The Distinction Between Inductive Confidence and Strength in Property Induction

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Abstract

The author distinguishes between inductive confidence and strength, and further distinguishes between similarity-based and property relevance-based property inductions in terms of inductive confidence. The author predicts that property relevance strength will affect inductive confidence and strength in different ways, resulting in a dissociation between inductive confidence and strength. Three experiments examined the influence of property relevance strength on inductive strength and confidence in both property inductions. The prediction is confirmed by the following findings. Property relevance-based inductions showed higher inductive confidence than similarity-based inductions. In property relevance-based induction, (a) the influence of relevance similarity on inductive strength increased with relevance strength, and thereby inductive strength is jointly determined by relevance strength and relevance similarity; (b) inductive confidence increased with relevance strength independent of similarity and inductive strength. Overall, relevance strength affected inductive strength and confidence in different ways, resulting in the dissociation between inductive confidence and strength. These findings are beyond the existing accounts of inductive reasoning. The author proposes a relevance similarity framework that integrates relevance strength and relevance similarity, which can explain these findings.

Keywords: property induction; property relevance; relevance strength; relevance similarity; inductive strength; inductive confidence.

Inductive reasoning is a process in which people project information from known cases to the unknown (Heit, 2000; Hayes, Heit, & Swendsen, 2010; Kemp & Jern, 2013). One research topic in inductive reasoning is category-based property induction (Hayes, Heit, & Swendsen, 2010; Kemp & Jern, 2013; Medin et al., 2003; Osherson et al., 1990; Sloman & Lagnado, 2005). It typically involves inferring the properties of some conclusion categories on the basis of the knowledge of some premise categories (Hayes, Heit, & Swendsen, 2010). A main function of categories is to support inductive inferences (Anderson, 1991; Bright, 2010; Hayes, Heit, & Swendsen, 2010; Rosch & Mervis, 1975). In category-based property induction, given that some premise category has a property (e.g. polar bears have thick subcutaneous fat), people infer the likelihood that a conclusion category has the same property (e.g. penguins have thick subcutaneous fat). The inferred property is the generalized property, and the inferred likelihood is the inductive strength. There are three kinds of main accounts for category-based property inductions: the similarity account, the knowledge account, and the integration account such as the Bayesian model and structured statistical models (Bright, 2010; Bright & Feeney, 2014; Feeney, Coley, & Crisp, 2010; Hayes, Heit, & Swendsen, 2010; Heit, 1998, 2000; Kemp & Tenenbaum, 2009; Medin et al., 2003; Sloman & Lagnado, 2005). These accounts concern only inductive strength, neglecting inductive confidence, which is the degree of certainty of inductive strength. The present research aims to distinguish the two concepts and examine the relationship between them in property induction.

The similarity accounts claim that property inductions are primarily based on similarity between premise and conclusion categories (Osherson et al., 1990; Sloman, 1993; Blok, Medin, & Osherson, 2007). These accounts emphasize the role of overall similarity and apply to inductive reasoning in knowledge-poor domains. However, they cannot explain some property inductions based on specific structured knowledge. For example, people may consider it a strong inductive argument

that “Grass has enzyme X, therefore cows have enzyme X”, even though the similarity between grass and cows is very low. This is because that people think of the food linkage whereby cows’ eating of grass may transmit enzyme X from grass to cows. This linkage is knowledge of specific relationships rather than general similarity.

The knowledge accounts concern the role of specific knowledge. These accounts can explain the above example. The main knowledge accounts are the hypothesis-assessment model (McDonald et al., 1996) and the relevance theory of induction (Medin et al., 2003). The hypothesis-assessment model argues that when judging the strength of an inductive argument, people actively construct and assess hypotheses in light of the evidence provided by the premises. The relevance theory claims that induction is based on the principle of relevance that premises are assumed to be relevant to conclusions (Medin et al., 2003). The core assumption of the relevance theory is that for an inductive argument involving multiple categories, people actively compare multiple categories to find category relevance (that is, distinctive similarity or relations between these categories) that serve as candidates for inductive inference (Hayes, Heit, & Swendsen, 2010). Such inductions are category relevance-based inductions. When no distinctive properties or relations are available, property induction will appeal to overall similarity between the premise and conclusion category. Overall, the knowledge accounts emphasize the role of specific structured knowledge and apply to inductive reasoning in knowledge-rich domains.

The integration accounts such as the Bayesian model and structured statistical models incorporate similarity and background knowledge in property induction (Bright, 2010; Bright & Feeney, 2014; Hayes, Heit, & Swendsen, 2010; Heit, 1998, 2000; Kemp & Tenenbaum, 2009). The Bayesian model treats induction as a form of Bayesian belief revision. It assumes that when generalizing a property (e.g., Disease X) between familiar categories (e.g., from sparrows to crows), people will

use prior knowledge about the distributions of familiar properties to determine which of these distributions the novel property most closely resembles. It uses the premises as evidence to revise beliefs about the prior hypotheses of the generalized property according to the Bayes theorem.

Kemp & Tenenbaum (2009) proposed a Bayesian framework that integrates general similarity and structured background knowledge in inductive reasoning. The framework shows that similarity-based statistical inferences can be based on structured background knowledge. It can guide building structured statistical models of inductive reasoning that integrate general similarity and specific structured background knowledge. Kemp, Shafto, and Tenenbaum (2012) demonstrated that people can integrate across-objects overall similarity and across-features causal structures to generalize causally related features.

However, the Bayesian model and framework do not concern inductive confidence. In many cases, inductive reasoning involves both specific similarity and specific structured knowledge. For example, here is an inductive argument: Polar bears have thick subcutaneous fat/Penguins (or African elephants) have thick subcutaneous fat. From the premise, people can surely infer the high likelihood that penguins have thick subcutaneous fat, and the low likelihood that African elephants have it, although the overall similarity between the premise and conclusion categories is very low. Such inductions can be explained as follows. For this argument, people seek the relevant property or variable that could predict or explain the generalized property in the premise. Polar bears live in a cold climate, and the cold climate causes polar bears to develop thick subcutaneous fat to resist coldness. Here, the cold climate is the specific relevant property of the generalized property. A similar cold climate where penguins live should cause penguins to develop thick subcutaneous fat to resist coldness. This conforms to the causal principle that similar causes are followed by similar effects (Hume, 1748). Some previous studies have shown similar property inductions across

categories based on the causal principle (Lassaline, 1996; Rehder, 2005). In contrast, the tropical climate where African elephants live, should lead to a low likelihood that African elephants have thick subcutaneous fat, which would hinder the body from emitting heat. There is a strong correlation between the climate factor as the relevant variable and the thickness of subcutaneous fat as the induction variable. The strong correlation implies that the climate factor can certainly predict the thickness of subcutaneous fat. Accordingly, people can confidently infer whether penguins and African elephants have thick subcutaneous fat according to whether the respective climates are similar to the climate in which polar bears live. In the same high inductive confidence, people will make a high inductive strength judgment for penguins, but a low inductive strength judgment for African elephants. Here, inductive strength will increase with the degree of climate similarity, and there will be the contrast between the high inductive confidence and the low inductive strength. Climate similarity will make a difference to inductive strength. Such inductions based on strong correlations are strong-confidence inductions. In contrast, inductions based on weak correlations are weak-confidence inductions. If the correlation is weak, the climate factor will not certainly predict the thickness of subcutaneous fat. Thus, people will not confidently infer whether penguins and African elephants have thick subcutaneous fat according to climate similarity. Climate similarity will make little difference to inductive strength for the two conclusion categories. Overall, correlation strength will affect confidence for inductive strength based on climate similarity. Such inductive confidence is neglected in the Bayesian model and framework.

Generally speaking, for an inductive argument like the above example, people first seek specific relevant properties that could predict the generalized property, and then infer inductive strength on the basis of specific similarity with respect to the relevant properties. Inductive strength will increase with specific similarity. The author refers to such specific similarity as relevance similarity.

In such induction, when property relevance between the generalized property and the relevant properties is stronger, relevance similarity can certainly predict whether the generalized property is present, resulting in higher inductive confidence. When property relevance is weaker, relevance similarity cannot certainly predict whether the generalized property is present, resulting in lower inductive confidence. Property relevance strength (henceforth, referred to as relevance strength) is structured knowledge about specific relationships between properties, which will determine inductive confidence. The author refers to such inductions based on property relevance as property relevance-based inductions, which are different from category relevance-based inductions.

Here, the author adopts a broad definition of similarity that includes both overall similarity and specific similarity. Although traditional research on inductive reasoning adopts a narrow definition (overall similarity), people often talk about specific similarity in everyday life. For example, people could say that two people are similar in terms of a specific property such as nose shape, hairstyle, skin color, or temper. Thus, the representation of specific similarity is reasonable from the perspective of everyday language. Moreover, Pothos (2005) has demonstrated that applying rules based on matching/mismatching individual properties is similar to reasoning based on overall similarity, and the process of property matching is also a process of similarity comparison. Thus, the conception of specific similarity is also reasonable from the perspective of theoretical basis.

In property relevance-based induction, relevance strength between a generalized property (G) and its relevant property (R) can be measured by a correlation index, $\Delta P = P(G|R) - P(G|\sim R)$. ΔP equals the difference between the two conditional probabilities. It is similar to causal strength in causal induction with binary variables (Cheng & Novick, 1990). People's knowledge about such probabilities may arise from causal or statistical knowledge in practice. Relevance strength increases with ΔP . Relevance strength will determine inductive confidence, and affect the effect of

relevance similarity on inductive strength (that is, the likelihood that a conclusion category has the generalized property). When relevance strength remains constant, inductive confidence will remain stable, whereas inductive strength will increase with relevance similarity. Thus, there will be a dissociation between inductive confidence and strength. When relevance strength increases, inductive confidence will increase, and the same difference in relevance similarity will make a greater difference to inductive strength in strong relevance strength than in weak relevance strength. Hence, the influence of relevance similarity on inductive strength will increase with relevance strength, and there will be an interaction effect of relevance strength and relevance similarity on inductive strength. Relevance strength and relevance similarity will jointly determine inductive strength. Overall, relevance strength as specific structured knowledge will constrain and affect inductive confidence and the influence of relevance similarity on inductive strength.

The prediction of the interaction between relevance strength and relevance similarity, is consistent with the interaction between structured knowledge and similarity-based statistics predicted by the Bayesian framework proposed by Kemp & Tenenbaum (2009). However, the Bayesian framework does not address the interaction between relevance strength and relevance similarity as specific similarity. Neither does it concern inductive confidence. No previous studies have investigated the possible influence of relevance strength on property inductions. Therefore, the present research aims to examine this possible influence.

When no specific correlates are available, people will appeal to overall similarity between the premise and conclusion category. Inductive strength will increase with overall similarity, as is confirmed by the similarity effect found in previous research (Bright, 2010; Heit, 2000; Kemp & Tenenbaum, 2009; Medin et al., 2003; Sloman & Lagnado, 2005). In such induction, there is no certain relevance between the generalized property and the premise category's other properties.

Thus, overall similarity could not certainly predict the generalized property. Hence, inductive confidence will be relatively low regardless of overall similarity. The author refers to such induction as similarity-based induction. It is weak-confidence induction because it has lower inductive confidence, compared with property relevance-based induction. In similarity-based induction, there will also be a dissociation between inductive confidence and strength, because inductive strength will increase with overall similarity, whereas inductive confidence will be relatively low regardless of overall similarity.

Overall, in similarity-based and property relevance-based induction, inductive strength will increase with overall or specific similarity, whereas inductive confidence will increase with relevance strength independent of similarity. Relevance strength will affect inductive strength and confidence in different ways. Thus, there will be a dissociation between inductive confidence and strength. Property relevance-based inductions will show higher inductive confidence than similarity-based inductions. No previous studies have tested these predictions.

The existing accounts of inductive reasoning neglect inductive confidence. The present research aims to investigate inductive confidence. Because relevance strength is the basis of whether people can certainly infer inductive strengths according to relevance similarity or overall similarity, the author predicts that inductive confidence will primarily be based on relevance strength regardless of similarity. Confidence rating is essentially an aspect of metacognition, which refers to cognitive processes about other cognitive processes or beliefs about one's own beliefs. Metacognitive research investigates how people assess the certainty or accuracy of their direct representations and judgments (Deroy, Spence, & Noppeney, 2016; Flavell, 1979). For instance, in decision making, people may rate their confidence about the correctness of their decision on a numerical scale (Gigerenzer, Hoffrage, & Kleinbölting, 1991). Inductive confidence is the degree of certainty of

inductive strength; it is therefore an aspect of metacognition in inductive reasoning. Inductive confidence is the second-order representation that reflects a first-order representation such as inductive strength. Thus, inductive confidence is essentially different from inductive strength.

Three experiments were conducted to test the above predictions for inductive strength and confidence. Experiment 1 examined similarity-based and property relevance-based inductions. Experiment 2 examined property inductions based on specific relevance with singular relevant properties. Experiment 3 further examined property inductions based on general relevance with multiple relevant properties.

Experiment 1

Method

Participants

A total of 42 college students (15 male, 27 female) from Shaanxi Normal University participated in the experiment. Every participant received a pen as a gift.

Materials

To avoid the possible influence of background knowledge, the present experiment used blank properties as generalized properties. The material was a questionnaire written in Chinese on a sheet of paper. The English translation of the questionnaire is as follows.

Instruction

In the following reasoning problem, there is the information of some insects in an island. Please answer the following questions. For the likelihood questions, please give your likelihood estimates on a scale from 0% to 100%. The higher number indicates the greater likelihood. For the confidence questions, please give your confidence estimates on a scale from 0% to 100%. The higher number indicates the greater confidence. Please complete the task carefully. Thank you for your sincere cooperation!

The distinction between inductive confidence and strength

The following information is known.

Insect A has properties: long antenna, one pair of wings, stripes, thin skins, and a weak immune system.

Insect B has properties: long antenna, one pair of wings, stripes, thin skins, and a strong immune system.

Insect C has properties: short antenna, two pairs of wings, no stripes, thick skins, and a weak immune system.

Insect D has properties: long antenna, one pair of wings, stripes, thick skins, and a weak immune system.

Insect E has properties: long antenna, two pairs of wings, no stripes, thick skins, and a strong immune system.

Now it is found that Insect A has new properties X and G, and its weak immune system causes its Property X.

1. How likely is it that Insect B has Property X? _____

How confident are you for your estimate? _____

2. How likely is it that Insect C has Property X? _____

How confident are you for your estimate? _____

3. How likely is it that Insect C has Property G? _____

How confident are you for your estimate? _____

4. How likely is it that Insect D has Property X? _____

How confident are you for your estimate? _____

5. How likely is it that Insect D has Property G? _____

How confident are you for your estimate? _____

6. How likely is it that Insect E has Property X? _____

How confident are you for your estimate? _____

The presentation order of the above six questions was counterbalanced. One was the above order, and the other was the reverse version of the former.

Design and procedure

A within-subjects design was used.

Table 1

The parameters settings of stimulus materials and the results of Experiment 1

Questions	Insects	Generalized properties	Inductive type	Relevance similarity	Overall similarity	Inductive strengths <i>M (SD)</i>	Confidence <i>M(SD)</i>
1	B	X	Relevance	0/1	4/5	22.17% (18.95%)	75.62% (17.97%)
6	E	X	Relevance	0/1	1/5	18.10% (17.35%)	77.76% (16.88%)
2	C	X	Relevance	1/1	1/5	71.62% (22.29%)	77.31% (17.02%)
3	C	G	Similarity	-	1/5	30.55% (22.72%)	69.50% (21.85%)
4	D	X	Relevance	1/1	4/5	77.95% (19.09%)	81.26% (12.43%)
5	D	G	Similarity	-	4/5	59.40% (20.70%)	69.88% (19.71%)

The parameter settings of stimulus materials are shown in Table 1. The common premise of the six conclusion questions was that Insect A had new properties X and G, and its weak immune system caused its Property X. The two new properties were the generalized properties. Overall similarity was the proportion of the common properties among the five known properties.

Generalized Property X had strong relevance to the relevant property: weak immune system. The relevance strength between both properties remained stable. Relevance similarity was defined as whether the conclusion categories had the weak immune system. Inductive strength ratings for Property X would be based on relevance, and increase with relevance similarity rather than overall similarity, thereby showing equal high inductive confidence. For the property relevance-based inductions with Property X, questions 1, 2, 4, and 6 formed a 2×2 similarity design that independently manipulated two similarity factors: relevance similarity (0/1 vs. 1/1) and overall

similarity (1/5 vs. 4/5). This design aimed to examine how the two factors would affect inductive strength and confidence in strong relevance.

Generalized Property G had no specific relevant properties. Thus, inductive strength ratings for Property G would be based on overall similarity, and would have equal low inductive confidence.

Overall, there would be higher inductive confidence for inferring Property X than for inferring Property G. Questions 6, 3, 4 and 5 formed a 2×2 inductive type design that independently manipulated two factors: inductive type (relevance-based vs. similarity-based induction) and similarity (relatively low [0/1 or 1/5] vs. high [1/1 or 4/5]). This design aimed to compare relevance-based and similarity-based inductions.

The participants completed the questionnaire in a large classroom. They took about 10 minutes to complete the questionnaire.

Results

The results are shown in Table 1. Data in each design were analyzed with a 2×2 analysis of variance with repeated measures on both factors. All the statistical tests used the alpha level of significance of .05.

For the similarity design, the analysis of variance of inductive strength revealed an effect of relevance similarity [Inductive strength increased with relevance similarity, $F(1, 41) = 604.19$, $MSE = 207.65$, $p < .001$]. The main effect of overall similarity was not significant. There was no significant interaction between the two factors. Thus, it was relevance similarity, rather than overall similarity, that affected inductive strength, as confirms the prediction of relevance similarity. The analysis of variance of inductive confidence revealed that neither relevance nor overall similarity yielded significant effects, and there was no significant interaction between the two factors.

Inductive confidence remained stable regardless of similarity. Thus, in property relevance-based

induction, inductive confidence remained stable in accordance with relevance strength, independent of inductive strength and relevance similarity. The author further conducted the Pearson correlation test for inductive strength and confidence. It revealed that the overall correlation between both was not significant ($N = 168$, $r = .133$, $p = .086 > .05$). Thus, there was a dissociation between inductive confidence and strength. This confirms the prediction for the influence of relevance strength on property induction.

For the inductive type design, the analysis of variance of inductive strength revealed an effect of similarity [Inductive strength increased with similarity, $F(1, 41) = 143.06$, $MSE = 577.65$, $p < .001$]. Inductive type yielded no significant effect. There was an interaction effect of the two factors [$F(1, 41) = 31.50$, $MSE = 320.38$, $p < .001$]. The analysis of variance of inductive confidence revealed an effect of inductive type, namely that inductive confidence was higher in property relevance-based induction than in similarity-based induction [$F(1, 41) = 11.44$, $MSE = 354.14$, $p < .01$]. Similarity yielded no significant effect. There was no significant interaction between the two factors. Overall, in the inductive type design, inductive strength increased with similarity, whereas inductive confidence varied with inductive type regardless of similarity. The author further conducted the Pearson correlation test for inductive strength and confidence. It revealed that the overall correlation between the two was not significant ($N = 168$, $r = .149$, $p = .054 > .05$). Thus, there was a dissociation between inductive strength and confidence. Property relevance-based inductions showed higher inductive confidence than similarity-based inductions. This confirms the prediction in the introduction.

Overall, the results of both the similarity design and the inductive type design showed that inductive strength increased with similarity, whereas inductive confidence accorded with inductive type regardless of similarity. Inductive strength and confidence showed different dependence

patterns. There was no significant correlation between inductive confidence and strength. Thus, there was a dissociation between inductive strength and confidence. These results confirm the predictions for both relevance-based and similarity-based inductions in the introduction.

Experiment 2

Method

Participants

A total of 46 college students (21 male, 25 female) from Shaanxi Normal University participated in the experiment. Every participant received a pen as a gift.

Materials

The material was a questionnaire written in Chinese on a sheet of paper. The instruction was identical to that in Experiment 1. The English translation of the remaining part of the questionnaire is as follows.

The following information is known.

Insect A has properties: long antenna, one pair of wings, stripes, a tail, and a weak immune system.

Insect B has properties: long antenna, one pair of wings, stripes, no tails, and a strong immune system.

Insect C has properties: long antenna, one pair of wings, no stripes, no tails, and a weak immune system.

Now it is found that Insect A has Properties X and G. Its Property X is caused by its weak immune system, and has a strong causal connection with its weak immune system; whereas its Property G has only moderate correlation with its weak immune system.

1. How likely is it that Insect B has Property X? _____

How confident are you for your estimate? _____

2. How likely is it that Insect B has Property G? _____

How confident are you for your estimate? _____

3. How likely is it that Insect C has Property X? _____

How confident are you for your estimate? _____

4. How likely is it that Insect C has Property G? _____

How confident are you for your estimate? _____

The presentation order of the above four questions was counterbalanced across participants.

Design and procedure

The experiment used a 2 (relevance strength: relatively weak vs. strong level) $\times$ 2 (relevance similarity: low vs. high level) within-subjects design. The common premise of the four conclusion questions was that Insect A had new properties X and G, and its weak immune system had causal relation with Property X and had usual correlation with Property G. The overall similarity between the premise and conclusion insects remained 3/5. Properties X and G were the generalized properties with the same relevant property (weak immune system). The relevant property had stronger relevance to Property X than to Property G. Thus, relevance strength was strong for Property X, but was weak for Property G. Relevance similarity was 0/1 for Insect B, but was 1/1 for Insect C. Thus, the four questions formed a 2 (relevance strength: relatively weak vs. strong) $\times$ 2 (relevance similarity: 0/1 vs. 1/1) within-subjects design.

The experimental procedure was similar to that in Experiment 1.

Results

The results of inductive strength and confidence are shown in Table 2. Data were analyzed with a 2 (relevance strength: weak vs. strong) $\times$ 2 (relevance similarity: 0/1 vs. 1/1) ANOVA with repeated measures on both factors.

Table 2

Mean inductive strength and confidence (*SD*) in Experiment 2

Relevance strength	Relevance similarity				Overall	
	0/1 (Insect B)		1/1 (Insect C)		Strength	Confidence
	Strength	Confidence	Strength	Confidence		
Weak (Property G)	47.50% (17.05%)	73.04% (17.97%)	51.80% (17.17%)	78.50% (12.36%)	49.65%	75.77%
Strong (Property X)	16.54% (18.39%)	83.02% (12.01%)	77.91% (21.53%)	83.43% (14.01%)	47.23%	83.23%
Overall	32.02%	78.03%	64.86%	80.97%		

The analysis of inductive strength revealed an effect of relevance similarity [Inductive strength increased with relevance similarity, $F(1, 45) = 124.97$, $MSE = 396.91$, $p < .001$]. The main effect of relevance strength was not significant. However, the simple effect analysis showed that at the level of high relevance similarity (1/1) of Insect C, the mean inductive strength of Property X was larger than that of Property G [$t(45) = 7.20$, $p < .001$]; whereas at the level of low relevance similarity (0/1) of Insect B, the mean inductive strength of Property X was less than that of Property G [$t(45) = 8.09$, $p < .001$]. There was an interaction effect of the two factors [$F(1, 45) = 81.76$, $MSE = 458.05$, $p < .001$]. In Table 2, the same difference (0/1 vs. 1/1) in relevance similarity yielded a larger difference (61.37%) in inductive strength for Property X than for Property G (4.30%). The interaction effect implies that the influence of relevance similarity on inductive strength increased with relevance strength, thereby depending on relevance strength. Thus, relevance strength mediated the influence of relevance similarity on inductive strength. Relevance strength and

relevance similarity jointly determined inductive strength. This result confirms the prediction for the interaction between relevance strength and similarity.

The analysis of inductive confidence revealed an effect of relevance strength [Inductive confidence increased with relevance strength, $F(1, 45) = 18.78$, $MSE = 136.20$, $p < .001$]. The main effect of relevance similarity was not significant. There was no significant interaction between relevance strength and relevance similarity. The results confirm the prediction that inductive confidence should be determined by relevance strength.

Overall, in property relevance-based induction, inductive strength was jointly determined by relevance strength and relevance similarity, whereas inductive confidence was determined by relevance strength, independent of relevance similarity. Inductive strength and confidence showed different dependence patterns. The author further conducted the Pearson correlation test for inductive strength and confidence. It revealed that the overall correlation between the two was not significant ($N = 184$, $r = .073$, $p = .32 > .05$). Thus, there was a dissociation between inductive strength and confidence. In particular, in strong relevance, there was a contrast between the two at the level of low similarity: inductive strength was very low, whereas inductive confidence was very high. These results confirm the predictions for property relevance-based inductions in the introduction.

Experiment 3

Experiment 2 examined property inductions based on specific relevance with singular relevant properties. Given a premise category with a generalized property, when no specific relevant properties are available, the known multiple properties of the premise category may be generally relevant to the generalized property. Thus, overall similarity with respect to the known properties will become relevance similarity. When different generalized properties have different relevance

strengths, the influence of relevance similarity on inductive strength will increase with relevance strength, and inductive confidence will increase with relevance strength regardless of relevance similarity. There will also be a dissociation between inductive strength and confidence. Experiment 3 tested these predictions for property inductions based on general relevance with multiple relevant properties.

Method

Participants

A total of 37 college students (17 male, 20 female) from Shaanxi Normal University participated in this experiment. Every participant received a pen as a gift.

Materials

The material was a questionnaire written in Chinese on a sheet of paper. The instruction was similar to that in Experiment 1. The English translation of the questionnaire is as follows.

Insect A has physical properties: long antenna, one pair of wings, stripes, thin skins, and no tails.

Insect B has physical properties: long antenna, one pair of wings, stripes, thin skins, and a tail.

Insect C has physical properties: short antenna, one pair of wings, stripes, thick skins, and no tails.

Now it is found that Insect A has Physical Property X and Behavioral Property G. Generally, for an animal, a physical property has a stronger association with other physical properties than a behavioral property.

1. How likely is it that Insect B has Physical Property X? _____

How confident are you for your estimate? _____

2. How likely is it that Insect B has Behavioral Property G? _____

How confident are you for your estimate? _____

3. How likely is it that Insect C has Physical Property X? _____

How confident are you for your estimate? _____

4. How likely is it that Insect C has Behavioral Property G? _____

How confident are you for your estimate? _____

Design and procedure

A 2 (relevance strength: weak vs. strong level) $\times$ 2 (relevance similarity: low vs. high level) within-subjects design was used. The common premise of the four conclusion questions was that Insect A had Physical Property X and Behavioral Property G. Properties X and G were the generalized properties. Both properties had no specific relevant properties, but were generally relevant to the set of Insect A's known physical properties. Physical Property X had a stronger association with the known physical properties than Behavioral Property G, because physical properties are mainly constrained by physical structures, whereas behavioral properties are more affected by environments and learning. Thus, Physical Property X had a stronger relevance to the set of Insect A's known physical properties than Behavioral Property G. The relevance strength of Physical Property X was stronger than that of Behavioral Property G. Relevance similarity was equal to overall similarity. The overall similarity between Insects B and A was 4/5, and the overall similarity between Insects C and A was 3/5. Relevance similarity was varied with the two levels: 3/5 and 4/5. Thus, the four questions formed a 2 (relevance strength: relatively weak vs. strong) $\times$ 2 (relevance similarity: 3/5 vs. 4/5) within-subjects design.

The experimental procedure was similar to that in Experiment 1.

Results

The results of inductive strength and confidence are shown in Table 3. The data in each table were analyzed with a 2 (relevance strength: behavioral weak relevance vs. physical strong relevance) $\times$ 2 (relevance similarity: 3/5 vs. 4/5) ANOVA with repeated measures on both factors.

The distinction between inductive confidence and strength

The analysis of inductive strength revealed an effect of relevance similarity [Inductive strength increased with relevance similarity, $F(1, 36) = 44.54$, $MSE = 259.55$, $p < .001$], and an effect of relevance strength [Inductive strength increased with relevance strength, $F(1, 36) = 10.54$, $MSE = 372.37$, $p < .01$]. There was an interaction effect of the two factors [$F(1, 36) = 15.82$, $MSE = 222.68$, $p < .001$]. The same difference (4/5 - 3/5) in relevance similarity yielded a larger difference (27.44%) in inductive strength for Physical Property X than for Behavioral Property G (7.92%). The interaction effect implies that the influence of relevance similarity on inductive strength increased with relevance strength. Thus, relevance strength and relevance similarity jointly determined inductive strength.

Table 3

Mean inductive strength and confidence (*SD*) in Experiment 3

Relevance strength	Relevance similarity				Overall	
	3/5 (Insect C)		4/5 (Insect B)		Strength	Confidence
	Strength	Confidence	Strength	Confidence		
Weak (Property G)	46.89% (19.41%)	67.43% (18.62%)	54.81% (20.25%)	66.03% (18.31%)	50.85%	66.73%
Strong (Property X)	47.43% (20.43%)	72.62% (17.32%)	74.87% (12.66%)	77.11% (15.36%)	61.15%	74.87%
Overall	47.16%	70.03%	64.84%	71.57%		

The analysis of inductive confidence revealed an effect of relevance strength [Inductive confidence increased with relevance strength, $F(1, 36) = 7.27$, $MSE = 336.94$, $p < .05$]. The main effect of relevance similarity was not significant. There was an interaction effect of the two factors

$[F(1, 36) = 4.96, MSE = 64.93, p = .03 < .05]$. Overall, inductive confidence increased with relevance strength regardless of relevance similarity.

Overall, Experiment 3 shows that when specific relevance is not available, property inductions can be based on general relevance with multiple relevant properties. For such property inductions, inductive strength was jointly determined by relevance strength and relevance similarity, whereas inductive confidence was determined by relevance strength, independent of relevance similarity. Inductive strength and confidence showed different dependence patterns. The author further conducted the Pearson correlation test for inductive strength and confidence. It revealed that the overall correlation between the two was not significant ($N = 148, r = .115, p = .164 > .05$). Thus, there was a dissociation between inductive strength and confidence. In particular, in strong relevance, there was a contrast between the two at the level of low similarity: Inductive strength was low, whereas inductive confidence was high. These results confirm the predictions for property inductions based on general relevance.

Experiment 3 demonstrates that property inductions based on general relevance replicate the overall pattern of property inductions based on specific relevance.

General discussion

Summary of the present findings

Experiments 1 and 2 demonstrate the distinction between relevance-based and similarity-based inductions. Experiments 2 and 3 demonstrate the consistency between property inductions based on specific relevance and general relevance. In both relevance-based and similarity-based induction, inductive strength increased with specific or overall similarity, whereas inductive confidence increased with relevance strength regardless of similarity. When relevance strength remained constant, inductive confidence remained stable regardless of inductive strength. Inductive strength

and confidence showed different dependence patterns. There was a dissociation between inductive confidence and strength. Property relevance-based inductions showed higher inductive confidence than similarity-based inductions.

In property relevance-based induction, there was an interaction effect of relevance strength and relevance similarity on inductive strength. The influence of relevance similarity on inductive strength depended on relevance strength. The same difference in relevance similarity made a greater difference to inductive strength in strong relevance than in weak relevance. Thus, it was the combination of relevance strength and relevance similarity that determined inductive strength. In both specific and general relevance, inductive confidence increased with relevance strength regardless of relevance similarity and inductive strength. Overall, relevance strength affected inductive strength and confidence in different ways.

The results of the three experiments confirm the predictions for the influence of relevance strength on property induction in the introduction.

There are three novel findings here. First, there was a dissociation between inductive confidence and strength in both relevance-based and similarity-based induction. Second, in property relevance-based induction, relevance strength affected inductive strength and confidence in different ways. Relevance strength and relevance similarity jointly determined inductive strength, while relevance strength alone determined inductive confidence. Third, property relevance-based inductions showed higher inductive confidence than similarity-based inductions.

Theoretical implications

The present experiments demonstrate that relevance strength affects inductive confidence and strength in different ways, resulting in the dissociation between inductive confidence and strength.

This finding is beyond the predictions of the existing accounts of inductive reasoning. The existing accounts all neglect inductive confidence and the influence of relevance strength on inductive confidence and strength.

Relevance strength is specific structured knowledge about the relationship between a generalized property and the relevant properties. It is the basis that determines whether people can certainly infer the likelihood that a conclusion category has the generalized property on the basis of relevance similarity. It determines the degree of certainty (that is, inductive confidence) of inductive strength. Strong relevance results in higher inductive confidence, whereas weak relevance results in lower inductive confidence. Thus, property relevance-based inductions show higher inductive confidence than similarity-based inductions. The author first distinguishes the two kinds of inductions on the basis of the difference in inductive confidence.

Relevance strength mediates the influence of relevance similarity on inductive strength. The same difference in relevance similarity makes a larger difference in inductive strength in strong relevance than in weak relevance. The influence of relevance similarity on inductive strength increases with relevance strength. In property relevance-based induction, inductive strength increase with relevance similarity rather than overall similarity. These two findings demonstrate that specific relevance knowledge constrains how people use similarity. Here, similarity operates on the basis of relevance knowledge. This is consistent with the principle of the Bayesian framework that similarity-based statistical inference can operate over structured background knowledge (Kemp & Tenenbaum, 2009). However, the Bayesian framework neglects relevance similarity.

The Bayesian framework does not concern inductive confidence either. The previous accounts also neglect inductive confidence. The present results show that in property relevance-based induction, inductive confidence is dissociated from inductive strength. Inductive confidence is

determined by relevance strength, whereas inductive strength is determined by the conjunction of relevance strength and relevance similarity. This dissociation demonstrates the conceptual distinction: inductive strength is the likelihood of inductive inference, whereas inductive confidence is the degree of certainty of inductive strength. The latter is an aspect of metacognition in inductive reasoning. Thus, inductive confidence is conceptually different from inductive strength. The concept of inductive confidence is necessary for research on inductive reasoning.

Since relevance strength belongs to structured knowledge in the relevance theory (Medin et al., 2003), it is feasible to explain the influence of relevance strength on inductive confidence and strength as an extension of the relevance theory and the Bayesian framework (Kemp & Tenenbaum, 2009), although both accounts neglect inductive confidence. According to the relevance theory, induction is based on the principle of relevance that premises are assumed to be relevant to conclusions (Medin et al., 2003). For the category-based property induction, there may be two kinds of relevance: category and property relevance. Category relevance refers to relevance between different categories, that is, distinctive similarity or relations between different categories. Property relevance refers to relevance between a generalized property and its relevant properties within a premise category. The original relevance theory concerns the former (Hayes, Heit, & Swendsen, 2010), but neglects the latter. Property relevance is another basis of category-based property induction, as is confirmed by the present experiments. Property relevance is different from category relevance which the original relevance theory is concerned with. Overall, the present finding of property relevance-based induction extends the scope of relevance established in previous research. The principle of relevance should involve property relevance.

More importantly, property relevance-based induction implies a new relevance framework that integrates property relevance strength and relevance similarity. These two factors are not associated

with each other in previous research. The author calls this the relevance similarity framework, detailed as follows. Property induction is based on the integration of property relevance strength (that is, relevance strength) and similarity of relevant properties (that is, relevance similarity). Relevance strength constrains how people use relevance similarity and overall similarity. Similarity operates on the basis of relevance strength. The influence of relevance similarity on inductive strength increases with relevance strength. In relevance-based induction, inductive confidence is dissociated from inductive strength. Inductive confidence is determined by relevance strength, whereas inductive strength is determined by the conjunction of relevance strength and relevance similarity. The relevance similarity framework can explain the present findings, and it is a theoretical contribution to the research on inductive reasoning.

Relation to previous research

Experiment 1 found that inductive strength for the causally-related property accorded with relevance similarity based on causal relevance, independent of overall similarity. This result is consistent with the finding in Rehder's Experiment 3 (2006). He examined whether Property Generalization across categories is based on causal relations or overall similarity, and found that when causal explanations were available, the effect of similarity was almost completely eliminated. Thus, both experiments consistently demonstrate that causal relations override overall similarity in category-based Property Generalization. However, Rehder (2006) did not examine inductive confidence and the influence of relevance strength on inductive confidence and strength.

Moreover, although a few studies have examined property induction based on causal transmission, these studies did not examine inductive confidence and the interaction effect of relevance strength and relevance similarity on inductive strength (Kemp, Shafto & Tenenbaum,

2012; Kemp & Tenenbaum, 2009; Rehder, 2006, 2007; Shafto et al., 2008). Compared with previous research, the author for the first time found that (1) in property relevance-based induction, the influence of relevance similarity on inductive strength depends on relevance strength; (2) there is a distinction between inductive confidence and strength; and (3) inductive confidence is higher for property relevance-based inductions than for similarity-based inductions. More importantly, the author proposes the relevance similarity framework to explain property relevance-based induction. It is different from the original relevance theory, which concerns category relevance-based induction.

Boundary conditions

The present findings of category-based property induction can extend to generalization across objects. The scope of the present results may be affected by the following boundary conditions. First, the present experiments used singular premises. Property induction under multiple premises may be different because multiple premises can provide more information. Second, in property relevance-based induction, properties generalize across categories through causal relationships between properties within a category. This is an indirect way, and it may be different from the way that properties directly transmit over a food web that represents causal relationships among some species. Thus, property inductions through the latter way may be different. Third, in order to manipulate relevance strength, the author set what properties are relevant to a generalized property. This resulted in relevance-based property inductions in certain situations. Such design conforms to the manipulation principle in experimental design, like the previous experiments on property inductions (Kemp, Shafto & Tenenbaum, 2012; Rehder, 2006, 2007). For property inductions with natural categories in uncertain situations, what specific relevance is available depends on reasoners' background knowledge. When no specific relevance is available, property inductions will rely on

general relevance or overall similarity.

Conclusion

The present research first distinguishes between inductive confidence and strength, and further distinguishes relevance-based and similarity-based inductions in terms of inductive confidence. Property relevance-based inductions show higher inductive confidence than similarity-based inductions. In property relevance-based induction, inductive strength is determined by the combination of relevance strength and relevance similarity, whereas inductive confidence depends on relevance strength independent of similarity. Relevance strength affects inductive strength and confidence in different ways, resulting in the dissociation between inductive confidence and strength. The influence of relevance similarity on inductive strength increases with relevance strength. These findings are beyond the existing accounts of inductive reasoning. The relevance similarity framework that integrates relevance strength and relevance similarity can explain these findings.

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