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A NEW ARGUMENT SCHEME FOR CAUSAL EXPLANATIONS BY ANALOGY? THE CASE OF GALILEO'S EXPLANATION OF THE TIDES

Abstract. This paper is a case study. After formulating three norms for critical assessment of argumentation (section 1), I give a brief overview of Galileo's argumentative strategy in his *Dialogue* and present his argument for the cause of the tides, which appears as an argument by analogy (section 2). I then discuss possible reconstructions of this argumentation, with one particular suggestion in detail. These arguments seem to fall short, given the aforementioned set of norms (section 3). This leads to my own proposal of Galileo's argument. I defend this proposal and it's general idea – that is, the argument's pattern. It will be classified as 'interventionist' and useful regarding the goals of critical assessment (section 4). Finally, I suggest that the pattern of argument is applicable to other cases and useful for applied theory of science (section 5).

Keywords: analogy, causation, interventionism, argumentation theory, Galileo Galilei.

Introduction: Three norms of critical assessment of argumentation

In this paper I will show and defend a possibly new way to analyse a specific type of causal explanation. Altogether, the central argument is just one example of a general argumentative strategy and thus merely a proof of principle. At the end, I present some ideas on how to apply the argument scheme to other cases. In this way, I suggest that it is indeed a new and valuable argument scheme worthy of further use.

My three main claims are that (a) the way I reconstruct Galileo's explanation of the tides is adequate – it can be seen as capturing what Galileo wanted to say –, that (b) this reconstruction follows a new and interventionist pattern of argument and that (c) the reconstruction is useful due to the properties of the argument-pattern, if one accepts three norms of argument reconstruction.

Arguing for these claims is the main goal of this paper. The main goal is thus *not* to defend or attack Galileo Galilei's explanation, it's also *not* to suggest that Galileo invented a new strategy of argumentation and it's *even less* to deconstruct other argument schemes for analogies or causal explanation, or suggest that the one-and-only true version of Galileo's argument has been found. Often, there seem to be a couple of possible reconstructions, all stressing different aspects of the argumentation, each useful for different purposes. Thus, the defence of my way to formulate Galileo's argument will be one *given a set of norms* and *relative to other ways* of formulating analogies.

The view on the relation of explanations and arguments in play here should be made explicit. Arguments and explanation are not the same thing. Still, arguments and explanations are inferentially connected. Also, intuitively we believe that when explaining something, especially in a scientific context, sound argumentation should be involved. Since Galileo clearly gives an explanation of the tides, this should be the case for him too. One way in which arguments and an explanation can be connected is an *inference to the best explanation* (Betz, 2013; Lipton, 1991), where an explanation is involved as a premise in an argument scheme.[1] The idea regarding Galileo's work on the tides is that he is giving an argument for the cause of the tides via an analogical inference and that this – as he himself suggests – contributes to the quality of his explanation. I am referring to this point when I say, for example, 'explanation by an (analogical) argument'. I will return to this later when commenting on the argument, but to say it briefly in advance, the way the causal claim about the tides is inferred by 'technical' (manipulative) knowledge, thus, the kind of premises involved, is crucial for the evaluation of his explanation. As the Dialogue shows, this is Galileo's opinion and I think it can be made explicit by the construction of a new argument scheme.[2]

Returning to the question of the criteria of quality for the following argument reconstruction: what norms do I have in mind and for which ends should they be accepted? Philosophy has a long tradition in analysing arguments in an abstract and more or less formal way. One possible way to use the insights of this tradition is to apply identified patterns of arguments to real life argumentation. In this way, a certain way of speaking about argumentations that is already carried out in everyday life is professionalized: in everyday life we already comment on inferences as being unjustified. For example, we say that one cannot infer that one should refuse vaccines just because they are not 100% safe, since when deciding about vaccinating one should at least also consider the risk of disease effects. This can be

understood as stating that the form of the argument used to decide about a vaccine was not the best one. Professionalizing such structural comments on argumentation by talking about argument schemes[3] could mean agreeing to the following norms: *An argument scheme should help identify the reasons used to justify a claim.* In an application of the scheme, reasons given in a piece of argumentation should be represented, 'reconstructed'. Traditionally this will be done by formulating premises and a conclusion. *The applied argument scheme should also help to identify the critical points of a piece of argumentation*, that is, for example, not well formulated or defended premises or even missing ones. Maybe wrong or too strong inferences can be found as well. Lastly, *it should be possible to identify and assess the qualities of the argument given.* By discussing the logical form or relation of premises it should become clear for example, how the premises can be shown to be true or false.

This is not a complete list and a lot of details could be added, but I call following these norms 'attending to a project of critical assessment of argumentation'. Breaking these norms down to explanations and explanations with analogies in particular, they can be stated like this: (1) After applying an argument scheme for analogy to a real piece of argumentation the author's reasons for his conclusion should be part of the premises. (2) After application it should be possible to map the analogy's problems, mistakes, missing premises or further inferential obligations to the premises in the argument. (3) After application it should be possible to assess why the analogy is a good (or bad) way to convince the reader of the conclusion.

Galileo's explanation and its position in the Dialogue

The piece of argumentation I'll be working on from now on is found in Galileo's '*Dialogue concerning the two main world systems*' (Galilei, 1967). In this book, Galileo defends in three steps the thesis that the Earth is moving around itself and around the sun: The first step is to show that Earth and celestial bodies are not different in principle. The second step is to show that assuming the Earth rotates is consistent with our knowledge of movement in general. His explanation of the tides now plays the crucial role of the last step in his overall argumentation because he is giving a positive, not a negative argument for his main goal. The idea is to infer the causal claim about the tides with the main thesis of the Dialogue as one of the premises. While this might look circular at first sight – Salviati's fictive opponent even raises this objection on the 'fourth day' of the dialogue – this strat-

egy is highly plausible: *If* an explanation of a very common phenomenon works extremely well and one of the premises involved in the argumentation is thesis x, this raises the likelihood that x is indeed the case (or the claim 'that x' is true). And since Galileo cleared the path of arguments set forth against his 'x' (the Copernican thesis) beforehand, nothing is in the way of accepting x.

This strategy is nothing unusual. Think about explanations from evolutionary biology or archaeology: if a puzzling change in the fossil record is best explained by a dramatic global change of environment resulting in a mass extinction, it becomes more likely that such an event – maybe a meteorite impact – took place. If a new type of hand-axe that was found in a certain area is pretty well explained by an argument based on a premise that a particular tribe migrated northwards, then this premise is more plausible as well. From now on, I am just concerned with Galileo's explanation of the tides though, not with the a reconstruction of the ways the explanation contributes to his justification of the Copernican thesis in combination with the other parts of the Dialogue. Galileo's explanation of tides begins with a list of suggestions that have been made to explain them before. According to him, all of them (including an explanation involving the light of the moon) are clearly wrong, and they especially suffer from not being backed up by any sort of physical experiment:

> [A]mong all things so far adduced as *verae causae* [of the tides, A.K.] there is not one which we can duplicate for ourselves by means of appropriate artificial devices. For neither by the light of the moon or the sun, nor by temperate heat, nor by differences of depth can we ever make the water contained in a motionless vessel run to and fro, or rise and fall in but a single place. (Galilei, 1967, pp. 421 sq.)

His own explanation though, as the reader already presumes, is a better one and can be 'duplicated', as he says. At this point Galileo gives an explanation by analogy: the water on Earth is moving just as water in moved vessels on Earth does. He gives the example of the water-filled barges, being navigated to Venice to bring freshwater to the city. The water inside sloshes back and forth and up and down at the rims of the boat just as the water does in the Earth's ocean basins:

> Now gentlemen, what the barge does with regard to the water it contains, and what the water does with respect to the barge containing it, is precisely the same as what the Mediterranean basin does with regard to the water contained within it and what the water contained does with respect to the Mediterranean basin, its container. (Galilei, 1967, pp. 425 sq.)

For him, this is far more than an observation. It's a fact that can be proven by hand and investigated in a series of experimental set-ups. In a very detailed discussion Galileo goes on to show how he is able to explain details of the real tides in analogy to his experimental system, if specific practical options of setting water in motion in vessels are taken into account. For sure, Galileo suggests that the type of movement that has to be performed with the water is the same type of movement he suggests to be the real movement of the Earth, namely a combined non-uniform movement: the Earth's rotation around itself and around the sun. To reproduce the effects of this kind of movement, Salviati tells Sagredo and Simplicio, he has also built a specific apparatus. As I have shown with the first quotation, Salviati – Galileo's spokesman in the Dialogue – considers this to be the great advantage of his explanation compared with those of others:

> And though to many people it may seem impossible for us to test the effects of such events in artificial devices and vessels, nevertheless this is not entirely impossible; I have a mechanical model in which the effects of these marvellous compositions of movements may be observed in detail. (Galilei, 1967, pp. 430 sq.)

Unfortunately Galileo didn't give any further information about this apparatus. Anyway, his argumentation clearly rests on successful experimentation. Since the goal here is not defending or attacking his argumentation, the following discussion of argument reconstructions is independent of the properties of devices he really worked with. It is assumed that it was actually built and worked to successfully establish the experimental result that Galileo claims.

Possible ways to reconstruct the explanation

Argumentation by analogy is a problematic way of reasoning – that's why some authors even label such attempts as fallacies or not even arguments and more of heuristic than explanatory value. This is because arguments with analogies involve comparisons, but it is not clear, if the two compared items differ in an aspect that is relevant for the inference.

To understand this repeatedly diagnosed problem (see for example Botting, 2012, Walton, 2014, p. 23 and the discussion of Gamboa, 2008, pp. 231 sqq.) take one of Walton's reconstructions:

> Similarity Premise: Generally, case C_1 is similar to case C_2.
> Base Premise: A is true (false) in case C_1.
> Conclusion: A is true (false) in case C_2. (Walton, 2014, p. 23)

The similarity of two cases stated in the first premise does not guarantee that dissimilarities of the two cases are not relevant in such a way that the conclusion is false.

Still, we need analogies from time to time to talk about something we don't have any direct access to or when making up our minds about new tasks or events. Since this might be a good description of our situation in everyday life and especially of learning situations of children, analogical thinking for some even is – as Hofstadter and Sanders put it – 'fuel and fire of thinking' in general (Hofstadter and Sander, 2013). When it comes to scientific explanation, our field of interest might be too big, too small, too hot, too long ago or too far away to do any research with it directly. So we try arguments by analogy just as Galileo did with the tides. The question remains though, whether an explicit formulation as an analogical argument is a good representation of why it is justified to consider the conclusion to be true.

With the following application of an explicit analogy scheme given by Tetens (Tetens, 2006a, pp. 171 sqq.), possible uses and problems of analogies can be discussed in a fruitful way.[4] The basic idea according to Tetens that I will discuss and apply in detail below is that with analogical inferences a claim about a system of interest is inferred via stating a structural identity to another system with respect to a special property.

For the case of Galileo's explanation of the tides the structural identity would be one of water on a moving Earth and water in moved vessels under technical control.[5] For the technical systems mentioned, a causal relation is established experimentally. Since it might be unclear which events correspond exactly to the identified cause in the experiments, the movements used to make the water go up and down are connected explicitly to a combined rotation of the Earth and from these premises the conclusion is drawn. Thus, the argument consists of a premise about a state of affairs in one system (typically called the 'source system' in the literature on analogy), a conclusion about a state of affairs in a second system ('target system') and two further premises: with one, properties of the two system are matched and with the other the structural identity of the two systems concerning these matched properties is stated:

Galileos's explanation$_1$

(P_1) Regarding the relation of cause and effect, tides and Earth movement are structurally the same as water in non-uniformly accelerated vessels.
(P_2) In the experiment, rhythmical water movements are caused by the non-uniform acceleration.
(P_3) The cause of the water movement in the vessel matches the Earth's self-rotation and rotation around the sun.

—— Analogy inference principle ——

(K_1) Thus, the tides are caused by the Earth's rotation around itself and around the sun.

This argument expresses relevant parts of Galileo's argumentation. His explanation of the tides is a causal explanation involving the particular 'Copernican' movement of the Earth as a cause of the tides. Thus, (K_1) is a proper formulation. As seen in the beginning, (P_1) is almost explicitly given in the text. (P_2) seems to be the causal fact that Galileo holds to be relevant for his explanation. (P_3) then could be a typical premise addition – something added when making arguments explicit that makes the whole argumentation more reasonable and probably acceptable for Galileo.

Formulated this way, the problematic character of analogies can also be identified. How can Galileo rely on (P_1)? How can he be sure that (P_1) is true without knowing that (K_1) is true? Isn't the structural, causal similarity as much a result of his explanation as the causal claim about the tides itself is? This problem of the argument scheme has been identified since its first explicit formulation. It is a structural problem that has nothing to do with the case of Galileo's explanation of the tides specifically: the 'analogy inference principle' cited above between premises and conclusion is an if-then sentence formulating the argument's structure. Were this sentence true, empirically or analytically, the argument might be deductively valid. But it is not, as can be seen when the argument's scheme is formulated as can be found in the literature (Tetens, 2006a, p. 177).[6]

Analogy scheme by Tetens

(P_1) **Structural identity**: With respect to aspect A, object a is as object b with respect to aspect B.
(P_2) **Claim about source system**: With respect to aspect B, state of affairs F is the case for b.

(P_3) **Matching premise**: With respect to aspect A, state of affairs F corresponds to F^* for object a.

(P_4) **Analogy inference principle**: If with respect to aspect A, object a is as object b with respect to aspect B and with respect to aspect B, state of affairs F is the case for b and with respect to aspect A, state of affairs F corresponds to F^* for object a, then F^* is the case for a.

—— Satisfied sufficient condition ——

(C) **Claim about target system**: Thus, F^* is the case for a.

This reconstruction, I thinks, shares common features with the ideas of other authors writing on analogies in general. Before defending this though, I'd like to discuss some details of the scheme to avoid misunderstandings and to show how the problematic aspect of analogical inference can be discussed using this reconstruction.

Premise (P_4) requires some clarification: this premise states the inference pattern as one sentence with an if-then structure. With this premise the general idea of the argument is expressed and the argument becomes deductively valid, since it is an if-then sentence, the if-part is satisfied by premises (P_1)–(P_3) and the conclusion is its then-part. There is no problem with this at all: if one wants to argue that analogical inferences are not deductively valid one can attack (P_4) as not being true. The idea of this reconstruction is just that analogies in general can be well understood as consisting of (P_1), (P_2), (P_3) and (C) and that this implicitly presupposes the truth of a premise (P_4).

Tetens's version is – as I suggested above – an explicit argument scheme similar to the thoughts of other people writing about analogical reasoning. The general premise (P_1) expresses what other people, with or without formulating explicit schemes, call 'isomorphism' or 'general similarity' of a start and target system (see Weitzenfeld, 1984 and the first scheme cited by Walton, 2014). (P_3), called 'matching premise' above, expresses thoughts of authors that emphasize sets of 'correspondence' between target and analogue (see, for example, Juthe, 2005, p. 5). Thus, the diagnosed structural problems of analogical inferences seems to be the same for other accounts as well. Tetens's version can be taken as an elaborated and very explicit example.

Presented this way though, some aspects of Galileo's explanation are not covered, and this is unsatisfying regarding the norms formulated above. First of all, Galileo's reasons are not yet present in the reconstruction. It

seems that he would still have to explain why he holds (P_1) to be true. A mere observation of *some* similarities, subsuming both systems under *some* common partial description would be too weak given the strong demand for structural identity *with respect to cause and effect* formulated with (P_1).[7]

Secondly, the specific points Galileo got wrong with his explanation cannot be matched to the premises. The argument seems to stand and fall as a whole with the premise of structural similarity. Looking at Galileo's explanation with our current knowledge about the tides, it should be possible to point our fingers at the false assumptions or inferences that he made. Given that his experiments have been carried out sufficiently again it is (P_1) we have to struggle with.

Last, but perhaps most important for Galileo, the epistemic quality of his analogy is not represented. It seems to be of special importance for Galileo that (P_2) is justified by experimental means. For him it is not just the fact of a causal relationship between some movement of a vessel and the water inside, but the fact that he himself (and everyone else) is able to show, to repeat this causal relationship, to be able to set the water into rhythmical motion. For him, the method of justification for (P_2) is extremely important, but premises of technical character, i.e. premises referring to actions and their consequences, are not included in the argument. So with regard to all three norms there is some room left for improvement.

A possible solution could be an inference to the best explanation (IBE) as a general strategy to reconstruct Galileo's argumentation. Isn't he stating a set of facts (facts about the tides) that he is able to explain (with a combined rotation of the Earth) – while other authors are not? Isn't he just claiming that, given these facts, his causal explanation is the best? A first obstacle while following this road would be the integration of the specific epistemic quality of the claims about his technical device. One might try to solve that by laying weight on the degree of unification that one achieves by giving an explanation with laws or generalisations that already hold for mesocosmic technical devices. But how exactly would this look, especially when Galileo's emphasis should be represented – an emphasis that might represent the scientist's desire for reproducible data in general?[8] To preserve the fact that Galileo is using an analogy, the conclusion of the IBE could be the structural similarity premise (followed by a 'classical' argument from analogy). This way doesn't seem to be very attractive either: isn't it the Earth's rotation itself that explains the tides best for Galileo – and not the similarity to his technical device? Should the IBE's conclusion state only the cause or the causal claim as well?

It's true that considerations of good explanation are involved in Galileo's argumentation. The question of how to represent the argument though, still is not answered sufficiently. Defending a new argument scheme for this (and similar) argumentation should also involve a discussion of how exactly the inference and the kinds of premises contribute to the assessment of his explanation. The epistemic strategy to infer the cause is not yet represented and, thus, there is no corresponding information that can be used in a discussion of the explanatory quality of his explanation of the tides.

A new – and interventionist – way?

The following proposal for Galileo's explanations cites as one of the premises the experimental result itself, formulated as a sentence about the action of the experimenter and the consequences of his or her actions. The basic idea is to expand this manipulative knowledge about the experimental system of water-filled vessels to the Earth and it's movement by falsifiable premises. These premises state the success of a gradual improvement of the set-up and result according to the background knowledge about the tides and the movement of the Earth. 'Gradual improvement' is achieved if, for example, the fresh water is replaced by salty water and thus the experiment is set up more adequately. If such adjustments still give the same results and results that don't conflict with the knowledge about the target system then the causal conclusion is justified. The success of this 'experimental expansion' can be formulated with the following premises (P_2) and (P_3). In addition, since Galileo aims at a common cause of all tides that happen – a common cause of this natural phenomenon – he has to assume that the described apparatus is the only valid model for the tides. This will be done with premise (P_4).

Galileo's explanation$_2$

(P_1) We can change the height of water in vessels rhythmically by accelerating the vessel in a non-uniform way.

(P_2) The changes in water height cannot be suppressed by adjusting the experimental system to the properties of the Earth and its movement.

(P_3) By such adjusting no course of events is brought about that is in conflict with our knowledge about the movements of the Earth and the tides.

(P_4) By no other means can we bring about rhythmical changes of water height and adjust the experimental system as an adequate model of the tides.

—— Interventionist inference principle ——

(K_1) Thus, the tides are caused by a non-uniform movement of the Earth.

This argument is adequate – the main claim (a) mentioned in the beginning – in the weak sense that it covers the main point Galileo is making in the 'fourth day' of the *Dialogue*. Before addressing the label 'interventionist' and the aspect of novelty – my main claim (b) –, the evaluation with regard to the three norms formulated above – regarding my main claim (c) – and finally the argument's status (inductive/deductive), let me go through the premises again and add some clarification and details about Galileo's argumentation in the *Dialogue*. (P_1) is the experimental result. Finding a precise formulation that is not too broad or too narrow to capture the results in the best way is not an easy task. One problem is the generalization of the terms involved. Speaking of 'vessels' here is already more general than speaking of 'barges'. The context and his various comments on details of the changes in water height show that Galileo naturally claims to have consistent control over a whole range of vessels. The same holds for the manipulative action: it's not just one specific kind of non-uniform acceleration, but non-uniform acceleration in a broad sense. Here it is just assumed that agreement about this is possible if the experimental setups were reconsidered.

(P_2) could be falsified by further adjustment of experimental set-ups. When Galileo tells the reader about the mysterious rotation apparatus, he claims that such a double rotation still has the same result. In this way he already prevents possible attacks against (P_2). Other relevant changes could be changes in size and movement velocity. A couple of comments from Galileo can be understood as claims that for his experimental set-ups (P_3) is satisfied or – maybe a better way to say it – not yet falsified. He cites facts about the tides and shows that the results do not contradict these. So, for example, the fact of greater tidal effect in the Red Sea corresponds to bigger effects in the moved vessels. The effect is biggest in the direction of the movement and since the Red Sea is stretched out from East to West and thus in the direction of the suggested movement of the Earth this experimental effect does not contradict the Red Sea's tides. A trivial violation of (P_3) would be a robust knowledge that tides existed before

there was a rotation of the Earth. So the time asymmetry of the experimental process (movement first, then the tides) would contradict the real succession of events. Another violation would be a violation of amount: if the change of water height were much too high or low when extrapolated to planetary dimensions and velocities the experiment would also contradict the real system.

With (P_4), the described process is assumed to be unsuccessful for other experimental models. While there might be couple of ways to set water in motion or change the height of water in a vessel all these processes fail to 'scale up' as adequate models of the tides.

I would like to label this argument 'interventionist' for the following reasons: the core idea of the interventionist tradition in philosophy of causation is the primacy of human action. This is used, for example, by von Wright to define causation (von Wright, 1971). The argument here does not rely on interventionism as a theory of causation, but it is still using insights from the analytical debate concerning the logical structure of action descriptions, the importance of models and ways to improve them.[9] The argument works well without any explicit reference to causes and effects, but with terms that refer to human action and its consequences. Most important though is that all four premises are premises about manipulative knowledge and its scope. The *analytic* focus of interventionism is preserved in the argument's *epistemic* focus on what we are able to do.

Most important for the argumentation in this paper is the answer to the question: is this reconstruction strategy favourable over the current strategies to analyse analogies given the norms of critical assessment of argumentation formulated above? First, the reason Galileo considers to be most important is represented directly: With (P_1) the analogy becomes a technical analogy and the explanation is grounded in replicable knowledge. Further descriptions of the experimental set-ups and results can be understood as strategies to convince the reader that (P_2) and (P_3) are not violated even when more detailed empirical information about the tides is considered.

The second norm formulated above, demands potential for a critical analysis of the argument. Can Galileo's mistakes be mapped onto the premises? From today's perspective we surely would ask for a better description of the experiments, especially his rotating apparatus. So when critically assessing his argumentation we would ask for a more precise formulation of the actions carried out and thus, for a more precise formulation of (P_1). A crucial point is the scope of the second and third premises. There is reason to believe that they can never be proven to be true. They can only stand the tests. The adjustment of the set-up will have its limits – other-

wise physicists would be able to set the Earth in motion and there would be no need for an analogy at all. One big flaw of Galileo's explanation is that it doesn't explain a constant feature of the tidal changes: the daily time shift of the flows of approximately 50 minutes. The constant rotation of the Earth might explain two flows per day, but not this particular constant change in times. This problem can be mapped to (P_3). It's a problem of adequacy of the experimental result and Galileo would have to come up with a replicable effect through an experimental set-up that fits the Earth's movement. Last, but not least, Galileo was wrong about the ways of manipulating masses in general. Gravitational effects can also be replicated as lab effects with a Cavendish experiment or with a magnetic fluid and an analogy between gravitation and magnetism. This kind of knowledge surely was not available to him, but, structurally, it's premise (P_4) that this problem can be mapped to. Since the premise is a general one, and thus the risk of falsification one of principle, Galileo should have avoided pretending to have shown other technical analogies to be impossible. Only one possible means to an end at a certain time and cultural situation doesn't imply only one means for all time.

Still, regarding the third norm, the knowledge in the argument's first premise is replicable, its other premises at least falsifiable and the technical model maybe the best available at Galileo's time. The biggest flaws are its inadequacy regarding already well described facts of the tides and insufficient information about the actions carried out. So, this reconstruction to me seems quite suitable for discussing the piece of argumentation from Galileo in a detailed and critical way with a straightforward connection to the premises, while for other accounts this is only possible if additional questions are given with the argument scheme (see for example Walton, 2014, p. 234). For critical use and detailed discussions, standard analogy schemes seem to be too abstract.

The argument can be taken as an application of the following interventionist argument scheme:

Interventionist model inference

(P_1) **Experimental premise**: At the experimental system s_e we can bring about y_e by doing x_e.[10]

(P_2) **Source system adequacy**: Adjusting s_e to the target system's x_t and y y_t is no means to suppress y_e.

(P_3) **Target system adequacy**: With no such adjusting a course of events can be brought about which is in conflict to our knowledge about s_t.

(P_4) **Sole model principle**: By no other means can we bring about y_e and adjust the system to an adequate model of y_t.

(P_5) **Interventionist principle**: If (P_1), (P_2), (P_3) and (P_4) then x_t is caused by y_t.

—— Satisfied sufficient condition ——

(K_1) **Causal claim**: Thus, x_t is caused by y_t.

Epistemic qualities, limits and obligations arise from the structure of the scheme's premises. But is such an argument valid? It is set up here as a deductive argument. As for the analogy scheme cited above though, all depends on the justification of (P_5), because this premise turns the argument to a modus ponens. (P_5) in my opinion though only expresses the idea of the argument and is not a conceptual truth. For the argument to be deductively valid an analytically true principle would be necessary that allows one to draw the conclusion. Instead, I think there is a plausible way to justify this argument scheme as an inductive one. It's the close relationship between analogy and inference to the best explanation that helps clarify: IBEs are inductive inferences as well. Though often accepted, and maybe even without any alternative in some situations, premises there cannot guarantee the truth of the conclusion. Instead, the premises in best cases fulfil a set of criteria and thus justify one in accepting the conclusion. This seems to be the case with the interventionist argument as well. (P_1) is – remember Galileo's emphasis – a premise citing replicable knowledge. Building up an explanation on a technical analogy adds '*unificatory strength*' (Betz, 2013, p. 3568) to our body of knowledge. With good interventionist model inferences, the same process will be involved in source and target systems. With (P_2) the explanation becomes falsifiable by further experimental research and with (P_3) it becomes adequate concerning our background knowledge. This adds up to a collection of premises that together fulfil important epistemic qualities and allow one to draw the conclusion similar to the way it is justified in an IBE – inductively, not deductively.

In addition to that, here, as suggested at the beginning, a connection of explanations and (especially interventionist) analogical arguments can be seen. It consists in the consequences that the argument has on the quality of our system of beliefs and this can be used to formulate (relatively best) explanations. Interventionist analogical arguments use premises that contribute positively to the assessment of IBEs justifying the cause-event, since the experimental system is adjusted to properties the cause-event must have had *if it happened*. If the Earth rotates, then it does so with a com-

bined rotation movement and fast. Such a movement does not suppress the effect in the model-system for the tides. Thus, this process contributes to the claim that the Earth rotates.

Can the scheme be applied to other cases?

As I said at the beginning, even if my own argumentation is sound so far, it serves only as a proof of principle. Still, I think the style of argument reconstruction, and the interventionist model inference in particular, can be applied to other cases in a way that is helpful for analysing real knowledge claims. I'd like to end this paper with some suggestions about other cases.[11]

Bringing about events and inferring causes from that is a procedure in different sciences. For critical philosophy of science it's necessary to develop methods for assessing the structure and quality of these inferences. Developing case-sensitive, applicable argument schemes could be a way to not deviate too far from the language and practice of the respective scientific communities. The new scheme for causal explanation by analogy could be a good contribution.

Evolutionary biology, for example, seems to have only a loose connection to experimental practice. Still, the justification of one of the most famous textbook examples – the population change of the peppered moth – can be easily reconstructed as an analogy following the scheme above with the famous experiments of Kettlewell in the 1950s (Kettlewell, 1955, Kettlewell, 1956). The fact that the peppered moth is a text book example suggests that the structure of the evolutionary adaption process and the causes involved can be easily identified in the argument. The epistemic situation with evolutionary processes longer ago and with less background knowledge might be far more complicated. Still, it might be that the uncertainty of evolutionary explanations corresponds to the degree of support for the premises. In addition, a lot of experimental knowledge (from human and animal psychology to plant or cell physiology) is interpreted from an evolutionary perspective. If these evolutionary inferences are understood as sketches of interventionist evolutionary model explanations, then the inferential obligations become obvious. The process manipulated in the lab has to be projected onto phylogeny. It shouldn't break down when adjusted to historical background conditions, it shouldn't contradict the historical record and there should be historical evidence that the 'possible' causal factor driving an evolutionary change was real in the past. This suggests that applying the scheme to evolutionary explanations can help to identify

the crucial points and obligations, and the work that is still to be done. Scientific discourse about a specific thesis about evolution could be taken as a dispute about the premises of an instantiated analogy scheme. If one causal were 'The typical white skin of human eyes evolved to facilitate cooperative social practices' (see Tomasello, Hare, Lehmann, and Call, 2007), then an explicitly causal reconstruction of the thesis and an application of the scheme helps to assess the contribution of the experiment that is cited as support for this thesis.

Etiological claims in medicine are often justified with animal modelling. Since it is ethically prohibited to bring about diseases in humans, infecting animals is the key step to finding pathogens. The Henle-Koch-postulates can be seen as pointing exactly in the direction of an interventionist analogy argument scheme. While initially developed for infectious diseases, carcinogenicity tests today also have the structure of bringing about cancer and using this for causal medical explanations. Carrying out the experiment in vitro instead of in vivo just changes the object of manipulation and the limits to prove the adequacy of the model – not the structure of the argument itself. If classical inoculation experiments or brushing cigarette tar onto rabbit ears to prove 'smoking causes cancer' are nowadays replaced by inserting tuberculosis aerosols (Saini et al., 2012) and cigarette fume into animal cages (Kennaway, 1924), then this development in experimental techniques can be mapped to problems of (P_2)- and (P_3)-premises.

If there are contrary views about the origin of a singular event in natural history, such as Lake Cheko in Siberia – geologists arguing for it to be a meteorite crater (Gasperini et al., 2007), experimental physicists arguing against it (Collins et al., 2008) – applying the argument scheme can help to map the contributions onto the structure of a good analogy argument. Understanding the crucial points and also the specific epistemic limits of the scheme can then help to identify too strong inferences and possible solutions to mediate between the opposing views.

Galileo's false explanation of the tides is thus a historical case that contains enough material to develop an argumentative scheme that might also be useful for the critical assessment of current claims of causal knowledge.

NOTES

[1] The DN-model of explanation by Hempel and Oppenheim (Hempel and Oppenheim, 1948) is constructed as a deductive argument: '[T]*he explanation should take the form of a sound deductive argument in which the explanandum follows as a conclusion from the premises in the explanans.*' (Woodward, 2017. Compare also his description of Kitcher's account of explanation.)

[2] There are at least two more views that might be controversial: First the attempt to present Galileo's inference in a single argument. The second is the attempt to capture justified analogies in a structured argument in general.

[3] 'Argument scheme' here is meant in a broad way as inference representations with 'placeholders', ranging from Aristotelian syllogisms to the different accounts in modern argumentation theory (for example Walton, Reed, and Macagno, 2008; Tetens, 2006a).

[4] Examples given are the watch analogy by Leibniz, Hume's teleological proof of God (Tetens, 2006a, pp. 171 sqq., the wave theory of light (Tetens, 1987, p. 83) and Einstein's explanation of the photoelectric effect (Tetens, 1987, pp. 84 sq. and Tetens, 2006b, p. 438). Löwenstein discusses an argument of Dummett's against Frege (Löwenstein, 2015).

[5] 'Being structurally identical' here means having a common true partial description. 'Similarity' then means being identical in at least one respect/under one description.

[6] I translated the scheme and added names for premises and the conclusion.

[7] The reason why Tetens is talking about identity instead of similarity here is probably that similarity would be too weak to allow for the inference and would not cover the strong sense in which analogies like Hume's analogy between parts of nature and parts of machines are actually formulated: parts of nature and parts of machines are not just similar, regarding their purposeful interaction they are the same.

[8] For ideas on qualities of explanation and their impact on the degree of justification of a conclusion inferred by an inference to the best explanation see Betz, 2013, p. 3566.

[9] For a long discussion of the debate as a debate of the proper explication of causation and epistemic element involved, see Kremling, 2018. Compared with the 'modern', Woodwardian manipulability account (Woodward, 2003) the idea here is to substitute the counterfactual talk about action-like events and their consequences (resulting in discussions about 'possible interventions' and types of impossibility) by talk about what can actually be done and what cannot be done so far.

[10] 'x_e' refers to the result of the action carried out – the intervention into the system – and 'ye' to the consequence of the action carried out – in the sense von Wright used them (see von Wright, 1971, pp. 67 sqq.)

[11] See Kremling, 2018, part two, for a detailed discussion of these and more examples.

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