Circular but Suggestive: Pragmatic Insights from Reductive Tautologies

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Abstract

What makes an explanation seem insightful? Prior work shows that even circular explanations can seem insightful when they include information from a lower level of explanation (reductive information). Here, we suggest that this impression of insight is not an illusion. Rather, circular explanations with reductive information are pragmatically instructive: they suggest at which level of description the phenomenon should be explained. In Study 1, even single-sentence circular explanations appeared insightful when infused with reductive information. In Study 2, rating circular explanations with reductive information as insightful correlated with rating them as helpful both with searching for explanatory information and with narrowing down which mechanisms an explanation should address. Study 2 also provides preliminary evidence that these ratings were not driven by prior knowledge of these circular explanations' explicit propositional content.

Keywords: explanation; circularity; reductive information; insight

Introduction

From an early age, we all seek to better understand the mechanisms responsible for artificial and biological systems. Owing to the complexity of these causal systems, we must often rely on summary explanations. Do we accurately assess how much mechanistic insight is offered by these explanations?

Circular explanations (or tautologies) are a good test case for these intuitions since their form cannot contain insight. Consider the following example: "Vocal cords change pitch by changing pitch." By offering the explanandum (how to change pitch) as the explanans (changing pitch), it is an empty explanation. In such obvious cases, young children agree. Three-year-olds choose non-circular explanations over circular ones (Corriveau & Kurkul, 2014; Baum, Danovitch, & Keil, 2008); and some six-year-olds will rate circular explanations worse than isolated non-circular ones without directly comparing the two (Mills, Danovitch, Rowles, & Campbell, 2017).

But people's intuitions differ when confronted with reductive tautologies. Reductive tautologies also offer their explanandum as their explanans, but at a lower level of scientific explanation. (Lower level here denotes a more fundamental location in the hierarchy of scientific explanation: for example, psychology is explained by lower-level neuroscience, which is explained by lower-level biology, all the way down to particle physics (Anderson, 1972).) We can render our former example a reductive tautology accordingly: "Vocal cords change pitch by modulating the frequency of vibrations that pass through the medium of air." Modulating frequency is just what it means to change pitch – only at the much lower explanatory level of physics. What mechanisms vocal cords use to change pitch remains unexplained. Nevertheless, the inclusion of reductive information makes what remains formally vacuous appear more insightful. These findings are most robust with the inclusion of neuroscience jargon into psychological explanations (Weisberg, Keil, Goodstein, Rawson, & Grey, 2008; for a recent review see Bennett & McLaughlin, 2023), but have been found to generalize (Hopkins, Weisberg, & Taylor, 2016; Liquin & Lombrozo, 2022).

Why does the inclusion of reductive information increase impressions of insight? People might just be overextending a heuristic that explanations with reductive information are better (Hopkins, Weisberg, & Taylor, 2016; Weisberg, Hopkins, & Taylor, 2018). Alternatively, they may genuinely be learning useful information. The usefulness account is suggested by cases where formal tautologies are perceived as insightful. Unlike the explanans of a reductive tautology (which provides the explanandum at a lower level of description), the explanans of a formal tautology restates the explanandum as a category. For example, "alcohol causes cancer because it is a carcinogen" (Aslanov & Guerra, 2023). Here too, the perceived insight could arise from erroneous heuristics, e.g., the assumptions that statements with syllogistic form (Aslanov & Guerra, 2023) or which use language invoked by experts (Hemmatian & Sloman, 2018) are insightful. But the impression that formal tautologies are insightful may not be an illusion: the category invoked in the explanans might be interpreted as a placeholder for an internal causal mechanism (Gelman, Cimpian, & Roberts, 2018; Giffin, Wilkenfeld, & Lombrozo, 2017), or the statement itself might be taken to describe a principal connection between a part and a whole (Rivera, Prasad, & Prasada, 2023). However, the latter theories of formal tautologies do not clearly generalize their reductive cousins: the explanans of a reductive tautology does not suggest a causal mechanism the explanandum does not, nor does it pick out a broader category to which the explanandum is principally connected.

Here, we propose a novel way in which reductive tautologies could be legitimately insightful, too: they specify the explanandum and thereby indicate the optimal level of description for the explanation. Consider again the vocal cord example: "Vocal cords change pitch by modulating the

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frequency of vibrations that pass through the medium of air." Formally, this statement just repeats the output of the causal system. Pragmatically, it suggests that modulating the frequency of vibrations is what should be explained. The tautology directs its reader to consider what vocal cord mechanism could expand or contract sound waves. In so doing, it narrows the range of possible levels of explanation and possible mechanisms the learner might consider. Critically, this focusing on a certain level would help even when people are fully aware of the level and the kinds of components involved (e.g. frequency of vibrations); it helps by highlighting the mechanistic import of that level.

Past research into intuitions about reductive circular explanations have often stretched the vacuous relationship between explanandum and explanans over a few sentences and interspersed the tautological elements with irrelevant facts (e.g., Weisberg et al. 2008; Hopkins, Weisberg, & Taylor 2016). Given that the structural repetition of a given tautology undergirds intuitions of their unreasonableness (Rips, 2002) and irrelevant facts present an additional phenomenon to be explained, intuitions about "pure" reductive tautologies merit a closer look. In Study 1, we examined participant intuitions about structurally obvious tautologies. In Study 2, we investigated what people find compelling about these tautologies through correlational methods.

Study 1

To determine whether people found reductive tautologies insightful, we designed single-sentence stimuli such that the repetitive structure of the tautology would be obvious to anyone familiar with the lower-level description of the explanandum. As a control, we created circular explanations that stayed at one level of explanation, but still varied wording between the explanandum and explanans (horizontal tautologies). As an additional control, we created statements describing the relevant mechanism (non circular explanations). We had participants rate multiple explanations, but since one rating could influence the next, we also examined only the first insight ratings given by each participant. Using the R package simr (P. Green & MacLeod, 2016), we were able to determine an appropriate sample size for testing the latter, between-subject effects.

We expected that even with such an obviously circular structure, reductive tautologies would be rated as more insightful than horizontal tautologies, and that both kinds of tautologies would be rated as less insightful than non circular explanations. We did not preregister any predictions about the comparison between non circular explanations and reductive tautologies. (Previous research indicates the former is typically seen as more insightful (e.g., Hopkins, Weisberg, & Taylor 2016); however, our theory is agnostic toward this outcome.)

Method

Participants 260 of 300 people recruited through Prolific were used in our analyses (13.3% excluded). Excluded participants failed the attention check or did not properly enter their Prolific IDs into the survey. Non excluded participants were 67% White (17% Black, 16% Other), 50% female, and 36 years old on average (SD = 13.3).

Procedure Participants were shown four single-sentence explanations, one for each of four causal systems (refrigerator, liquid crystal display, pupil, and vocal cords). There were 3 possible kinds of explanations: horizontal circular, reductive circular, and non circular. Within each causal system, the length of each explanation was kept within 10 characters and 2 words of the others. The order of device presentation and the kind of explanation provided for each device were randomized. Participants were asked to rate how much insight each explanation gave them into the given explanandum on a 100-point slider starting at "Not much" and ending at "A lot."

The method for producing these stimuli is as follows. Take a causal system *x* with effect *y*. The explanandum is roughly: "x does y by…" For a horizontal tautology, the appended explanans is roughly "...doing y" where the effect is described at the same level of explanation through the use of synonyms. For reductive circular, the explanans is roughly "...doing y" where the effect is described at a lower level of explanation. For non circular, the explanans illuminates the mechanism through which the system caused the effect. See Table 1 for an example.

Table 1: Example Stimuli Set for Study 1

	Example
Horizontal Circular	Vocal cords change pitch by making the human voice sound either at a higher register or a lower one.
Reductive Circular	Vocal cords change pitch by modulating the frequency of vibrations that pass through the medium of air.
Non Circular	Vocal cords change pitch by being stretched or shortened via contractions of muscles in the throat.

Pre-Registration Non exploratory analyses were preregistered (https://aspredicted.org/7D6_RLD).

Results and Discussion

First, we looked at strictly between-subject effects. The data were subsetted to contain only the first ratings given by participants (n = 260). Horizontal tautologies were rated as less insightful than reductive tautologies (Holms-corrected Dunn's test, $Z = 3.20$, $p = 0.002$) and non circular explanations ($Z = 4.99$, $p < 0.0001$). However, the difference

between reductive tautologies and non circular explanations was below significance ($Z = 1.75$, $p = 0.08$).

The data were then analyzed using all 4 observations for each participant ($n = 1040$). Our preregistered analysis showed that horizontal tautologies were rated as less insightful than reductive tautologies ($Z = -5.45$, $p < 0.0001$) and non circular explanations ($Z = -8.78$, $p < 0.0001$). In this larger sample, reductive tautologies were rated as less insightful than non circular explanations ($Z = 3.33$, $p < 0.001$). (See Fig. 1.) In an exploratory analysis, we accounted for within participant variation by running a regression model with participant intercepts as a random effect. Non circular explanations and reductive tautologies remained significant predictors of insight ($\beta = 19.5$, $SE = 1.86$, $p < 0.0001$; $\beta = 12.1$, $SE = 1.85$, $p < 0.0001$).

Finally, we looked for an item effect. Only a trending effect was detected for the dataset containing participants' first impressions ($\chi2 = 7.17$, $p = 0.07$). In the full dataset, however, the effect was significant ($\chi2 = 32.5$, $p < 0.0001$). This effect was driven by one item (the refrigerator), which showed lower insight ratings than the other items (Z's > 3 and p's < 0.001). To control for this, in an exploratory regression, we made a regression with random intercepts for item and participant. Non circular explanations and reductive tautologies remained significant predictors of insight ($\beta = 19.7$, $SE = 1.81$, $p < 0.0001$; $\beta = 12.0$, $SE = 1.79$, $p < 0.0001$).

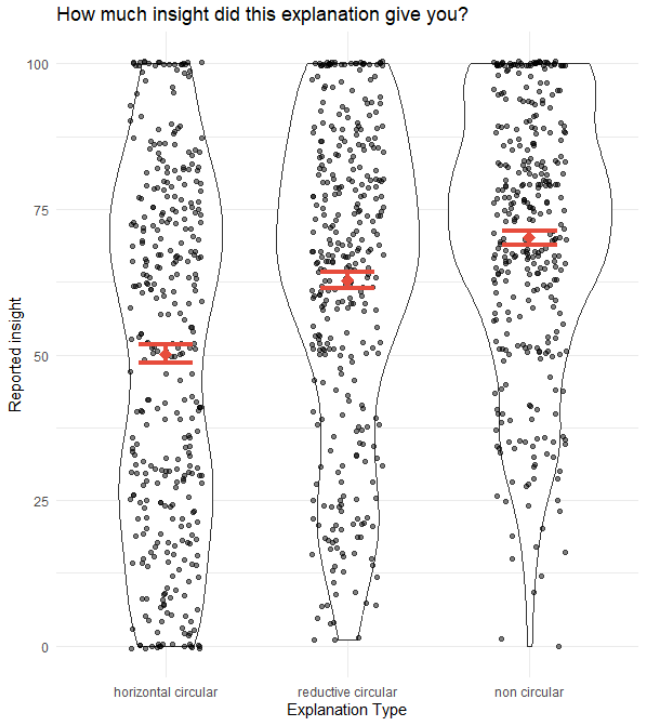

Figure 1: Reductive tautologies impart more insight than horizontal tautologies, but less than non circular explanations. Dots are individual data points, red diamonds are means, and red bars represent one SEM. $n = 1040$

Tautologies with reductive information in their explanans are rated as more insightful than tautologies that merely reword their explanans, and as less insightful than non circular explanations. Reductive tautologies are therefore perceived as (mechanistically) insightful even when stripped to their pure, single-sentence form. Indeed, participants showed no difference in their initial ratings of these pure reductive tautologies and non circular explanations.

These findings are likely not the result of weakening non circular explanations by limiting them to a single-sentence: the distribution suggests that the rating of all kinds of explanations were high. Indeed, even horizontal circular statements were not at floor. This is in line with the proposed theory that reductive tautologies impart insight by specifying what an explanation should explain; horizontal tautologies could do this as well, just to a lesser extent (see General Discussion).

Study 2

To further investigate the appeal of reductive tautologies, we tested correlations between insight imparted by the tautologies and what our theory suggests motivates these perceptions. If reductive tautologies offer insight by specifying the explanandum, then explanations rated as insightful should also be rated as helpful in (1) narrowing down the necessary mechanisms for the explanandum and in (2) searching for further information about the explanandum.

We also looked at the effects of background knowledge. Take our example of a reductive tautology: "Vocal cords change pitch by modulating the frequency of vibrations that pass through the medium of air." Depending on the subject's background knowledge, it could impart different kinds of insight. (1) If the subject is not aware that changing pitch can be described as changing the frequency of air vibrations, the explanation might teach them that these notions are related (or baffle them). (2) If the subject knew that changing pitch can be described as changing the frequency of air vibrations but had not inferred that vocal cords (in being changers of pitch) must change the frequency of air vibrations, then the explanation provides them with the inference that vocal cords (in particular) modulate the frequency of air vibrations. Finally, (3) if the subject has already explicitly inferred that vocal cords modulate the frequency of air vibrations, then the explanation could only be legitimately insightful in the way described by our proposed theory: the subject learns that a good explanation of vocal cords changing pitch should explain how they modulate the frequency of air vibrations. For ease of discussion, these three possible states of background knowledge will be called respectively (1) no knowledge, (2) no inference, and (3) inference.

Testing the effects of background knowledge allows us to investigate whether any insight from reductive tautologies derives from the pragmatic inference posited by our theory. If the perceived mechanistic insight from the reductive tautology comes only from a mistaken heuristic that explanations which use reductionist jargon are instructive, then we would expect participants in the inference state to report insight levels that are at floor. Such participants should be unimpressed by the reductionist jargon, as they already

know that "Vocal cords changing pitch" means "Vocal cords modulating the frequency of air vibrations." There is nothing that should subvert their recognition that such an explanation offers no insight into a vocal cord's mechanisms. In this case, Study 1's finding that pure reductive tautologies are insightful would be driven largely by participants in the no knowledge and no inference states. If, on the other hand, perceived insight from the reductive tautologies also follows from a pragmatic suggestion (e.g., modulating the frequency of air vibrations is what should be explained), then even people in the inference state, despite knowing the explanations' explicit proposition contents, should find reductive tautologies mechanistically insightful.[1]

Method

Participants 89 of 100 people recruited through Prolific were used in our analyses (11% excluded). Excluded participants failed the attention check or did not properly enter their Prolific IDs into the survey. Non excluded participants were 64% White (13% Black, 22% Other), 51% female, and 33 years old on average (SD = 11.1).

Procedure Participants were randomly shown one of the reductive tautologies from Study 1. They were then asked to rate, relative to the causal system to be explained, how much insight this tautology imparted, how helpful it would be in searching for further information, and how much it narrowed down what the necessary mechanisms are on 100-point sliders, ranging from "Not at all" to "A lot." They repeated this procedure with another reductive tautology.

Participants were then asked to report their background knowledge prior to the experiment. For each displayed tautology, they were given a forced choice between three options, which were generally as follows: they were not aware of the low level description of the causal system's effect (no knowledge), they could have inferred the low level description of the causal system's effect but had not (no inference), or they had inferred the low level description of the causal system's effect (inference).

Pre-Registration Non exploratory analyses were preregistered (https://aspredicted.org/KQ2_YBT).

Results and Discussion

We found a significant correlation between insight given by the reductive tautology and the degree to which the tautology narrowed the necessary mechanisms by using both Pearson ($r(176) = 0.497$, $p < 0.0001$) and Spearman methods ($\rho(176) = 0.510$, $p < 0.0001$). Insight and the degree to which the tautology would assist with search were also correlated ($r(176) = 0.420$, $p < 0.0001$; $\rho(176) = 0.427$, $p < 0.0001$). In an exploratory analysis, we found that these correlates of insight were themselves correlated ($r(176) = 0.305$; $p < 0.0001$; $\rho(176) = 0.294$, $p < 0.0001$), but that neither mediated (P. Tingley, Yamamoto, Hirose, Keele, & Imai, 2014) the relationship of the other with insight (ACME's = 1).

There was no effect of background knowledge on insight ratings (Kruskal-Wallis test, $\chi2 = 0.0994$, $p = 0.952$). There was also no effect of background knowledge on narrowing of necessary mechanisms ($\chi2 = 1.362$, $p = 0.506$) or on assistance with search ($\chi2 = 2.72$, $p = 0.257$).

In an analysis preregistered as exploratory, we found no evidence that background knowledge moderates the relationship between insight ratings and its correlates (t's < 1.38, p's > 0.170). In an analysis that was not preregistered, we performed a Bayesian mixed-effects regression analysis (P. Makowski et al. 2019) to confirm whether the effect of background knowledge on insight ratings was null. Bayes Factors for the effect of the no inference and inference conditions were minor: 0.78 and 0.81 respectively.[2]

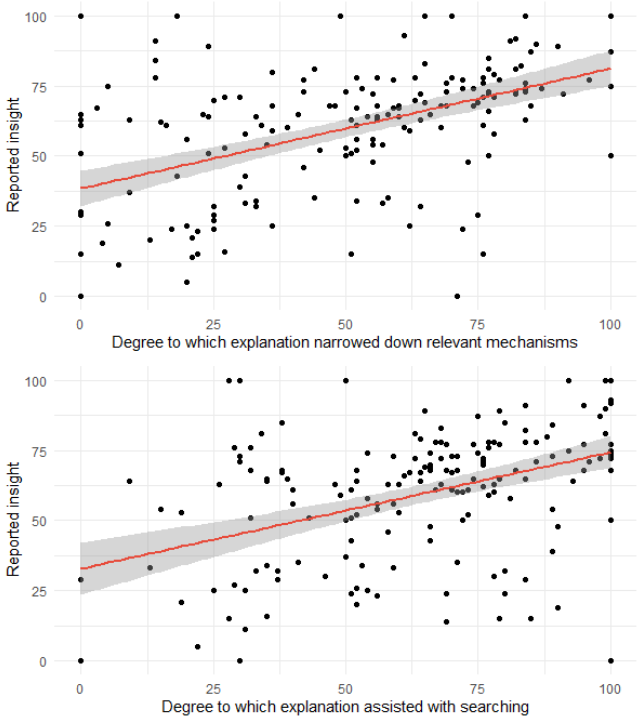

Figure 2: Correlations between insight and assistance with search and narrowing down of mechanisms were significant. Red line is the fit of a linear regression with a 95% confidence interval. Dots are individual observations. n = 178

[1] Notably, in determining how insightful a statement is, participants could be assessing whether an explanation conveys information in general or whether they learned something from it. The schematic here tracks the latter. However, if participants were instead tracking the former, the predictions are similar: participants with no knowledge and even no inference may be impressed, but crucially, participants in the inference state should find the content of the explanation – insofar as it provides insight into the explanandum – vacuous.

[2] In Studies 1 and 2, we also ran a preregistered test of whether the causal system being biological or artificial affected insight ratings. We only found a significant effect in Study 1 with the full sample ($\chi2 = 14.7$, $p = 0.0001$), but removing the errant item eliminated this effect ($\chi2 = 0.801$, $p = 0.37$).

These findings provide initial evidence for the theory that reductive tautologies are insightful insofar as they specify the explanandum. Such specification ought to help in searching for proper explanations and in narrowing down what the necessary mechanisms must be. Both of these predictions found support. (See Fig. 2.)

If reductive tautologies only appear insightful because they utilize scientific jargon, then people who understand that jargon should find the tautologies to be vacuous. On the contrary, we found no difference in insight rating between people who knew the reductive contents of the tautology and those who did not. While our findings do not prove background knowledge has no effect, they do suggest that background knowledge is not the sole determinant of insight ratings of tautologies.

Conversely, if reductive tautologies also appear insightful because they impart data pragmatically (i.e., over and above their propositional contents), then people in the inference condition should still find the tautologies insightful. The null effect of background knowledge and the distribution of inference (see Fig. 3) provide preliminary evidence for this prediction of our theory.

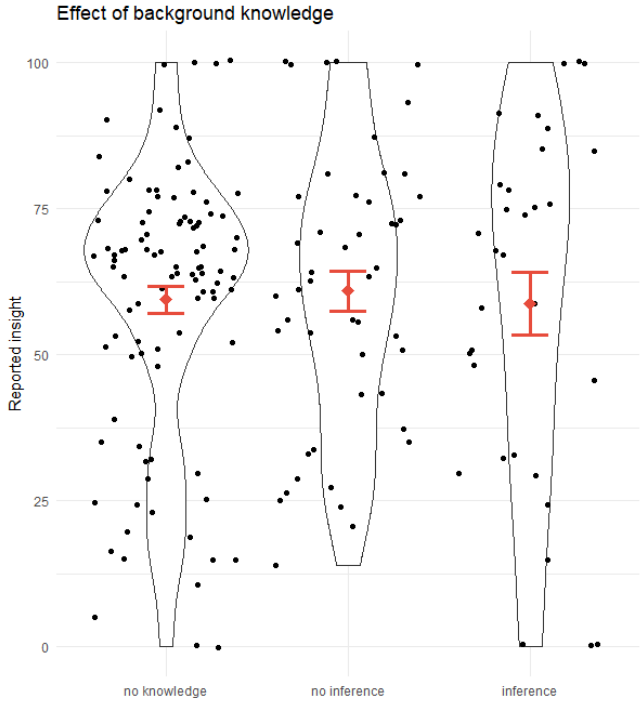

Figure 3: No effect of background knowledge was found. Dots are individual data points, red diamonds are means, and red bars represent two SEM. n = 178 (n = 98 in no knowledge, n = 48 in no inference, and n = 32 in inference)

General Discussion

Circular explanations are perceived as more insightful if their explanans is at a lower explanatory level than their explanandum. In our first study, we found that this difference obtains even when the tautology is not stretched over several sentences, buoyed with irrelevant facts, or propped-up by its comparison with different explanations. Indeed, when only looking at participant's first judgments, the difference between insight ratings on reductive tautologies and non-circular explanations was only trending in significance. In our second study, these high ratings of insight were correlated with an expectation that the reductive tautology would help with search and with narrowing down the necessary mechanisms of the causal system it describes. We found no evidence that these insight ratings were related to the familiarity the participant had with the tautology's propositional contents (background knowledge).

The reductive redescriptions in the explanantia of these tautologies could generate an illusion of insight: when confronted with unfamiliar explanations, people assume those with reductive information are more insightful (e.g., Hopkins, Weisberg, & Taylor, 2016). However, if such an illusion were the only reason for finding reductive elements insightful, we would expect participants familiar with the propositional content of the tautology to find it lacking in insight. Yet, these results did not occur, suggesting that the reductive redescription of the explanans contains a pragmatic insight beyond its propositional content (Grice, 1975). It specifies the explanandum by supplying the level of description at which it ought to be explained. Because phenomena can always be explored at multiple levels of explanation, this gesture imparts genuine mechanistic insights. Namely, it narrows down the level of explanation and kinds of mechanisms that could explain the explanandum. To be clear, effects of knowledge and of reductive explanation heuristics still might be additional factors. These and our proposed pragmatic mechanism could all influence impressions of whether a reductive tautology is insightful. Our evidence simply offers preliminary support, using correlational methods, for the presence of a pragmatic mechanism.

Implications of the Proposed Theory

Learning information from explanations by going beyond their propositional content is not exclusive to our account of reductive tautologies. When given non-tautological explanations, people infer the normality of a causally relevant event when only given the knowledge that the event occurred and the causal structure to which it pertains – and vice versa (Kirfel, Icard, & Gerstenberg, 2022). Similarly, when given tautological formal explanations, people may infer a principal connection between the invoked category and the explanandum (Rivera, Prasad, & Prasada, 2023). In general, summary explanations, in virtue of being communicative phenomena, are often incomplete; listeners rely on pragmatically inferred information in assimilating those explanations into their causal models of the world (Hilton, 1990).

The kind of information we propose reductive tautologies impart is part of a broader explanatory phenomenon as well. In narrowing down the kinds of mechanisms that could explain the explanandum, reductive tautologies supply a form

of mechanism metadata: information external to a mechanism that still elucidates it (Kominsky, Zamm, & Keil, 2018).[3] In this case, the source of the metadata is the specified output of the mechanistic system (e.g., the effect of the vocal cords on the frequency of vibrations). But consider explanations that impart information about the inputs of a causal system. If someone learns a car is powered by electricity instead of fuel, this will narrow the mechanisms that could lead to its locomotive effect, without saying anything about the engine's mechanisms directly. Explanations that describe the parts of a causal system might work the same way. Indeed, even some horizontal tautologies could impart similar mechanism metadata. Their specification of the explanandum is likely more trivial (e.g., replacing "changing pitch" with "making pitch higher or lower" probably does little to help narrow down mechanisms), but is not *a priori* excluded from supplying mechanistic insight. Exploring this possibility may explain the high on average but bimodally distributed insight ratings on horizontal tautologies found in Study 1.

This mechanism metadata – whether derived by reference to a system's inputs, outputs, or its parts – can be invaluable insight. People prefer explanations that are useful and supply the most information (Lombrozo and Liquin, 2023). Given no knowledge about the mechanisms of a phenomenon, narrowing down the range of possible mechanisms would be crucial for meeting these explanatory goals. Children given (uninformative) circular explanations are more likely to engage in search activities compared to their peers, owing to a tantalizing deficit in information (Mills, Sands, Rowles, & Campbell, 2019); a pragmatically informative circular explanation may guide, rather than provoke, their inquiry.

That being said, such mechanism metadata can mislead as much as they enlighten. Consider this reductive tautology: "A refrigerator cools the air by slowing the movement of air particles." In understanding how a refrigerator works, it would be of little use to consider its effects on individual particles. Of course, ordinary mechanistic explanations can mislead as well: "A refrigerator cools the air by moving hot air out and cold air in." The only difference is that the tautology is, strictly speaking, true. It would be the inferred pragmatic statement "slowing the movement of particles is relevant to understanding the refrigerator" (i.e., the inferred metadata) which is false.

Whether people can distinguish between pragmatically insightful and misleading tautologies remains untested. Interestingly, our participants considered the aforementioned refrigerator item to be significantly less insightful than the others in Study 1. Moreover, recent research suggests that people find reductive tautologies insightful insofar as they impart relevant rather than just general information (Liquin & Lombrozo, 2022). Without appealing to mechanism metadata, it is difficult to imagine a property of reductive tautologies that could plausibly be tracking these variations in judgments of relevance. But the possibility that mechanism metadata is filling this role requires further investigation.

Limitations and Future Directions

Study 2 operationalized background knowledge by asking people to report what they had known prior to the experiment about the causal systems they rated. This limited the number of participants in the inference condition (n = 32 out of 178 observations), weakening the power of our analysis. Moreover, since subjects were asked to report their background knowledge after being exposed to the reductive tautologies, recall and learning may have been confounded: Participants who reported possessing the inference knowledge state may have fabricated a memory of making an inference that they never had, or may have found the recall of that memory as insightful as obtaining genuinely new information. Background knowledge might instead be manipulated experimentally to test the null effect found in this study, with insight ratings for horizontal tautologies serving as a floor for insight (rather than zero on the reported insight slider). Furthermore, Studies 1 and 2 relied on only four causal systems, one of which proved to be errant in Study 1. To ensure there was nothing peculiar about these systems, these studies should be replicated with stimuli generated from different ones.

If these limitations are addressed, there are several predictions of the theory worth testing: (1) given the correlation in Study 2 between insight and the degree to which the tautology would assist with search, reductive tautologies should assist search procedures in an experimental setting (whether in the development of a query or in looking through results); (2) tautologies should be rated as less insightful to the extent that their explanantia describe the explananda in such a way as to suggest impossible or implausible mechanisms; (3) explanations that only offer semantically irrelevant facts but describe inputs or parts of a causal system (even at a horizontal level of explanation) should be appraised as insightful; (4) tautologies that are shown to select their level of description of the explanans randomly should be perceived as less insightful than tautologies whose construction remains mysterious; and (5) the evaluation of the insightful quality of reductive tautologies should be subjectively rational, thus offering participants more time or more incentive to evaluate reductive tautologies properly should not change the degree to which they find them insightful, after controlling for background knowledge effects (e.g., Mercier & Sperber, 2009).

In conclusion, people find insight in the most unexpected places. We show a way in which those perceptions might in some cases be legitimate.

[3] Kominsky, Zamm, & Keil (2018) add some qualifications: these metadata must be consistent given equal exposure to the device and domain general. But these features are more relevant if the mechanistic metadata is being used to gauge expertise.

References

Anderson, P. W. (1972). More Is Different: Broken symmetry and the nature of the hierarchical structure of science. *Science*, *177*(4047), 393-396.

Aslanov, I., & Guerra, E. (2023). Tautological formal explanations: does prior knowledge affect their satisfiability? *Frontiers in Psychology*, *14*, 1258985.

Baum, L. A., Danovitch, J. H., & Keil, F. C. (2008). Children's sensitivity to circular explanations. *Journal of Experimental Child Psychology*, *100*(2), 146-155.

Bennett, E. M., & McLaughlin, P. J. (2023). Neuroscience explanations really do satisfy: A systematic review and meta-analysis of the seductive allure of neuroscience. *Public Understanding of Science*.

Corriveau, K. H., & Kurkul, K. E. (2014). "Why does rain fall?": Children prefer to learn from an informant who uses noncircular explanations. *Child development*, *85*(5), 1827-1835.

Gelman, S. A., Cimpian, A., & Roberts, S. O. (2018). How deep do we dig? Formal explanations as placeholders for inherent explanations. *Cognitive psychology*, *106*, 43-59.

Giffin, C., Wilkenfeld, D., & Lombrozo, T. (2017). The explanatory effect of a label: Explanations with named categories are more satisfying. *Cognition*, *168*, 357-369.

Green, P., & MacLeod, C. J. (2016). SIMR: An R package for power analysis of generalized linear mixed models by simulation. *Methods in Ecology and Evolution*, *7*(4), 493-498.

Grice, H. P. (1975). Logic and conversation. In P. Cole & J.L. Morgan (Eds.), *Speech Acts*. New York: Academic Press.

Hemmatian, B., & Sloman, S. A. (2018). Community appeal: Explanation without information. *Journal of Experimental Psychology: General*, *147*(11), 1677.

Hilton, D. J. (1990). Conversational processes and causal explanation. *Psychological Bulletin*, 107(1), 65.

Hopkins, E. J., Weisberg, D. S., & Taylor, J. C. (2016). The seductive allure is a reductive allure: People prefer scientific explanations that contain logically irrelevant reductive information. *Cognition*, *155*, 67-76.

Kirfel, L., Icard, T., & Gerstenberg, T. (2022). Inference from explanation. *Journal of Experimental Psychology: General*, *151*(7), 1481.

Kominsky, J. F., Zamm, A. P., & Keil, F. C. (2018). Knowing when help is needed: A developing sense of causal complexity. *Cognitive Science*, *42*(2), 491-523.

Liquin, E. G., & Lombrozo, T. (2022). Motivated to learn: An account of explanatory satisfaction. *Cognitive psychology*, *132*, 101453.

Lombrozo, T., & Liquin, E. G. (2023). Explanation Is Effective Because It Is Selective. *Current Directions in Psychological Science*, *32*(3), 212-219.

Makowski, D., Ben-Shachar, M. S., & Lüdecke, D. (2019). bayestestR: Describing effects and their uncertainty, existence and significance within the Bayesian framework. *Journal of Open Source Software*, *4*(40), 1541.

Mercier, H. & Sperber, D. (2008). Intuitive and Reflective Inferences. In Jonathan Evans & Keith Frankish (Eds.), *Two Minds, Dual Processes and Beyond*. Oxford University Press.

Mills, C. M., Danovitch, J. H., Rowles, S. P., & Campbell, I. L. (2017). Children's success at detecting circular explanations and their interest in future learning. *Psychonomic Bulletin & Review*, *24*, 1465-1477.

Mills, C. M., Sands, K. R., Rowles, S. P., & Campbell, I. L. (2019). "I want to know more!": Children are sensitive to explanation quality when exploring new information. Cognitive Science, 43(1), e12706.

Rips, L. J. (2002). Circular reasoning. *Cognitive science*, *26*(6), 767-795.

Rivera, S., Prasad, S., & Prasada, S. (2023). Are formal explanations mere placeholders or pointers?. *Cognition*, *235*, 105407.

Tingley, D., Yamamoto, T., Hirose, K., Keele, L., & Imai, K. (2014). Mediation: R package for causal mediation analysis. *Journal of Statistical Software*, *5*(59).

Weisberg, D. S., Keil, F. C., Goodstein, J., Rawson, E., & Gray, J. R. (2008). The seductive allure of neuroscience explanations. *Journal of cognitive neuroscience*, *20*(3), 470-477.

Weisberg, D. S., Hopkins, E. J., & Taylor, J. C. (2018). People's explanatory preferences for scientific phenomena. *Cognitive Research: Principles and Implications*, *3*, 1-14.