1990). I will start this section with some deliberations on how to describe such different positions on the scale in 2.1.

2.1 Characteristics of expert knowledge – different types of specification

Expert knowledge, understood as the acquired knowledge reservoir of experts that functions as the basis of their expert performance (epistemic cultures, Knorr-Cetina

1999), is characterized by a high degree of specification, compared to more everyday knowledge (Jakob 1991: 75ff; Wichter 1994). The degree of specification concerns for one thing a split into more fine-grained aspects of the concepts of which the expert knowledge consists. An example is that where I as a non-car driver know that the car of my wife is driven by an engine placed in the front of the car, an expert of car engines can distinguish between different types and subtypes of engines and also knows the major functional parts of such engines. In the terms of frame semantics, we may say that my knowledge structure of an engine has a fairly limited number of slots (i. e., dimensions) like ‘overall function’ and ‘position’, whereas the expert knowledge structure has a higher number of slots like ‘types’ and ‘components’. A second type of being more fine-grained consists in the fact that each slot is split up into more subslots, giving the expert access to a more detailed perception of each of the slots. An example is that I may also know that the engine has a spark plug, which my wife has to clean every now and then, in order for the rest of the engine to function. So, I have a rudimentary knowledge of a component slot. The engine expert, on the other hand, knows much more about the different parts of the engine and about subtypes of spark plugs, to mention just a few examples. One may call these two aspects the quantitative aspects of expert knowledge and of expertise, as they are connected to a higher number of slots and a higher number of subslots to each slot. In other words, the knowledge networks of experts consist of more elements and are thus more complex from a quantitative point of view (Bromme/ Bünder 1994). Another more qualitative way in which expert knowledge differs from more everyday knowledge is the degree to which systematic relations between elements leading to functional descriptions and explanations of functions are part of the knowledge. Reverting to the engine example, I know that when my wife steps on the gas pedal the engine speeds up the car. However, I have very little knowledge about the mechanisms behind this effect. An engine expert, on the other hand, has a clear knowledge about the functional relations between the different parts of the engine and the underlying systems and mechanisms that make the wanted effect emerge. In other words, the engine expert has knowledge about the systems that underlie the functioning of an engine. Central is here such systematic knowledge from natural science as combustion, force, characteristics of different materials, etc. By way of this type of more complex knowledge, the expert is able not only to describe the engine in more detail, but also to explain why the engine works and how comes that it can have the effects that may be observed, when it works. This leap into systematic explanations is a qualitative one, as the holder of such knowledge can go from description to functional understanding.

To sum up: Expert knowledge consists of knowledge structures that are different from similar everyday knowledge structures in quantitative aspects (number of dimensions, resolution of each dimension in sub-dimensions) and in qualitative aspects (introduction of explanations of relations between elements, leading to understanding of effects).

From the point of view of communicative efficiency, the conceptualization of the differences between everyday knowledge and expert knowledge presented above is relevant, when we want to study the dissemination of expert knowledge to non-experts. We can formulate quantitative and qualitative goals of the dissemination process and thus make empirical assessments of the efficiency of the communicat in the situation.

2.2 Level of explanatory ambition

In order to connect the characteristics of expert knowledge to actual situated text (*communicats*) and their efficiency, I will in the following present the concept of the level of explanatory ambition (Engberg 2020b; Maier/Engberg 2021). The concept may be used to assess the degree to which the communicative effort of a text producer enables a non-expert receiver to construct a knowledge structure that bears relevant resemblance with the expert's knowledge structure, without intending identity, cf. later in this section. In principle, the description of the level of explanatory ambition may include quantitative as well as qualitative aspects as described above. In this section, however, I want to focus upon the qualitative aspects and have a specific emphasis upon suggesting a descriptive system for categorizing situated texts according to how they potentially contribute to explanatory understanding. Thus, the higher the degree of explanatory understanding potentially constructable from a situated text, the higher the level of explanatory ambition.

The concept of level of explanatory ambition aims at diagnosing the degree to which a text producer may claim to pursue the intention of enabling non-expert communicators to gain access to the expert knowledge. Behind this lie a number of presuppositions. First and foremost, I follow the idea that knowledge asymmetries, i. e., differences in what communication partners know, may be introduced differently in communicative interaction, giving rise to different suggested relations between the partners. As two relevant relations, an expert may as one possibility present the difference in ways that enables the other to understand that there is a difference but does not enable the other to bridge the gap. As the second possibility, the expert may communicatively enable the other to bridge the gap by strategically enabling the other to build knowledge with basically the same structure as the expert knowledge. In the first instance, I would talk about a mere dissemination intention. In the second instance, I would suggest talking about the intention of popularizing the expert knowledge. The second presupposition underlying this statement is that knowledge and understanding in communication is constructed from the knowledge reservoir of the understander in combination with the textual input offered. Analytically, the textual input may be described along the lines of the distinction between knowledge telling and knowledge transforming (Scardamalia/Bereiter 1987). My basic assumption is that an expert communicating expert knowledge may only claim to have pursued a high level of explanatory ambition in cases where the textual input allows the receiver to build knowledge structures that are both quantitatively and qualitatively similar in complexity to expert knowledge structures. As I will demonstrate in the following, similarity in qualitative complexity, i. e., in explanatory depth is actually most central in this respect, at least when the projected receiver is a non-expert and not already initiated to the field.

Assessing the level of explanatory ambition that may be claimed in a situation is connected to ascertaining the hypothesized communicative efficiency of the situated text. However, it is important to qualify the idea in order to relate it to different ways of discussing the concept of communicative efficiency. Other than the concept of for instance semiotic efficiency of Holste (2019), the concept of level of explanatory ambition as I apply it here is restricted in that it may not be used to explain conventionalization of communicative means. It is a concept oriented towards assessing individual communicative situations with a focus upon the presented content rather than the chosen verbal or non-verbal material. On this basis, it will be difficult to connect it directly to any normative conventions of formulation, also because the efficiency of ways of demonstrating a high level of explanatory ambition will be different from one situation to another. Instead, the efficiency of the individual situated text will have to be projected on the basis of assumptions about the knowledge reservoir of the intended understanders, and eventually the efficiency can only be tested empirically after the communicative interaction through survey methodology (e. g., Luttermann 2015).

2.3 Level of explanatory depth

As shown in figure 1 above, the concept of level of explanatory ambition is designed to create a link between assessments of the content of texts and the interaction between communicative participants termed *capacity*. The deliberations in section 2.2 have focused more on the aspect of the communicative participants. However, we also need an analytical concept with a focus upon the content or *intension* of the situated text. For this purpose I rely upon the concept of explanatory depth developed in psychology in the form of the *Illusion of explanatory depth* (Rozenblit/Keil 2002). The illusion is an empirically established phenomenon, which is used to describe the fact that humans generally and systematically overestimate the degree of detail of their explanatory knowledge on concepts in communicative interactions. It has been shown through experiments that for instance university students, who are not experts of aeronautics, tend to denote their explanatory understanding of the functioning of, e. g., a helicopter as good, although they are actually not able to subsequently describe the actual causes leading to the ability of a helicopter to hover and lift off vertically. From this it may be deduced that non-expert explanatory knowledge structures are more skeletal and fragmentary than similar expert structures. However, as they fulfil the requirements of explanation in non-expert situations, holders are functionally satisfied with their knowledge. Hence, when asked whether they can explain how a helicopter works, they will often give a positive answer. Only when put into a situation where a higher level of detail is contextually required (e. g., through more detailed questions in an experimental setting) does the holder of the knowledge realize that the degree of explanatory depth is not high. In other words: as non-experts, we feel satisfied even with skeletal representations of concepts presented to us.

The study of the *Illusion of explanatory depth* has led researchers to suggest a scale of different degrees of explanatory depth, which I use in order to describe qualitatively the content of instances of explanation in knowledge dissemination and as a central component in assessing the level of explanatory ambition. The psychologists distinguish between three types of skeletal explanatory knowledge structure: *Causal relevance, Causal powers* and *Causal relations* (Keil 2003: 675–680, 2011: 254–255). To underline the defining characteristic of the last-mentioned category, I have changed the term and talk instead of *Causal system* for this category. Furthermore, for the purposes of analysing cases like the one in focus here, i. e., dissemination of scientific knowledge for entertainment purposes, it is relevant to supplement with a fourth category inspired by studies of types of explanations in popularization like (Calsamiglia/van Dijk 2004) and (Garzone 2006) viz. *denomination*. I situate this category hierarchically before *causal relevance.* The four types may be described as follows:

- *Denomination*: This potentially explanatory device has the lowest explanatory force as it mainly introduces a word for the treated concept (cf. *(De-)Nomination* as the connection between knowledge system and language system (Hoffmann 1999: 29–30). The introduction of the word may be accompanied by a few defining characteristics without causal content (Calsamiglia/van Dijk 2004: 374–376), but even that is not necessary. However, not all instances of *denomination* are explanatory, this depends on the aspect introduced. The aspect of the act of denominating something, which makes it relevant here, is that the formulation may indicate the category to which the treated concept belongs (e. g., ‘easy problem’). The category or the defining characteristic may tell the recipient that there is an underlying causal relation, which is not mentioned or specified, but merely hinted at. As an example, saying that a specific problem belongs to the category of problems that are easy to solve without giving any reasons for this denomination indicates that characteristics of the problem causally interact with the result that the problem is easy to solve. We are not told anything about the nature of the interacting characteristics or their causal relation, it is only very subtly hinted at.

- *Causal relevance*: This explanatory relation is the coarsest of the three levels proposed by Keil, hence indicating a rather low level of explanatory ambition, but still more than just presenting the category of the concept. “Coding of causal relevance does not encode specific patterns of causal interactions but rather a sense of what properties matter most in a particular domain” (Keil 2003: 675). The example given by Keil is that calling something a hand tool shows that specific aspects of the thing (e. g., shape and size) are more causally relevant for understanding the functioning of the thing.

- *Causal powers*: In this explanatory relation, the holder of the respective knowledge knows not only that there is some kind of functional relation between two characteristics but also what kind of influence one characteristic has on the other. “I know that magnets have the ability to exert an attractive force on various metals but may know little about magnetism and the reasons that some metals make good magnets while others do not. We can think of this level as the first level at which distinct causal roles are attributed to properties” (Keil 2003: 678). The explanation remains coarse and shallow, although demonstrating a higher level of explanatory ambition than causal relevance representations.

- *Causal system*: In this type of relation, the knowledge structure has system character, but the system consists only of main units and their functional relations. No insights concerning the internal functioning of these entities are present. “For many people, their mental representations of the causal relations for cars may largely be confined to knowing that they convey people from place to place on roads, that they are propelled by an engine whose output is increased by pressing on an accelerator, and that they are slowed down by brakes” (Keil 2003: 679). Here, the functional role of the car is presented as part of systems of transportation and of physical rules and regularities underlying the functioning of the car. The knowledge to be built hence reaches a deeper level of explanatory depth and thus also indicates a higher level of explanatory ambition.

In contrast to the application of the categories in psychology, not the depth of the explanatory cognitive structures of people, but the knowledge structure to be built based upon the verbal text is assessed in the analyses in this section. The outcome of the analysis is a substantiated hypothesis about the complexity of the knowledge structure to be constructed by the user in order to comply with the textual intentions of the author.

All four types of explanatory structures are coarse and do not show the complexity level of expert explanations. However, they may be satisfactory to users in popularization situations. In the dissemination of scientific knowledge for entertainment purposes, experts have to choose the relevant level of explanatory depth (intension, content) in order to comply with the level of explanatory ambition (capacity, interaction) suitable for the communicative situation at hand. In the following, we will have a look at this in a concrete example.

3 Analysis

In order to exemplify the use of the diagnostic tool, I will analyse excerpts from the BBC Radio 4 program “In our time”. It is a long-running radio program in which academic experts present delimited disciplinary questions in a conversation normally held between three experts and the host. “***In Our Time*** is a live BBC radio discussion series and podcast exploring a wide variety of historical topics, presented by Melvyn Bragg, since 15 October 1998. […] Each programme covers a specific historical, philosophical, religious, cultural or scientific topic” (Wikipedia n. d.). It is an interesting venue for an analysis of the efficiency of explanations for two reasons: First, the idea with the program is that researchers disseminate their expertise to non-experts, and so explanations of underlying theories, structures, connections, etc. play a central role here. Secondly, the setup as a conversation especially between the experts and the host (as representative of the non-expert listeners) means that it is possible to assess the perceived efficiency of the explanations through feedback signals from the host of the type *I think I get that,* *but I still haven't got, what makes it so very difficult*, or *as it is being said, it's clear, I have no idea whether I will remember it tomorrow at lunch time, but still* … Hence, it is possible to have a hint as to the efficiency to support the textual diagnosis.

The example chosen is on mathematics. The title of the episode is "P v NP" (Bragg 2015). In the notes included in the post on YouTube, the topic is explained as follows:

> Melvyn Bragg and guests discuss the problem of P versus NP, which has a bearing on online security. There is a $1,000,000 prize on offer from the Clay Mathematical Institute for the first person to come up with a complete solution. At its heart is the question "are there problems for which the answers can be checked by computers, but not found in a reasonable time?" If the answer to that is yes, then P does not equal NP. However, if all answers can be found easily as well as checked, if only we knew how, then P equals NP. The area has intrigued mathematicians and computer scientists since Alan Turing, in 1936, found that it's impossible to decide in general whether an algorithm will run forever on some problems. Resting on P versus NP is the security of all online transactions which are currently encrypted: if it transpires that P=NP, if answers could be found as easily as checked, computers could crack passwords in moments. (Bragg 2015)

The episode has been chosen, because the choice of topic for the program meant that the researchers were faced with a specifically complex task when navigating between what to explain and to what level of explanatory depth. The basic distinction between P and NP is one between problems that are easy to solve and problems that are difficult or impossible to solve. The researchers are thus faced with the challenge to make it clear to listeners why a problem is difficult to solve. The challenge lies in deciding, to what extent and to what level of detail it is necessary to explain the causal reasons leading to the difficulty to a non-expert in order for the non-expert to accept the difficulty. Furthermore, NP problems are typically presented as being quite quotidian, like how to calculate the shortest route between five cities, starting in one city, visiting each city only once, and returning to the start city again. Hence, apparent simplicity and actual complexity are characteristics of this type of mathematical problem. The challenge is to make non-experts understand the actual complexity, without having to go into lengthy descriptions of the causal factors in the underlying mathematical knowledge system.

In the following analysis I use the four levels of explanatory depth presented above to interpret, where the experts position themselves between the two ways of using explanation in dissemination at different places in the conversation on 'P v NP'. For that purpose, I have chosen some instances at which Melvyn Bragg (MB), the host in the program, challenges the explanations given by the experts (Timothy Gowers (TG), Leslie Ann Goldberg (LG) and Colva Roney Dougal (CRD)). Focus is on instances where the challenge is about the chosen level of explanatory depth, i. e., instances where MB is not satisfied with the level of complexity in the causal description.

The first instance I want to analyse happens between the minutes 10:15 and 13:30 in the conversation. Before this interaction, TG has explained that the central distinction in this is between 'polynomial time' algorithms ('P') and exponential algorithms, which are relevant to explain the problematic aspects in 'non-deterministic polynomial time' ('NP'). In the notation of the example, I have highlighted (bold face) aspects of special interest for our analysis, whereas I have put elements that are emphasised in the conversation through underlining:

(1) MB: LG, we are now moving to complexity theory to work out which problems are quicker. Why is it so hard to distinguish between, let's call it fast and slow?

LG: OK, so I am going to give you some examples to tell you about that, but the short answer is that most of the problems that we look at, the obvious algorithm is exponential, so there is exponentially many possibilities, it's just that for some problems there is a clever way to narrow them down and find the right one. […] OK, so let me start with a couple of problems that are actually easy, they're polynomial time like TG was talking about, polynomial, practical, good. OK, so here is the first one. Let's say you have a group of n people and you want to match them up into pairs, this is called the matching problem, OK, and you know compatibilities, so CRD and MB are compatible, and some people are incompatible, and all you want to do is to take people and put them into teams to work together, but you want to know, can you do this in such a way that no one is left out, everybody with somebody that is compatible. OK. If you just looked at how many pairings there were, it is exponential, and just to give a kind of scale of that, if you had even a hundred people, the number of possibilities is more than the number of atoms in the universe. You cannot look at them all.

MB: You can't pair up 100 people into 50 compatible units without it taking more … more <u>time</u> than the number of atoms in the universe?

LG: Yeah, sorry, I wasn't very clear, **the point is that the number of different pairings that there are, if you look at the number of possibilities, that's more than the number of atoms in the universe**. Now, obviously, an exponential dumb algorithm might just consider every possibility and say 'Oh, is this possibility good, are all the people that were paired compatible? No, let's try the next one, no, let's try the next one,' that's ridiculous. But **this is actually an easy problem, because we do know a polynomial time algorithm**, I mean in fact we have even known that since the 1960s, due to Jack Edmonds, so, that's an easy problem.

MB: **Just a second. First of all, it's very, very complicated, and now it's very easy?**

LG: OK, let me try. So, **the point is, the number of solutions is huge**.

MB: Yeah, I got that, we've all got that.

LG: OK, so we've all got that. So, if you just blindly look at one solution, the next, the next, the next, that would take forever. However, that is not a good idea, there are smarter ways to solve the problem, and **there is a clever algorithm, which it would take more than 43 minutes to explain, that does something else, OK, and manages to find the good pairing**, it doesn't just look at every possibility, it cleverly constructs the best one.

In the first instance, the expert (LG) presents an example of the type of problems of relevance here. The first challenge by MB is not about causality, but about the dimension that leads to the difficulty. He suggests that the problem is time, and LG underlines that the difficulty lies in the number of pairings that is the problem. Hence, what causes the difficulty of the problem is the fact that the number of pairings is so high that the obvious algorithm cannot give an overview within reasonable time. In the categories of explanatory depth, this is an explanation using the level of causal powers (high number of pairings → difficult problem).

In the following sentence, LG then says that the problem is actually easy to solve, due to some specific type of algorithm. So now LG has presented the problem as difficult and easy at the same time, again using a causal-powers explanation by explicating the reason for the problem being easy (specific algorithm → easy problem). MB challenges this explanation, and as a reaction to this, LG repeats the causal-powers explanation for the difficulty, which MB also recognises (*Yeah, I got that, we've all got that*). In her next turn, LG then repeats also the causal-powers explanation concerning the actual easiness of the problem and gives as a reason why she does not go to a deeper explanatory level that it *would take more than 43 minutes to explain*. In this interaction, MB pushes towards getting an explanation at the level of causal system, where we would be told what the background is for the causal effect of the specific algorithm. LG, however, sidesteps this challenge with the argument that it would be too complicated to explain. From the point of view of explanatory ambition, you can say that LG here on record signals that she has relevant expertise, which she does not think is accessible or necessary for the non-expert listener. As MB accepts the sidestep, he obviously accepts the explanatory ambition level suggested by the expert in this instance.

The next instance to be analysed happens between 17:25 and 19:20 minutes:

(2) MB: TG, please, now let's move on to NP complete problems.

TG: Right, so, the NP problems are those, where it is easy to check, so this factorization is a very good example of an NP problem. Suppose I got a 200-digit number and the challenge is to find two 100-digit numbers that multiply together in order to give the 200-digit number, as was just said, but if someone tells you two 100-digit numbers and says 'I think these might work', then it is much easier to check, you just go away and do a quick, I mean a computer would need to do it for you, because multiplying 100-digit numbers by hand is not that easy, but a computer can do it very easily, so that's an NP problem. And … **a bit of a miracle occurs**, **something that has no real right to be the case**, which is that there are a lot of NP problems that turn out to be of equivalent difficulty in the following sense, **that if you got a good method for solving one of them, then by a completely non-obvious process you can convert it into a good way of solving one of the other problems**. The interest in integer factorization is actually not one of these NP complete problems, but I am sure we will at some stage discuss ones that are.

MB: Now, can you just give us a hint now, it is too tantalizing to leave?

TG: Ehm … well, there is one which is the so-called Travelling Salesman problem, which we are coming to, so maybe I should just stop for the moment, we can have these examples, and then we can talk about the sense in which they are NP complete. But just a thing … what I am saying here is **something that is really not obvious** in the sense that if you look at … you can get two problems that look completely different, and it turns out that if you have a good way of solving one of them, you could use it for example to factorize integers when the problem itself looks as if it had absolutely nothing to do with integers.

In this interaction, the expert (TG) presents a specific type of mathematical problems called 'NP complete'. The details of the concept are irrelevant for my analysis. What is interesting here, is that TG first presents an explanation of the concept at the level of causal powers (NP problem easy to check → NP complete). In a second step, TG gives another explanation at the level of causal powers by stating that solving one NP problem helps solving other NP problems (Solution to one NP problem → solution to other NP problems). He also kind of approaches the level of a causal-system explanation by indicating that there are underlying characteristics behind this causal relation. However, instead of trying to make these structural similarities clear to the non-expert listener, they are hidden under the label of 'miracle', 'something that has no real right to be the case', and 'something that is really not obvious'. Hence, the level of explanatory ambition is a little deeper here than above, but we still see some sidestepping on the part of the expert: TG does not want to tell us the details, but he wants us to know that this is something very special. The approach towards the level of causal system may be said to have a pseudo-quality: The expert indicates that there is a next level but does not take the non-expert onto this level of complexity in the explanation. Again, MB does not challenge the level of ambition.

The third instance is positioned between 25:30 and 27:19 minutes:

(3) MB: Can you take that on, TG, as it is being said, it's clear, I have no idea whether I will remember it tomorrow at lunch time, but still, can you take that on**, the idea of these apparently ordinary problems, with which people get through every weekend, seating people at dinner tables, are so, when you think about it, so difficult**, and in that difficulty the solving of that difficulty will open up a whole realm of solutions to problems which affect the deepest parts of experimental science.

TG: Yes, so there is a couple of things that it is important to understand, so one is that when we take one of these practical problems, **the first thing you do as a mathematician is to abstract out**, you try to strip it of all its details, like what the wedding table looks like, and that sort of thing, and convert it into a purely abstract mathematical problem. So, the mathematical problem in this case is you'll have a network, and a network consists of some nodes, and maybe some links between some of the nodes, and **these nodes and links can represent any sorts of things**, the nodes could represent cities, and nodes could represent roads between the cities, or nodes could represent people and links could represent whether it is OK to put two people next to each other at a wedding. So, once we have turned it into an abstract problem, we can then take it a little bit out of the realm of the practical, we can make these networks get larger and larger, and actually, when we study it abstractly, **we think we just got a network with n nodes where we think of n as just one very large number, and we are interested in how solving the abstract problem scales with n**. So, once you've sort of slightly left the real world behind, **I think that it then gets more plausible that these problems should be very hard**. If you present it in the abstract form and just look at it, there is just no reason to suppose that it would be an easy thing to do, and in many cases, as far as we know, it isn't an easy thing to do.

Here, MB sets the scene by not just suggesting a topic for the turn of the expert, but by presenting two causal relations and requesting an explanation at the level of causal system. First, he wants TG to talk about the fact that NP problems are apparently quotidian and ordinary but become complicated when entering the realm of mathematics (apparently ordinary problem entering mathematics → complicated and difficult). Secondly, the specific difficulty of the mathematicians is of a kind that means that solving the ordinary problem will mean solving intricate problems in science (solving ordinary problem → solving scientific problems).

In his subsequent turn in the conversation, TG focuses mainly on the first set of causal relations, viz. that taking ordinary problems into the realm of mathematics makes them difficult. He here takes the non-expert listener to the next level of explanatory depth and explains the underlying system that is the reason for the causal-powers relation between apparent ordinary simplicity and mathematical difficulty. The underlying systematic characteristic is the necessity to work in the abstract, so that solutions are not singular, but principled. Here we see a higher level of explanatory ambition, as the expert ventures to reveal the reasons for the causal-powers relation and thus creates the possibility on the side of the non-expert to construct a deeper understanding. Through this, TG actually also renders a causal-system explanation to the second causal-powers relation mentioned by MB. For the abstraction requirement is also the reason why solutions to one problem may be used in the solution of other problems that may be abstracted to a similar structure. What TG still does not reveal (but is also not asked to say something about) is what the common internal characteristics of the abstract descriptions are that allow the solution of the problem of seating guests at a wedding table, so that they are all compatible, to help with *solutions to problems which affect the deepest parts of experimental science.*

Finally, the fourth example is situated between 27:20 and 29:12 minutes in the conversation:

(4) MB: LG, how fine a line is there between the problems that can be solved and those that become NP complete – unsolvable?

LG: Often, you only have to change a very small thing. So, let me go back to the problem I introduced first, about taking n people and pairing them up into pairs. So, the way I described this to you we have n people, we have compatibilities, …

MB: ‘n’ meaning ‘any number of people’, right?

LG: Any number, so ‘n’ is the number of people, and we have compatibilities between them, we know who loathes who and we want to pair them up so everybody gets matched up to one other person with whom he or she is compatible. **That’s NP, that’s easy**. Now, suppose I change it just slightly, and I say we’ve still got n people, we’ve still got compatibilities, but now what I want to do is split them up into groups of three, so that within each group of three, there is compatibility. That’s NP complete. **So, when we move from two to three, it goes from easy to NP complete**.

MB: **Why is that?**

LG: Why is that? Well, (longer laughter), **well, it simply is** (laughter).

MB: Now what if the gang of people like each other?

LG: Oh, if all like each other? If everybody like each other, it is easy. And that is actually a really good point. So, these problems, why they are hard, and **maybe actually we should have explained this**, **why they are hard is because you have to solve every single input**. So, what we want is an algorithm which if you give me n people and you give me the set of compatibilities between them, which could be anything, I have got to give you

> the pairings into threes. **Now, that's hard**. If you happen to give me compatibilities that happen to say 'everybody is compatible', I'm gonna have an easy job, I am just gonna say 'Fine, pair them up how you like'. And so, **the hard thing is that the algorithm has to work in polynomial time, no matter what instances you give**.

In this instance, the expert (LG) is asked to explain the difference between NP and NP complete. She gives an explanation at the level of causal powers, stating that the difference between looking for groups of two to groups of three is important (higher complexity in grouping → NP complete). As seen before, MB challenges this level of ambition (*Why is that?*). The expert's first reaction is actually to lower the level of explanatory ambition by going to an explanation at the level of denomination (*Why is that?* […] *well, it simply is*). The expert thus signals to the non-expert listeners that this is too complicated for them to understand. MB does not challenge this level of explanatory depth directly, but instead poses a different question, which the expert then starts answering. In connection with this answer, she probably realises why MB keeps asking about background reasons for her explanations (*maybe actually we should have explained this*) and changes her strategy. Here we get another example of an explanation at the level of causal system. However, interestingly she does not present a causal-system explanation of the difference between NP and NP complete problems. Instead, she reiterates TG's explanation of why mathematicians work with seemingly easy, ordinary problems as unsolvable problems, viz. that they want to solve problems in a way so that the actual circumstances in the problem play no role for the solution (*the algorithm has to work in polynomial time, no matter what instances you give*). The level of explanatory ambition is thus equally high here as in the interaction between MB and TG in example 3. However, this also means that LG continues not to give a causal-system explanation to the differentiating characteristics between NP problems and NP complete problems, or to the uniting characteristics between all NP complete problems.

To sum up: There are mainly three questions that come up in the conversation I have just analysed extracts from:

(1) Some mathematical problems are solvable within relevant time limits ('P'), some are not ('NP complete') – why?

(2) NP complete problems are often phrased as very ordinary problems that appear to be easy to solve, but they are difficult in mathematical terms – why?

(3) Solving the seemingly ordinary problems would help solving intricate problems in experimental science – why?

In the instances analysed here, the experts seem to want to focus upon giving explanations at the level of causal powers (A influences B causally). Hence, the chosen level of explanatory ambition is to tell that one factor influences another and thus creates a specific effect which the expert thinks is interesting:

- example 1: hard problems become easy (question 1)
- example 2: problems difficult to solve but easy to check become NP complete (question 1)
- example 2: solving one problem enables to solve other problems (question 3)
- example 3: apparently easy problems become difficult when entering the realm of mathematics (question 2)
- example 4: Complications in conditions turn NP problems into NP complete problems (question 1)

The potential effect of choosing this level of explanatory ambition is that focus is on giving listeners insight into the fact that (in our case) something is difficult, and what the central factors are in creating the difficulty. However, the idea is not to introduce them to the deeper reasons for the causal relations between factors. This level of knowledge is reserved for the experts, non-experts are not expected to enter that level. Example (2) is a little different from the others in that the expert himself offers an approach towards the level of causal-system explanations by indicating some underlying system. However, this has pseudo-character, as it is presented as 'magic', which again means it is something that the expert cannot explain to the non-expert.

However, quite consistently (example 1, 3, 4) the host of the program, MB, does not accept the presented limitations and challenges the experts' chosen level of explanatory ambition. The reactions to this are different. In example 1, the expert explicitly sidesteps by indicating that this is too difficult to explain. In example 3, the expert complies and gives an explanation of the level of causal system, offering an answer to question 2 above. In example 4, again the expert sidesteps by choosing an explanation at the level of simple denomination (*well, it simply is [NP complete, i. e., difficult]*). However, after that she offers the same causal-system level explanation to question 2 that the expert gave in example 3. Hence, when challenged, the experts react and try to give explanations belonging to a higher level of explanatory ambition, according to the idea of the program. It is, however, interesting that they only do this in connection with question 2 and not for question 1 and 3. Here, they either sidestep or ignore the challenges.

4 Conclusion and outlook

It would not be relevant to speculate about the reasons for the observed behaviour on the very narrow basis of these four examples. However, in order to at least venture some preliminary thoughts, the tendency of the experts to sidestep challenges in connection with question 1 could be an attempt to not lose the red thread in the argumentation – but anyway it signals a lower level of explanatory ambition. Furthermore, it is interesting that the experts feel especially pressed to go into explaining the backgrounds of exactly question 2. Curiously, to choose to phrase an abstract problem in an everyday format (grouping people in groups of 2 and 3 according to compatibilities) is a dissemination trick used to make the problem accessible to non-experts (Niederhauser 1997: 119–120). Obviously, the impression of the experts, which is probably based on the fact that the non-expert host consistently challenges their qualifications of the problems as actually difficult and almost unsolvable, is that the trick backfires in this conversation. Therefore, they seem to make an exception to their regular choice of level of explanatory ambition. This is probably a wise move, because it enables non-experts to stop thinking about why they cannot see the problem. Furthermore, it is a move towards approaching the non-experts to the actual thinking of the experts. In this way, it can be seen as an instance not only of dissemination, but actually of popularisation (Engberg 2020a).

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