Brit. J. Phil. Sci. **53** (2002), 477–496

Analogy Counterarguments and the Acceptability of Analogical Hypotheses

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ABSTRACT

The logical empiricists held that an analogical hypothesis does not gain any acceptability from the analogy on which it is founded. On this view, the acceptability of a hypothesis cannot be discounted by criticizing the foundational analogy. Yet scientists commonly appear to level exactly this sort of criticism. If scientists *are* able to discount the acceptability of analogical hypotheses in this way, then the logical empiricist view is mistaken. I analyze four forms of analogy counterargument, *disanalogy*, *misanalogy*, *counteranalogy*, and *false analogy*, with examples from the debate over the asteroid impact hypothesis. These counterarguments *do* address the acceptability of analogical hypotheses, indicating that analogies can confer acceptability, confirmation notwithstanding.

1 Introduction

Do analogical inferences confer any degree of acceptability on their conclusions? Among the logical empiricists, the answer was *no* (see, e.g., Hempel [1965], pp. 433–47). A crucial reason for this view concerned the concept of confirmation that was being developed at the time: for a hypothesis to be confirmed in any degree requires predictions to be deduced from it that can then be checked against observation. Agreement of prediction with observation tends to confirm or corroborate the hypothesis. Because it is not deductive, analogical inference cannot participate in this procedure and so cannot help to confirm a hypothesis, by definition. Bunge ([1967], p. 267) expresses the logical empiricist view as follows:

> Arguments from analogy may be fertile but they are invalid: their success, if any, does not depend on their form but on the nature of the case—whence there can be no logic of analogy. [...] [An analogical hypothesis] is a conjecture that must be subjected to tests other than that of validating the analogy premise. If the hypothesis proves false we should conclude that the inference was not only invalid but also barren.

In other words, the only sensible test of an analogical hypothesis is the confirmation or disconfirmation of its conclusion. The sole virtue belonging to analogies as such is fertility—their capacity to generate hypotheses. But this virtue is strictly pragmatic. No assessment of the form of an analogy counts as an assessment of the hypothesis generated by it.

There are several possible responses to this view. First, we might claim that analogical inference is deductive after all and so must be acknowledged to bestow acceptability, by definition (see Weitzenfeld [1984]). Second, we might claim that the potential fertility of analogy, which no one denies, imparts acceptability to its conclusions, confirmation notwithstanding (see, e.g., Hesse [1966]). Analogies are universally acknowledged as very useful in producing new hypotheses and this usefulness itself might motivate acceptance of them, in spite of Bunge's insistence to the contrary. Third, we could note that scientists sometimes treat analogies as though they do confer some acceptability on their conclusions. Ruse ([1973], pp. 252–3) points out that critics of Darwin's concept of natural selection raised disanalogies against his comparison between natural selection and domestic breeding. The only plausible motivation for this criticism is to discount the theory of natural selection, a nonsensical procedure from the logical empiricist perspective.

The attitude of the logical empiricists regarding analogy remains widespread and is still repeated in popular textbooks in the philosophy of science (e.g., Giere [1997], p. 22). Nevertheless, this attitude needs to be reassessed in the light of the last point made above. In this paper, I will revisit and expand Ruse's criticism of the logical empiricist view of analogical inference. In particular, I wish to extend his argument into a complete exploration of the logic of counterarguments to analogical inferences. There have been substantial advances in the study of analogies and analogical inference since the time that the debate over analogies died down among philosophers of science (see Bailer-Jones [1999]). Although this work has been fruitfully applied to the understanding of scientific analogies, work on the nature of counterarguments to analogies has begun only recently (Shelley [2002a], [2002b]). In the following sections, I will lay out a classificatory scheme of counterarguments to analogical inferences and discuss examples of each type taken from the recent debate over the asteroid impact hypothesis of Alvarez *et al.* ([1980]). I propose four types of counterargument, namely *disanalogies*, *misanalogies*, *counteranalogies*, and *false analogies*. This scheme helps to clarify the nature and force of the various counterarguments, and this, in turn, helps to clarify the force of the analogical inference that they are meant to controvert. In addition to clarifying this aspect of scientific inference, this paper shows that the logical-empiricist view, as expressed by Bunge, is mistaken and that analogical inferences can confer acceptability on their conclusions.

2 The asteroid impact hypothesis

To clarify the nature of counterarguments to analogical inferences, we must start by clarifying the nature of analogical inferences themselves. The volume of research on this topic precludes a review (but see Gentner *et al.* [2001]), so I will take the simple and expeditious route of adopting the *multiconstraint theory* (Holyoak and Thagard [1995]), which is well-known and established. In this section, then, I present the *multiconstraint theory* by showing how it captures the Krakatoa-asteroid analogy of the asteroid impact hypothesis of Alvarez *et al.* ([1980]). This analogy is a useful example because it is recent and attracted a good deal of criticism, some of which is presented in section 3.

By the middle of 1979, Alvarez *et al.* were convinced that an asteroid had struck the Earth at the end of the Cretaceous era (see Asaro [1987]; Alvarez [1987] and Alvarez [1997]). Such an impact would explain an apparently global spike in the concentration of iridium in the geological layer that marked the Cretaceous to Tertiary (K-T) transition. But how had the debris of the impact been distributed globally, and how might it have caused the extinction of the dinosaurs (among others) that occurred at the same time? Alvarez ([1997], p. 77) describes how an analogy suggested an answer:

> Finally, [Luis Alvarez] started thinking about the dust that would be thrown in to the air by an impact. He remembered reading that the 1883 explosion of the Indonesian volcano, Krakatoa, had blown so much dust and ash into the atmosphere that brightly colored sunsets were seen for months in London, on the other side of the world, and he tracked down the book he remembered (Symons [1888]). Scale the Krakatoa event up to the size of a giant impact, Dad thought, and there would be so much dust in the air that it would get dark all around the world. With no sunlight, plants would stop growing, the whole food chain would collapse, and the result would be a mass extinction.

Table 1. The Krakatoa-asteroid analogy of Alvarez *et al.* ([1980]). Subscripts distinguish separate instances of identical types of predicates.

Krakatoa	Asteroid
Krakatoa-eruption	asteroid-impact
debris$_k$	debris$_a$
winds	winds
stratosphere	stratosphere
Earth	Earth
sunlight	sunlight
shade	darkness
two-years	three-years
eject$_k$(Krakatoa-eruption,debris$_k$)	eject$_a$(asteroid-impact,debris$_a$)
enter$_k$(debris$_k$,stratosphere)	enter$_a$(debris$_a$,stratosphere)
disperse$_k$(winds,debris$_k$)	disperse$_a$(winds,debris$_a$)
cover$_k$(debris$_k$,Earth)	cover$_a$(debris$_a$,Earth)
attenuate$_k$(debris$_k$,sunlight)	attenuate$_a$(debris$_a$,sunlight)
persist$_k$(shade,two-years)	persist$_a$(darkness,three-years)
cause$_{k0}$(eject$_k$,enter$_k$)	cause$_{a0}$(eject$_a$,enter$_a$)
enable$_{k0}$(enter$_k$,disperse$_k$)	enable$_{a0}$(enter$_a$,disperse$_a$)
cause$_{k1}$(disperse$_k$,cover$_k$)	cause$_{a1}$(disperse$_a$,cover$_a$)
enable$_{k1}$(cover$_k$,attenuate$_k$)	enable$_{a1}$(cover$_a$,attenuate$_a$)
cause$_{k2}$(attenuate$_k$,persist$_k$)	cause$_{a2}$(attenuate$_a$,persist$_a$)

Debris from the Krakatoa eruption had remained suspended in the stratosphere for roughly two years, during which time winds distributed it over the entire world. By analogy, the impact of an enormous asteroid would have a similar effect but on an even larger scale: tinted sunsets would be replaced by pitch darkness for up to *three* years, with dire and predictable consequences for life on Earth. For obvious reasons, this explanation for the mass extinction at the K-T transition has sometimes been known as the 'lights-out scenario' (Hickey [1980]).

This scenario is what Thagard ([1988], pp. 60–3) calls an *analogical abduction*—that is, a novel explanation constructed by borrowing the structure of an already-accepted explanation. The structure of Luis Alvarez's analogical abduction is displayed in Table 1. This table represents the analogy in the manner set out in the *multiconstraint theory* of analogy (Holyoak and Thagard [1995]) (and the *Structure mapping* theory of Gentner [1983]). The table divides up the information in the analogy in several ways. First, the left-hand column represents the relevant information concerning the Krakatoa eruption, which is the *source* analog or the domain from which information is to be drawn. The right-hand column represents the asteroid impact, which is the *target* analog or the domain about which we wish to make an inference. Second, each row of the table pairs those elements from the source and target analogs that are placed in correspondence with each other in the analogy. For example, the Krakatoa eruption and asteroid impact, which correspond in the analogy, occur in the same row of Table 1. Finally, the rows are grouped into three boxes. The top box groups the corresponding attributes of the analogy, the basic elements of each analog. The middle box groups the corresponding simple relations of each analog, the ways in which the elements of each analog relate to one another. The bottom box groups the system or causal relations of each analog, the ways in which the simple relations are connected to one another causally.

The gist of this representation can be gained straightforwardly by reading through the causal relations in the bottom box. Consider the Krakatoa domain: the ejection of debris by the Krakatoa eruption caused ($cause_{k0}$) the debris to enter the stratosphere. Entry of debris into the stratosphere then enabled ($enable_{k0}$) winds to disperse it, which caused ($cause_{k1}$) the debris to cover the globe. This global coverage enabled ($enable_{k1}$) the debris to attenuate sunlight, which caused ($cause_{k2}$) shade that persisted for two years. The inference regarding the asteroid impact is made by a process of *copying with substitution* (Falkenhainer *et al.* [1989]; Holyoak and Barnden [1994]): predicates are copied from the source analog to the target analog and corresponding arguments are substituted as necessary. So, when we copy the system predicates to the asteroid impact domain and make the appropriate substitutions, we may conclude that the Earth was plunged into darkness for three years. Given the dependence of the food chain on sunlight, the result would surely have been widespread starvation and extinction, which would explain the deletions from the fossil record observed at the K-T transition.

The strength of the analogy may be evaluated by the extent to which it satisfies three conditions (Holyoak and Thagard [1995], pp. 22–38). First, the analogy is *structurally consistent* in the sense that no predicate in either domain corresponds to more than one predicate in the other domain. Table 1 shows that each row contains only one predicate from each domain, so this condition is completely satisfied. Second, the analogy displays *semantic similarity* in the sense that corresponding relational predicates are similar in meaning. Again, Table 1 shows that each relational predicate in either domain is paired with an identical predicate in the other domain. So, this condition is entirely satisfied as well. Third, the analogy is *useful* in the sense that it suggests an explanation for the problem at hand, namely the long suspension and global dispersion of the debris of the K-T asteroid impact.

By these criteria, the Krakatoa-asteroid analogy is a strong one. Nevertheless, it attracted intense scrutiny and criticism in the wider scientific community, which Alvarez *et al.* took quite seriously. In Section 3, I analyze

Table 2. The scheme of analogy counterarguments.

		Orientation	
		accept	*reject*
Effect	*destructive*	disanalogy	false analogy
	constructive	counteranalogy	misanalogy

several of those criticisms that took the form of counterarguments to this analogy. This analysis clarifies the nature and force of these counter-arguments and shows why they deserved serious consideration.

3 Analogy counterarguments

An analogy counterargument is a means of controverting an analogical inference that is not based upon a simple dismissal of analogical inference in general. Since such arguments leave open the issue of the acceptability conferred by analogies, they are ideal for the purpose of assessing it. Each kind of analogy counterargument is aimed at controverting a given or *model* analogy and its conclusion. In this section, I discuss examples of four types of counterargument, namely disanalogy, misanalogy, counteranalogy, and false analogy.

These counterarguments can be arranged in a scheme divided up along two dimensions, namely *orientation* and *effect* (see Table 2). Orientation concerns whether or not a counterargument proceeds from an initial acceptance or rejection of the model conclusion. Effect concerns whether or not the counterargument motivates a new (improved) conclusion. In this scheme, both disanalogy and counteranalogy take the model conclusion as the point of departure, whereas misanalogy and false analogy do not. Both misanalogy and counteranalogy tend to establish a new conclusion in the place of the model conclusion, whereas disanalogy and false analogy are simply destructive.

3.1 Disanalogy

A disanalogy is an analogy with the following features (for further discussion, see Shelley [2002b]): (1) it is similar in the relevant respects to a model analogy such that (2) the disanalogy and its model support incoherent conclusions. The point of a disanalogy is to show that more-or-less the same analogy supports irreconcilable conclusions, which suggests that the analogy supports no conclusion after all. In other words, a disanalogy has the *accept* orientation and the *destructive* effect.

Table 3. The Toba disanalogy of Kent ([1981]) based on Table 1.

Toba	Asteroid
Toba-eruption	asteroid-impact
debris$_t$	debris$_a$
winds	winds
stratosphere	stratosphere
Earth	Earth
sunlight	sunlight
darkness	darkness
some-time	three-years
most-species$_t$	most-species$_a$
eject$_t$(Krakatoa-eruption,debris$_t$)	eject$_a$(asteroid-impact,debris$_a$)
enter$_t$(debris$_t$,stratosphere)	enter$_a$(debris$_a$,stratosphere)
disperse$_t$(winds,debris$_t$)	disperse$_a$(winds,debris$_a$)
cover$_t$(debris$_t$,Earth)	cover$_a$(debris$_a$,Earth)
attenuate$_t$(debris$_t$,sunlight)	attenuate$_a$(debris$_a$,sunlight)
persist$_t$(darkness,some-time)	persist$_a$(darkness,three-years)
survive$_t$(most-species$_t$,darkness$_t$)	survive$_a$(most-species$_a$,darkness$_a$)
cause$_{k0}$(eject$_t$,enter$_t$)	cause$_{a0}$(eject$_a$,enter$_a$)
enable$_{k0}$(enter$_t$,disperse$_t$)	enable$_{a0}$(enter$_a$,disperse$_a$)
cause$_{k1}$(disperse$_t$,cover$_t$)	cause$_{a1}$(disperse$_a$,cover$_a$)
enable$_{k1}$(cover$_t$,attenuate$_t$)	enable$_{a1}$(cover$_a$,attenuate$_a$)
cause$_{k2}$(attenuate$_t$,persist$_t$)	cause$_{a2}$(attenuate$_a$,persist$_a$)
allow$_t$(persist$_t$,survive$_t$)	allow$_a$(persist$_t$,survive$_t$)

This concept of disanalogy is best elucidated through an example. In a letter to *Science*, Kent ([1981]) used a disanalogy to suggest that the Krakatoa-asteroid analogy of Alvarez *et al*. could *not* explain the extinction of the dinosaurs. To do so, Kent considered the eruption of the Toba volcano, an eruption much larger than the Krakatoa eruption yet well understood by geologists. The Toba eruption was 400 times larger than the Krakatoa eruption, judged by the size of the crater that the explosion excavated. So, it approached the magnitude of the asteroid impact as calculated by Alvarez *et al.* The attenuation of light caused by the Toba eruption should therefore have been similar to the attenuation caused by the asteroid impact. However (Kent [1981], p. 650),

> the pertinent point is that the eruption of Toba occurred 75,000 years ago, a time that has yet to be noted for massive effects on life.

In other words, the Toba eruption did not cause a mass extinction even though it should have by Alvarez *et al.*'s own analogy.

Kent's disanalogy is displayed in Table 3. It is very similar to the model, Krakatoa analogy and participates in all the same causal relations, as is clear from a comparison of Table 3 with Table 1. Furthermore, the Toba eruption is even more similar to the target analog than is the Krakatoa eruption in terms of volume of debris and severity and duration of darkness. On the *multiconstraint theory*, Kent's analogy should be considered stronger than Alvarez *et al.*'s analogy. So, Kent's substitution of Toba for Krakatoa in support of the original conclusion is unobjectionable. However, Kent's analog supplies an additional causal relation, namely that the persistence of darkness for some time (Kent does not specify how long) nevertheless allowed ($allow_t$) most species to survive it. That is, there was no mass extinction. By a process of copy with substitution, the analogous conclusion is supported for the asteroid impact scenario. Of course, this conclusion is incompatible with the model conclusion that the asteroid impact was the cause of a mass extinction.

The force of this counterargument is quite clear. It is oriented initially as an acceptance of Alvarez *et al.*'s model analogy. It is destructive to the model conclusion because it introduces a new conclusion, through an innocuous elaboration, that is plainly incoherent with the model conclusion. The destructive nature of the counterargument is confirmed by noting that Kent does not take himself to have disproved the occurrence of a mass extinction at the end of the Cretaceous period. Instead, he has simply shown that an analogy very like that of Alvarez *et al.* can support a conclusion ($allow_a$) that cannot be reconciled with the original conclusion. The implication is that the Krakatoa-asteroid analogy, as Alvarez *et al.* have it, ultimately produces *no* acceptable conclusion about why the dinosaurs became extinct (Kent [1981], p. 650).

Had they taken their analogy to be merely a heuristic device, Alvarez *et al.* could well have left this disanalogy unanswered. However, they clearly took the disanalogy to be a serious problem and sought to rebut it. Note that the obvious means of rebuttal would not work. Alvarez *et al.* cannot object that the disanalogy is methodologically unsound since Kent's method is the same as their own. They cannot object that Kent appeals to illegitimate evidence since his evidence is nearly the same as theirs. The very strength of the original analogy lends strength to this disanalogy as well. One thing that Alvarez *et al.* can do is to introduce an additional claim into the asteroid impact hypothesis to reconcile it with Kent's disanalogy. Specifically, they note that there remains an appreciable difference in magnitude between the Toba eruption and the asteroid impact (Alvarez *et al.* [1981], pp. 654–6):

> Kent estimates that the Toba eruption would have ejected about 400 times as much material as Krakatoa did, close to our estimate of 1000 times Krakatoa for the impact event, although Toba did not produce

> extinctions. This consideration may make it possible to place a lower limit on the size of extinction-producing events [. . .].

Here, Alvarez *et al.* do not deny Kent's conclusion. Instead, they deny that it is truly incoherent with their own. If there is a minimum threshold of explosive force necessary to trigger a mass extinction such that the asteroid impact exceeded this threshold whereas the Toba eruption did not, then Kent's disanalogy is compatible with their analogy after all. Given this *lower-bound hypothesis*, we would simply not expect the Toba eruption to cause a mass extinction.

This hypothesis is an empirical claim susceptible of testing in its own right. Subsequent research on this point has shown that there does appear to be a lower bound on extinction-producing events where Alvarez *et al.* supposed that it would be (see Frankel [1999], pp. 142–4). So, Kent's disanalogy was itself fertile, much like Alvarez *et al.*'s model analogy: it extracted an additional claim from Alvarez *et al.* that opened a productive avenue of research.

3.2 Misanalogy

A misanalogy is a version of the model analogy revised to correct for some mistake lurking in the model. For this reason, a misanalogy usually, though not invariably, supports a different conclusion than the model. Thus, a misanalogy is oriented as a rejection of the model conclusion but is constructive in effect. Interestingly, the main use for a misanalogy in the asteroid impact hypothesis debate was to prepare the ground for a counteranalogy (Section 3.3).

From their model analogy, Alvarez *et al.* inferred that the debris of the asteroid impact would remain suspended in the stratosphere for about three years. This interval would provide plenty of time for winds to disperse the debris over the entire globe. Several critics pointed out that the Krakatoa-asteroid analogy actually suggests a different scenario. Kyte *et al.* ([1980], p. 656) note that Alvarez *et al.* had not apprehended the effect of fallout on the attenuation of sunlight following an asteroid impact. Debris from volcanic eruptions tends to coagulate in the air, making it progressively coarser and heavier so that it falls out of the air at a high and accelerating rate. This fact is demonstrated by the Krakatoa eruption itself, in which most of the debris fell out of the atmosphere within a few weeks. Kyte *et al.* imply that the two years of tinted sunsets were caused by a mere fraction of the total debris kicked up by the Krakatoa eruption. In fact, the dynamics of fallout are such that (Kyte *et al.* [1980], p. 656)

Table 4. The early fallout misanalogy of Kyte *et al.* ([1980]) based on Table 1.

Krakatoa	Asteroid
Krakatoa-eruption	asteroid-impact
debris_k	debris_a
winds	winds
stratosphere	stratosphere
Earth	Earth
sunlight	sunlight
shade	darkness
few-weeks	several-weeks
eject_k(Krakatoa-eruption,debris_k)	eject_a(asteroid-impact,debris_a)
enter_k(debris_k,stratosphere)	enter_a(debris_a,stratosphere)
disperse_k(winds,debris_k)	disperse_a(winds,debris_a)
cover_k(debris_k,Earth)	cover_a(debris_a,Earth)
attenuate_k(debris_k,sunlight)	attenuate_a(debris_a,sunlight)
coagulate_k(debris_k,debris_k)	coagulate_a(debris_a,debris_a)
fall-out_k(debris_k,stratosphere)	fall-out_a(debris_a,stratosphere)
persist_k(shade,few-weeks)	persist_a(darkness,several-weeks)
cause_{k0}(eject_k,enter_k)	cause_{a0}(eject_a,enter_a)
enable_{k0}(enter_k,disperse_k)	enable_{a0}(enter_a,disperse_a)
cause_{k1}(disperse_k,cover_k)	cause_{a1}(disperse_a,cover_a)
enable_{k1}(cover_k,attenuate_k)	enable_{a1}(cover_a,attenuate_a)
cause_{k2}(coagulate_k,fallout_k)	cause_{a2}(coagulate_a,fallout_a)
cause_{k3}(attenuate_k & fallout_k,persist_k)	cause_{a3}(attenuate_a & fallout_a,persist_a)

> no matter how much dust you inject into the stratosphere, within a few months or less the level will drop to a value no more than a few times greater than that present immediately following the Krakatoa explosion.

So, what the Krakatoa-asteroid analogy truly suggests is that the impact debris would have remained in the stratosphere for only a number of weeks. Kyte *et al.* conclude that such a stretch of darkness would be inadequate to explain the mass extinction of land animals at the time of impact. By correcting the model analogy, then, Kyte *et al.* suggest that it does not, after all, explain the extinction of the dinosaurs as it was intended to do. This shortcoming, in turn, motivates their counteranalogy (Section 3.3).

Kyte *et al.*'s misanalogy is displayed in Table 4. The table is very similar to the model analogy given in Table 1 except that fallout due to coagulation ($cause_{k2}$) has been added and figured into the reduced duration of darkness ($cause_{k3}$). By analogy, similar predicates are introduced into the target domain. This new consideration suggests much lower times of sunlight attenuation. Kyte *et al.* clearly take the new conclusion to be the most acceptable result of the Krakatoa-asteroid analogy, since they take its insufficiency as motivation for their alternative hypothesis.

The ''coagulation'' misanalogy was pointed out and elaborated by several other scientists, e.g. Thierstein (Russell and Rice (*eds*) [1982], pp. 39, 64–5) and Toon *et al.* ([1982], p. 188). Luis Alvarez immediately accepted that the misanalogy superseded his model analogy and admitted that its effect was even more deleterious than Kyte *et al.* suggested. He noted that it takes stratospheric winds at least a year to disperse debris over the globe. If the asteroid impact debris remained in the stratosphere for only a number of weeks, then winds could not possibly have spread it over the globe as required (Russell and Rice [1982], p. 64). Alvarez ([1983], p. 635) characterized this misanalogy as 'a really serious challenge, involving good science' that placed the asteroid impact hypothesis in 'very serious trouble'. In the end, Alvarez *et al.* found a satisfactory response in another misanalogy, accepting the quick fallout of impact debris by analogy with volcanic debris, and finding a dispersal mechanism not by analogy but by ballistic spread of material above the Earth's atmosphere out of reach of the winds (Jones and Kodis [1982]; O'Keefe and Ahrens [1982]).

3.3 Counteranalogy

A counteranalogy is simply an alternative hypothesis that happens to be analogical. In other words, it is an analogical explanation that shares the explanandum of its model but employs a different source analog. Like a disanalogy, a counteranalogy is oriented as an initial acceptance of the model conclusion. Its effect is achieved by producing a more acceptable conclusion than the model produces. So, like a misanalogy, a counteranalogy is constructive.

Having softened up the asteroid impact hypothesis with their misanalogy (Section 3.2), Kyte *et al.* ([1980]) proceed to offer a counteranalogy. They propose that the Earth was struck by a shower of comet fragments at the end of the Cretaceous, perhaps derived from a comet broken up by tidal forces as it approached the Earth. Specifically, Kyte *et al.* ([1980], pp. 655–6) point to the Tunguska event which, it has been argued, was caused by a comet fragment that exploded over Siberia in 1908. Accordingly, they refer to their scenario as a 'super Tunguska'. This scenario is very similar to the asteroid impact hypothesis except that the dispersal of debris would be accomplished by the initial scattering of comet-fragment explosions over the whole globe—a shotgun blast rather than a bullet impact. Like the asteroid impact hypothesis, it explains the iridium concentration as debris from an extraterrestrial body, and the mass extinction as the result of debris-induced darkness—although of only a short duration.

Table 5. The super Tunguska counteranalogy of Kyte *et al.* ([1980]).

Tunguska	super Tunguska
aerial-explosion	aerial-explosions
$debris_t$	$debris_s$
stratosphere	stratosphere
Tunguska	Earth
sunlight	sunlight
shade	darkness
days	weeks
$eject_t$(aerial-explosion,$debris_t$)	$eject_s$(aerial-explosions,$debris_s$)
$enter_t$($debris_t$,stratosphere)	$enter_s$($debris_s$,stratosphere)
$cover_t$($debris_t$,Tunguska)	$cover_s$($debris_s$,Earth)
$attenuate_t$($debris_t$,sunlight)	$attenuate_s$($debris_s$,sunlight)
$persist_t$(shade,days)	$persist_s$(darkness,weeks)
$cause_{t0}$($eject_t$,$enter_t$)	$cause_{s0}$($eject_s$,$enter_s$)
$enable_{t0}$($enter_t$,$cover_t$)	$enable_{s0}$($enter_s$,$cover_s$)
$enable_{t1}$($cover_t$,$attenuate_t$)	$enable_{s1}$($cover_s$,$attenuate_s$)
$cause_{t1}$($attenuate_t$,$persist_t$)	$cause_{s1}$($attenuate_s$,$persist_s$)

Kyte *et al.*'s counteranalogy is displayed in Table 5. It is quite similar to Alvarez *et al.*'s Krakatoa-asteroid analogy except that it has a different source and contains no special dispersal mechanism. In this scenario, dispersal is explained by mapping a single explosion over Tunguska to multiple explosions over the Earth. According to the *multiconstraint theory* (Section 2), many-to-one mappings tend to weaken the strength of an analogy. In this case, however, there is no difficulty in treating multiple explosions as a unit since they occur more-or-less simultaneously and conserve the explosive force of the original comet had it not broken up.

Kyte *et al.* do not take themselves to have exposed any sort of fallacy in the asteroid impact hypothesis. Indeed, they are clearly in substantial agreement with it. What they have done is to propose a different analogical explanation for the K-T extinction that addresses a shortcoming in the model explanation. By revising the dispersal mechanism, they claim to have produced a hypothesis that is simply more acceptable than the original asteroid impact hypothesis.

However, the super Tunguska counteranalogy did not attract much support (see Kyte and Wasson [1982]). Its closeness to the asteroid impact hypothesis made it hard to think of tests that would confirm one and not the other. Also, not much was known about the composition of comets and therefore the composition of their impact debris. Finally, the problem of debris dispersal in the original asteroid impact hypothesis was quickly addressed so that the motivation for Kyte *et al.*'s counteranalogy was undercut.

Counteranalogies need not always be so similar to their models. Consider the counteranalogy offered by Toon *et al.* ([1982], pp. 189–90), who assert that the Martian atmosphere would be a good analog to the stratosphere of the Earth. The whole atmosphere of Mars is similar in mass to the stratosphere of the Earth and so should behave similarly when perturbed. Furthermore, Toon *et al.* note that dust storms on Mars have been observed to spread from a local dust cloud to global coverage within a week or two. This speed would enable debris from an asteroid impact to cover the Earth before falling out, thus preserving the 'lights-out' explanation for the K-T mass extinction. Now, a dust storm on Mars and an asteroid impact on Earth are far more diverse than the analogs in Kyte *et al.*'s counteranalogy, which illustrates that counteranalogies need not resemble their models. (Curiously, although Toon *et al.*'s counteranalogy was not followed up, Toon *et al.* ([1997], p. 57) use a study of the Mount Pinatubo eruption to argue that winds perturbed by a large explosion could distribute debris world-wide in short order. So, perhaps their counteranalogy was more fortuitous than they could originally have known.)

3.4 False analogy

To argue that an analogy is a false analogy is to say that it does not satisfy the conditions for being an analogy after all. So, a false analogy is not itself an analogy but, like a misanalogy, the exploitation of a mistake in a purported analogy. Necessarily, a false analogy is both destructive in effect and oriented as a rejection of the model conclusion.

On the *multiconstraint theory* (Section 2), the conditions on an analogy are structural consistency, semantic similarity, and pragmatic utility. A false analogy might be uncovered by considering any of these aspects of its model. As it turns out, the Krakatoa-asteroid analogy was vulnerable to criticism concerning its structural consistency. As noted in Section 3.2, volcanic eruption debris tends to fall out of the stratosphere within a few months at most. Yet Symons ([1888]) had claimed that it stayed aloft for at least two years, and Alvarez *et al.* had assumed this report to be correct. Clearly, the 1888 report contained a mistake that Alvarez *et al.* had subsequently incorporated into their analogy.

The error was a misapprehension about the composition of debris from volcanic eruptions. As Toon *et al.* ([1982], p. 188) point out, most of the long-lived debris from an eruption consists of minute sulfuric acid droplets generated when sulfur dioxide gas from the eruption reacts with the

Table 6. The acid-dust false analogy of Toon *et al.* ([1982]) based on Table 1.

Krakatoa	Asteroid
Krakatoa-eruption	asteroid-impact
acid	??
winds	winds
stratosphere	stratosphere
Earth	Earth
sunlight	sunlight
shade	darkness
two-years	three-years
$eject_k$(Krakatoa-eruption,acid)	$eject_a$(asteroid-impact,??)
$enter_k$(acid,stratosphere)	$enter_a$(??,stratosphere)
$disperse_k$(winds,acid)	$disperse_a$(winds,??)
$cover_k$(acid,Earth)	$cover_a$(??,Earth)
$attenuate_k$(acid,sunlight)	$attenuate_a$(??,sunlight)
$persist_k$(shade,two-years)	$persist_a$(darkness,three-years)
$cause_{k0}(eject_k,enter_k)$	$cause_{a0}(eject_a,enter_a)$
$enable_{k0}(enter_k,disperse_k)$	$enable_{a0}(enter_a,disperse_a)$
$cause_{k1}(disperse_k,cover_k)$	$cause_{a1}(disperse_a,cover_a)$
$enable_{k1}(cover_k,attenuate_k)$	$enable_{a1}(cover_a,attenuate_a)$
$cause_{k2}(attenuate_k,persist_k)$	$cause_{a2}(attenuate_a,persist_a)$

atmosphere. Unlike volcanic dust, these droplets do not coagulate but instead behave like a gas, which enables them to remain suspended in the air for years. It was the worldwide dispersal of these droplets that created the effect that Symons ([1988]) and then Alvarez *et al.* ([1980]) attributed to dust. The asteroid impact would not have generated sulfuric acid droplets because asteroids and most Earth-surface rocks that an asteroid might hit contain little sulfur. So, the impact could not have kept the sky dark for years as originally concluded (see Alvarez [1983], pp. 635–6). In effect, the Krakatoa-asteroid analogy violates structural consistency because it contains a one-to-none mapping: there is nothing in the target analog to correspond to the acid in the source analog.

The false analogy is displayed in Table 6. This structure is derived from the model analogy (Table 1) but with the nature of the debris clarified: $debris_k$ is now *acid* and $debris_a$ is now *??*. The new lacuna in the target analog compromises the structural consistency of five of the six relational mappings and all of the system mappings in the analogy. As a result, the consistency of this analogy is negligible, so that it is not really an analogy at all. In the final analysis, like a disanalogy, it cannot be said to suggest any acceptable conclusion.

However deleterious this false analogy is, Toon *et al.* took it to be merely a minor embarrassment. As they proceed to note, the false analogy could be downplayed since the nature of the volcanic debris can be disambiguated in a more charitable way. That is, instead of replacing $debris_k$ by *acid*, we can replace it by *dust* and, in effect, construct the misanalogy described in Section 3.2. Alvarez *et al.* were ultimately able to live with this misanalogy in which darkness prevailed for only a few months after the asteroid impact. In a way, then, this false analogy and the misanalogy of Section 3.2 are simply two different ways of dealing with the same problem in the model analogy. The misanalogy is to be preferred on the principle of charity, at least.

(In another dramatic twist, research has indicated that the rocks at Chicxulub struck by the K-T asteroid may be unusual in containing large quantities of sulfur (Brett [1992]; Pope *et al.* [1994]). Heat from the impact may have vaporized this sulfur and hurled it into the stratosphere where it could persist in droplet form for years, thus reconstituting the original 'lights-out' scenario.)

4 Acceptability

The discussion in Section 3 shows that scientists took an early and active interest in the form and strength of the Krakatoa-asteroid analogy. Their criticisms were indeed aimed at the acceptability of the 'lights-out' scenario for the K-T mass extinction. Furthermore, Alvarez *et al.* took at least some of these criticisms to be representative of good science and deleterious to their hypothesis. The breakdown of analogy counterarguments along specific dimensions, namely *orientation* and *effect*, also shows that there is a kind of logic to these counterarguments. That is, these arguments show that analogical hypotheses may be systematically evaluated apart from their confirmation or disconfirmation. In the remainder of this section, I will contrast the results of the previous section with the logical empiricist view of the logic of analogical inference. Recall Bunge's statement of the logical empiricist view of analogy quoted in Section 1 (Bunge [1967], p. 267):

> Arguments from analogy may be fertile but they are invalid: their success, if any, does not depend on their form but on the nature of the case—whence there can be no logic of analogy. [...] [An analogical hypothesis] is a conjecture that must be subjected to tests other than that of validating the analogy premise. If the hypothesis proves false we should conclude that the inference was not only invalid but also barren.

Bunge ([1967], pp. 268–9) later adds that our only assessment of the form of an analogy derives from its confirmation: only a successful analogy is a true (or strong) analogy. Unsuccessful analogies are false analogies, by implication.

On this view, the sole virtue of an analogy is its fertility, its ability to suggest hypotheses. Barrenness is its sole vice. The form of an analogy is irrelevant and, indeed, our only trustworthy information regarding it comes from the analogy's success or failure. Now, consider how this view appears to differ from that of the critics of the asteroid impact hypothesis.

First, critics did not wait to confirm or disconfirm the Krakatoa-asteroid analogy before critiquing it. Indeed, criticism of the analogy appeared immediately and subsided when the project of testing the hypothesis got underway in earnest. Neither do these criticisms resemble attempts at confirmation. Each analogy counterargument instead represents an effort to clarify the model analogy or replace it with a superior one. Contrary to Bunge's view, then, it is quite possible to controvert an analogical hypothesis before it has been confirmed or disconfirmed.

Second, only some counterarguments address the fertility of the Krakatoa-asteroid analogy. Destructive arguments, namely disanalogies and false analogies, do take this approach. A disanalogy to an analogical inference attests to the fertility of its model, indicating that it supports multiple, incoherent conclusions. In fact, the fertility of the analogy is precisely the problem with it. A false analogy, however, attests to the barrenness of its model, indicating that it supports no conclusion in the first place. Contrast this situation with the constructive counterarguments, namely counter-analogy and misanalogy, which tell us nothing about the fertility of the model analogy. As a whole, analogy counterarguments are not limited to assessing the fertility of their model, as Bunge's view implies. Indeed, counter-arguments may be made regardless of our estimation of the fertility of the model analogy.

Third, unsuccessful analogies cannot be equated with false analogies. The asteroid impact hypothesis is widely accepted as the explanation for the K-T mass extinction. Yet, even the leading critics of the theory, namely Officer and Drake ([1985]) (see Alvarez [1997], p. 99), have not maintained that the Krakatoa-asteroid analogy is a false analogy, all things considered. They maintain instead that vigorous volcanic eruptions provide a better, alternative explanation for the mass extinctions (see Glasby and Kunzendorf [1996]). In other words, even scientists who regard the asteroid impact hypothesis as unsuccessful need not regard the Krakatoa-asteroid analogy as a false analogy. So, contrary to Bunge's statement, the ultimate success or failure of an analogical hypothesis does not dictate our assessment of the model analogy.

Finally, note that the orientation of a counterargument—the initial acceptance or rejection of its conclusion—implies acceptance or rejection of its form. Disanalogies and counteranalogies, oriented as an initial acceptance of the model conclusion, do not result in revisions to the form of the model analogy. In fact, these counterarguments rely upon both the acceptability *and* the form of the model analogy. Counteranalogies and misanalogies, oriented as an initial rejection of the model conclusion, do result in revisions to the form of the model analogy. The sulfuric acid droplet false analogy in Section 3.4 was reduced compared to the model analogy, whereas the coagulation misanalogy in Section 3.2 was expanded from it. In these cases, then, to address the acceptability of the model analogy means to address its form. On Bunge's view, form and acceptability are unrelated, so that no criticism of a model analogy could possibly follow from a manipulation of its form. This view is clearly at odds with the cases discussed above.

On the logical empiricist view, fertility or barrenness are the only issues relevant to evaluating an analogical inference as such. The form of an analogy implies nothing about its value. We learn about the form of an analogy solely through its success or failure. The four points raised here illustrate that this view is completely at odds with at least one example of good scientific practise. There is nothing in the analysis of the counter-arguments to the asteroid impact hypothesis to indicate that its critics were being either illogical or irrelevant in putting their counterarguments forward. That is, the orientation and effect of their counterarguments are indeed relevant to the evaluation of the 'lights-out' scenario. So, we should conclude that there is a logic of analogical inference after all and that analogy counterarguments depend upon it and elucidate it.

5 Conclusions

On the logical empiricist view of analogy, we may praise analogical inferences for being fertile and criticize them for being barren. Nothing else about an analogy is relevant to its quality. The only scientifically respectable means of evaluating an analogical hypothesis lies in confirming or disconfirming it against observation.

In the case of the asteroid impact hypothesis, however, we find respectable scientists engaged in criticizing the Krakatoa-asteroid analogy instead of disregarding it. These criticisms come in a variety of forms, namely disanalogy, misanalogy, counteranalogy, and false analogy. Are these criticisms illogical? Although they are not deductions, they display systematic features that can be summarized by the two dimensions of orientation and effect. Are they irrelevant? The scientists involved in the debate clearly thought that the counterarguments were relevant to the acceptability of the asteroid impact hypothesis, and the close analysis presented above confirms this attitude. It is reasonable, then, that we should view these counter-arguments just as their originators apparently viewed them—as a means of testing the Krakatoa-asteroid analogy.

If analogical inferences can be subjected to reasonable and relevant tests, apart from confirmation or disconfirmation, then it follows that they do support the acceptance of their conclusions after all. This situation does not mean that analogical hypotheses should not or need not be tested against observation. Instead, it means that the acceptability of an analogical hypothesis depends both upon subsequent testing *and* upon the strength of the model analogy.

Acknowledgments

Thanks to Bill Harper and Jamie Tappenden for their feedback on these ideas. This research is supported by the Social Sciences and Humanities Research Council of Canada.

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References

Alvarez, L. W. [1983]: 'Experimental evidence that an asteroid impact led to the extinction of many species 65 million years ago', *Proceedings of the National Academy of Sciences USA*, **80** (2), pp. 627–42.

Alvarez, L. W. [1987]: *Alvarez: Adventures of a physicist*, New York: Basic Books.

Alvarez, L. W., Alvarez, W., Asaro, F. and Michel, H. V. [1980]: 'Extraterrestrial cause for the Cretaceous-Tertiary extinction', *Science*, **208** (4448), pp. 1095–108.

Alvarez, L. W., Alvarez, W., Asaro, F. and Michel, H. V. [1981]: 'Asteroid extinction hypothesis', *Science*, **211** (4483), pp. 654–6.

Alvarez, W. [1997]: *T. Rex and the crater of doom*, New York: Vintage Books.

Asaro, F. [1987]: 'The Cretaceous-Tertiary iridium anomaly and the asteroid impact theory', in W. P. Trower (*ed.*), *Discovering Alvarez: Selected works of Luis W. Alvarez, with commentary by his students and colleagues*, pp. 240–2, Chicago: University of Chicago Press.

Bailer-Jones, D. M. [1999]: 'Tracing the development of models in the Philosophy of Science', in L. Magnani, N. J. Nersessian and P. Thagard (*eds*), *Model-based reasoning in scientific discovery*, Proceedings of the International Conference on Model-based Reasoning in Scientific Discovery, December 17–19, 1998, Padua, Italy, pp. 23–40, New York: Kluwer.

Brett, R. [1992]: 'The Cretaceous-Tertiary extinction: A lethal mechanism involving anhydrite target rocks', *Geochimica et Cosmochimica Acta*, **56**, pp. 3603–6.

Bunge, M. [1967]: 'Analogy in quantum theory: from insight to nonsense', *British Journal for the Philosophy of Science*, **18** (4), pp. 265–86.

Falkenhainer, B., Forbus, K. D. and Gentner, D. [1989]: 'The structure-mapping engine: algorithm and examples', *Artificial Intelligence*, **41**, pp. 1–63.

Frankel, C. [1999]: *The end of the dinosaurs: Chicxulub crater and mass extinctions*, Cambridge: Cambridge University Press.

Gentner, D. [1983]: 'Structure-mapping: a theoretical framework', *Cognitive Science*, **7** (2), pp. 155–70.

Gentner, D., Holyoak, K. J. and Kokinov, B. (*eds*) [2001]: *The analogical mind: Perspectives from cognitive science*, Cambridge, MA: MIT Press.

Giere, R. N. [1997]: *Understanding scientific reasoning* (4th edn), Fort Worth: Harcourt Brace College.

Glasby, G. P. and Kunzendorf, H. [1996]: 'Multiple factors in the origin of the Cretaceous/Tertiary boundary: The role of environmental stress and Deccan Trap volcanism', *Geologische Rundschau*, **85** (2), pp. 191–210.

Hempel, C. G. [1965]: *Aspects of scientific explanation*, New York: The Free Press.

Hesse, M. B. [1966]: *Models and analogies in science*, Notre Dame: University of Notre Dame Press.

Hickey, L. J. [1980]: 'Paleontologists and continental drift', *Science*, **210** (4475), p. 1200.

Holyoak, K. J. and Barnden, J. A. (*eds*) [1994]: *Analogical connections*, Volume 2 of *Advances in connectionist and neural computation theory*, Norwood, NJ: Ablex.

Holyoak, K. J. and Thagard, P. [1995]: *Mental leaps: Analogy in creative thought*, Cambridge, MA: MIT Press.

Jones, E. M. and Kodis, J. W. [1982]: 'Atmospheric effects of large body impacts: the first few minutes', in L. T. Silver and P. H. Schultz (*eds*), *Geological implications of impacts of large asteroids and comets on the Earth*, Volume 190 of *Special Paper series*, Boulder, CO: The Geological Society of America, pp. 175–86.

Kent, D. V. [1981]: 'Asteroid extinction hypothesis', Science, **211** (4483), pp. 648–50.

Kyte, F. T. and Wasson, J. T. [1982]: 'Geochemical constraints on the nature of large accretionary events', in L. T. Silver and P. H. Schultz (*eds*), *Geological implications of impacts of large asteroids and comets on the Earth*, Volume 190 of *Special Paper series*, Boulder, CO: The Geological Society of America, pp. 235–42.

Kyte, F. T., Zhou, Z. and Wasson, J. T. [1980]: 'Siderophile-enriched sediments from the Cretaceous-Tertiary boundary', *Nature*, **288** (5792), pp. 651–6.

Officer, C. B. and Drake, C. L. [1985]: 'Terminal Cretaceous environmental effects', *Science*, **227** (4691), pp. 1161–7.

O'Keefe, J. D. and Ahrens, T. J. [1982]: 'Impact mechanisms of large bolides interacting with Earth and their implication to extinction mechanisms', in L. T. Silver and P. H. Schultz (*eds*), *Geological implications of impacts of large asteroids and comets on the Earth*, Volume 190 of *Special Paper series*, Boulder, CO: The Geological Society of America, pp. 103–20.

Pope, K. O., Baines, K. H., Ocampo, A. C. and Ivanov, B. A. [1994]: 'Impact winter and the Cretaceous/Tertiary extinctions: results of the Chicxulub asteroid impact model', *Earth and Planetary Science Letters*, **128**, pp. 719–25.

Ruse, M. [1973]: 'The value of analogical models in science', *Dialogue*, **12** (2), pp. 246–53.

Russell, D. A. and Rice, G. (*eds*) [1982]: *K-TEC II: Cretaceous-Tertiary extinctions and possible terrestrial and extraterrestrial causes*, Volume 39 of *Syllogeus*, Ottawa: National Museums of Canada.

Shelley, C. [2002a]: 'The first inconvenience of anthropomorphism: the disanalogy in part IV of Hume's *Dialogues*', *History of Philosophy Quarterly*. **19(2)**, pp. 171–89.

Shelley, C. [2002b]: 'The analogy theory of disanalogy: When conclusions collide'. *Metaphor and Symbol*, **17(2)**, pp. 81–97.

Silver, L. T. and P. H. Schultz (*eds*) [1982]: *Geological implications of impacts of large asteroids and comets on the Earth*, Volume 190 of *Special Paper series*, Boulder, CO: The Geological Society of America.

Symons, G. J. (*ed.*) [1888]: *The eruption of Krakatoa and subsequent phenomena*, London: Royal Society.

Thagard, P. [1988]: *Computational philosophy of science*, Cambridge, MA: MIT Press.

Toon, O. B., Pollack, J. B., Ackerman, T. P., Turco, R. P., McKay, C. P. and Liu, M. S. [1982]: 'Evolution of an impact-generated dust cloud and its effects on the atmosphere', in L. T. Silver and P. H. Schultz (*eds*), *Geological implications of impacts of large asteroids and comets on the Earth*, Volume 190 of *Special Paper series*, Boulder, CO: The Geological Society of America, pp. 187–200.

Toon, O. B., Zahnle, K., Morrison, D., Turco, R. P. and Covey, C. [1997]: 'Environmental perturbations caused by the impacts of asteroids and comets', *Reviews of Geophysics*, **35** (1), pp. 41–78.

Weitzenfeld, J. S. [1984]: 'Valid reasoning by analogy', *Philosophy of Science*, **51** (1), pp. 137–49.