The semantics of question-embedding predicates

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Abstract

The complementation pattern of question-embedding predicates, such as *know* and *agree*, presents a puzzle for the compositional semantics of complementation. The traditional Question-to-Proposition reduction approach to these predicates faces the problem of non-reducibility (George, 2011) and a problematic prediction concerning the interpretation of Predicates of Relevance (Elliot et al., 2017). We review three alternative approaches to question-embedding predicates, i.e., the Proposition-to-Question reduction (Uegaki, 2015, 2016), the uniform approach (Ciardelli et al., 2013) and the ambiguity approach (George, 2011), and compare them with respect to how they fare with the two problems for the Question-to-Proposition reduction.

Keywords question-embedding predicates, responsive predicates, complementation, know-wh, semantics of interrogatives, Inquisitive Semantics

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1 Introduction: responsive predicates

This paper surveys approaches to the issue concerning the compositional semantics of pairs of sentences like (1):

(1) a. John {**knows/realized/reported**} that Ann left. (declarative complement)
  b. John {**knows/realized/reported**} who left. (interrogative complement)

These examples show that the same predicate (i.e., *know*, *realize* and *report*) can embed either a declarative complement or an interrogative complement. Following Lahiri (2002), I refer to the predicates that show the complementation pattern exemplified in (1) as RESPONSIVE PREDICATES. Responsive predicates pose a non-trivial puzzle for the compositional semantics of complementation, in view of the following two fairly standard hypotheses:

(2) **Semantic distinction of clause types** Declarative complements and interrogative complements denote semantic objects with distinct types.

Non-ambiguity Responsive predicates are unambiguous between its declarative-embedding use and its interrogative-embedding use.

Of these two hypotheses, the non-ambiguity of responsive predicates is not only intuitively plausible but also empirically motivated by the fact that an interrogative and declarative complement can be coordinated under a single responsive predicate, as in (3):

(3) John **knows/realized/reported** which girl left and that none of the boys left.

If the complement clauses here are really coordinated, *know/realize/report* must have meanings that are compatible with both interrogative and declarative complements. Furthermore, even if (3) is somehow derived from two occurrences of the embedding predicate, as in (4), it has to be explained why the second occurrence of the predicate can be elided, if the two occurrences have different lexical meanings.

(4) John **knows/realized/reported** which girl left, and ~~he~~ **~~knows/realized/reported~~** that none of the boys left.

Similar argument comes from the possibility of gapping as exemplified below:

(5) John **knows/realized/reported** that Ann left and Bill **~~knows/realized/reported~~** which other girls left.

In addition, the declarative and interrogative uses of responsive predicates are generally expressed by the same lexical item not just in English, but also in genetically unrelated languages, e.g. Japanese, as demonstrated in (6) with the three responsive predicates *sitteiru* 'know', *kizuku* 'realize' and *hookoku-suru* 'report'.

(6) a. John-wa dono onnanoko-ga kita-ka **sitteiru/kizuita/hookoku-sita**.
  John-TOP which girl-NOM came-Q know/realized/reported
  'John knows/realized/reported which girl came.'
  b. John-wa Mary-ga kita-to **sitteiru/kizuita/hookoku-sita**.
  John-TOP Mary-NOM came-DECL know/realized/reported
  'John knows/realized/reported that Mary girl came.'

The problem then is how to account for the complementation pattern of responsive predicates given these empirical motivations for their non-ambiguity, while considering the plausibility of the semantic distinction of declarative and interrogative clause types.

In this paper, I will survey four approaches to this problem in the literature. Two of the approaches adhere to the basic hypotheses in (2) and reconcile their conflict by positing an operation that turns one kind of semantic object into the other. Depending the *direction* of this extra semantic operation, these two approaches will be called Question-to-Proposition reduction approach (or Q-to-P reduction) and Proposition-to-Question reduction approach (or P-to-Q reduction). On the other hand, the other two approaches each reject one of the hypotheses in (2). The one that rejects the non-ambiguity hypothesis is the ambiguity approach while the one that rejects the semantic distinction of clause types will be referred to as the uniform approach.

The structure of the paper will be the following. I will first present characteristics of the most traditional approach to question-embedding, namely the Question-to-Proposition reduction approach, together with concrete examples of compositional implementations in the literature (§2). After this, I will present two arguments against the Q-to-P reduction (§3). These arguments concern 'non-reducibility' of certain presuppositional responsive predicates discussed by George (2011) and interpretation of Predicates of Relevance, such as *be relevant*, *matter* and *care* (Elliot et al., 2017). I will then introduce three alternative approaches, i.e., the Proposition-to-Question reduction, the uniform approach and the ambiguity approach, and compare them in view of whether they can deal with the two problems for the Question-to-Proposition reduction (§5). Finally, in §6, I discuss how the approaches can be compared in view of restrictions they place on the space of possible responsive predicate denotations.

2 Question-to-Proposition reduction

The Q-to-P reduction approach is the most traditional approach to the semantics of responsive predicates. This approach dates back at least to Hintikka (1962) and is also adopted by most of subsequent analyses of question-embedding in the formal semantic literature, such as Karttunen (1977); Heim (1994); Dayal (1996); Beck and Rullmann (1999); Lahiri (2002), and more recently by Spector and Egré (2015) and Cremers (2016).[1] The characteristics of the Q-to-P reduction approach can be summarized as follows:

(7) **The Question-to-Proposition reduction**

[1]Technically, Karttunen (1977) and Spector and Egré (2015) define two lexical entries for a responsive predicate, one with a proposition-taking denotation and the other with a question-taking denotation. Thus, prima facie, they might seem to fall under the ambiguity approach. However, I categorize them as the Q-to-P reduction approach since their theories include a general mechanism that derives a interrogative-embedding denotation from a declarative-embedding denotation. In other words, their analyses commit to what George (2011) calls the Q-to-P reducibility property discussed below, which I take to be a defining feature of the Q-to-P reduction. Similarly, I categorize Ginzburg's (1995) theory as an instance of the Q-to-P reduction. Although Ginzburg (1995) posits a type-theoretic distinction between the declarative-embedding denotation of a responsive predicate (which selects for either the fact-type or the proposition-type) and its interrogative-embedding denotation (which selects for the question-type), the mechanism of question-to-fact/proposition coercion in his theory effectively plays the role of the Q-to-P reduction.

- Responsive predicates semantically select for the denotation of the declarative complement, i.e., propositions.
- The compositional semantics involves a mechanism that reduces the denotation of an interrogative complement into a proposition.

Analyses within this approach differ in the exact formulation of the reduction mechanism. One of the prominent formulations employs an ANSWERHOOD OPERATOR, which maps the question meaning denoted by an interrogative complement to a specific 'answer' of the question (Heim, 1994; Dayal, 1996; Beck and Rullmann, 1999; Cremers, 2016). I will give a concrete example of such an operator shortly below, but doing this requires explicit assumptions about (a) the semantics of interrogative complements and (b) what counts as an 'answer' to a question expressed by an interrogative complement.

As for (a), we follow Hamblin (1973) and assume that interrogative complements express *sets of propositions* that are obtained by, roughly, varying the argument corresponding to the *wh*-item. For example, the question expressed by *who left* is the set of propositions, as in the following:[2]

(8) $[\![\text{who left}]\!] = \{\, p \mid \exists x[p = \lambda w'.\mathbf{left}_{w'}(x)]\,\}$
$= \{\,\text{'Ann left', 'Bill left', 'Carol left'}\ldots\}$

As for (b), the issue of what counts as an answer to a question concerns the notion of EXHAUSTIVITY, i.e., how much true information an answer must convey relative to the question meaning. In the literature, at least three levels of exhaustivity are discussed: MENTION-SOME, WEAK EXHAUSTIVITY and STRONG EXHAUSTIVITY. Answers having these different levels of exhaustivity correspond to the following propositions in the case of (8), in the world where only Ann and Bill left.:

(9) *Situation: Only Ann and Bill left.*
  a. **Mention-some answers**: 'Ann left', 'Bill left'
  b. **Weakly-exhaustive answer**: 'Ann left and Bill left'
  c. **Strongly-exhaustive answer**: 'Ann left and Bill left, and no one else left.'

Comparing different theoretical accounts of exhaustivity in embedded questions requires a space for another survey article. Thus, here, I will gloss over this issue and assume that the default reading of embedded questions involves the *weakly-exhaustive* answer, following Karttunen (1977); Heim (1994); Dayal (1996); Klinedinst and Rothschild (2011) and Uegaki (2015). In addition to these works, see Groenendijk and Stokhof (1984); Beck and Rullmann (1999); George (2011); Xiang (2016); Theiler et al. (2018) for different overall treatments of exhaustivity in embedded questions.

With these assumptions in place, a concrete answerhood operator can be defined as follows.[3]

(10) $\mathbf{Ans}_w := \lambda Q_{\langle st,t\rangle}\!: \underline{\exists p \in Q[p(w)]}.\ \lambda w'_s.\ \forall p' \in Q[p'(w) \rightarrow p'(w')]$

[2]For reasons of space, I will not discuss the issue concerning the 'de re'/'de dicto' ambiguity of the *wh*-term. The interested reader is referred to the survey by Hagstrom (2003) and references cited therein.

[3]Following Heim and Kratzer (1998), I model presuppositions using domain restrictions on functions, written after the colon (':') in a lambda term with an underline. Truth conditions projected from presuppositions are also underlined.

This operator takes a question meaning as its input and outputs its weakly-exhaustive answer (i.e., the conjunction of all true propositions in the question meaning), presupposing that at least one proposition in the question meaning is true. Using this operator, we can analyze interrogative-embedding sentences as follows:

(11) a. $[\![\text{know}]\!]^w = \lambda p_{\langle s,t\rangle}\lambda x_e\text{: } \underline{p(w)}.\ \mathbf{know}_w(x,p)$

b. $[\![\text{John knows who left}]\!]^w = [\![\text{know}]\!]^w(\mathbf{Ans}_w([\![\text{who left}]\!]))(\mathbf{j})$
$= 1 \text{ iff } \underline{\exists x[\mathbf{left}_w(x)]} \wedge \mathbf{know}_w(\mathbf{j}, \mathbf{Ans}_w([\![\text{who left}]\!]))$

Under this analysis, the denotation of a responsive predicate, e.g., *know*, takes a proposition as its first argument. The question meaning is turned into a proposition by the **Ans**-operator, which is then fed to the proposition-taking denotation of the predicate.

Another implementation of reduction is seen in Spector and Egré (2015), who analyze interrogative-embedding examples in terms of existential quantification over propositions in the question meaning.[4] That is, they analyze an interrogative-embedding sentence as follows, glossing over some irrelevant details:

(12) $[\![\text{John knows who left}]\!]^w = 1 \text{ iff } \exists p[p \in [\![\text{who left}]\!] \wedge \mathbf{know}_w(\mathbf{j},p)]$

Lahiri (2002) proposes a yet another form of reduction mechanism, where an LF operation called INTERROGATIVE RAISING resolves the type-mismatch between the proposition-taking denotation of responsive predicates and the interrogative complement. These different forms of reduction make distinct predictions with respect to the interpretation of embedded questions, but such differences within the Q-to-P reduction is irrelevant for the purpose of this survey.

Note that this approach adheres to the two basic hypotheses in (2). Declarative and interrogative complements have distinct types of objects. In the formulation illustrated above, declarative complements denote *propositions* while interrogative complements denote *sets* of propositions. At the same time, responsive predicates are unambiguous between the declarative-embedding use and the interrogative-embedding use. They have a proposition-taking denotation, and the embedding of interrogative complements involve some form of reduction.

The discussion in the rest of the paper will center around the following two predictions of the Q-to-P reduction approach. To aid readability, I intentionally conflate variables in the object language and metalanguage.

(13) **Predictions of the Q-to-P reduction**

a. **Q-to-P Reducibility**: Let V be a responsive predicate. Then, for every entity-denoting term x and every interrogative complement Q, whether $\ulcorner x\ Vs\ Q \urcorner$ is true depends only on which declarative complements p are such that $\ulcorner x\ Vs\ p \urcorner$.

b. **Entailment Prediction**: Let V be a responsive predicate. Then, for every entity-denoting term x, every declarative complement p and interrogative complement Q, if $\ulcorner x\ Vs\ p \urcorner$ entails $R(x,p)$ for some relation R, then $\ulcorner x\ Vs\ Q \urcorner$ entails that there is a proposition $p' \in Q$ such that $R(x,p')$.

[4]Incidentally, this analysis is close to one of the first formal semantic analysis of 'knowing-who' by Hintikka (1962, 131), who analyzes the meaning of 'S knows who is P' as $\exists x[K_S(P(x))]$.

Simply put, the first prediction states that the truth conditions of an interrogative-embedding sentence with a responsive predicate can be paraphrased only in terms of declarative-embedding sentences with the same predicate. For example, the prediction states that whether $\ulcorner$*John knows which students left*$\urcorner$ is true depends only on what declarative clauses p are such that $\ulcorner$*John knows* $p$$\urcorner$ is true. On the other hand, the second prediction states how the interpretation of a declarative-embedding sentence has to be reflected in the interpretation of an interrogative-embedding sentence. If $\ulcorner$*John Vs* $p$$\urcorner$ entails that John is in a certain relationship to p, then $\ulcorner$*John Vs* $Q$$\urcorner$ must entail that there is a proposition $p' \in Q$ such that John has that relationship to p'. For example, we can see that the entailment concerning the subject's knowledge state in *know* conforms to this prediction. That is, $\ulcorner$*John knows* $p$$\urcorner$ entails that John's knowledge entails p, and $\ulcorner$*John knows* $Q$$\urcorner$ entails that some proposition in Q is such that John's knowledge entails that proposition. In the rest of the paper, we evaluate the viability of Q-to-P reduction as a general theory of responsive predicates by examining these two predictions.

3 Problems with the Question-to-Proposition reduction

The Q-to-P reduction approach introduced in the previous section has been the standard approach to question-embedding at least since Karttunen (1977). Moreover, it fares well with the standard view in epistemic logic after Hintikka (1962) that *know* is a modal operator applying to a proposition. However, in recent years, there have been a number of empirical counterarguments against the approach. In this section, I review two such arguments: one based on non-reducibility of presuppositional predicates, the other based on the so-called Predicates of Relevance.[5]

3.1 Non-reducibility of some presuppositional predicates

The first argument concerns the Q-to-P reducibility prediction in (13a). George (2011) points out that there are examples involving the responsive predicate *know* that go against (13a). The problematic example George describes involves a situation where two individuals have exactly the same set of propositional knowledge, but have different question-knowledge. The concrete example goes as follows.

(14) **Scenario for *know***

- Newstopia sells an Italian newspaper, but PaperWorld doesn't.
- John and Bill know that one can buy an Italian newspaper at Newstopia.
- John neither believes nor disbelieves that one can buy an Italian newspaper at PaperWorld.
- Bill wrongly believes that one can buy an Italian newspaper at PaperWorld.
- Otherwise, John and Bill have exactly the same beliefs.

[5] See Uegaki (2016) for another argument against the Q-to-P reduction based on nominal complements of attitude predicates.

(15) a. John knows where one can buy an Italian newspaper.
b. #Bill knows where one can buy an Italian newspaper.

In the scenario described in (14), sentence (15a) is intuitively true, but (15b) isn't.[6]

This is problematic for the Q-to-P reduction analysis of *know*. This is so since John and Bill have exactly the same set of relevant 'propositional' knowledge. That is, all sentences with the declarative-embedding *know* do not differ in truth values, regardless of whether *John* or *Bill* is the subject. Both sentences in (16) are true while both sentences in (17) are presupposition failures because of the factivity of *know*.

(16) a. John knows that one can buy an Italian newspaper at Newstopia.
b. Bill knows that one can buy an Italian newspaper at Newstopia.

(17) a. John knows that one can buy an Italian newspaper at PaperWorld.
b. Bill knows that one can buy an Italian newspaper at PaperWorld.

Thus, if question-knowledge can be reduced to propositional knowledge, John and Bill should have the same question-knowledge. The fact that (15a) and (15b) differ in the truth values speaks against this prediction.[7]

One way to describe the data above is that the question-embedding meaning of *know* is sensitive to the subject's false belief (Theiler et al., 2018; Xiang, 2016). If the subject believes a false proposition in the question meaning, an interrogative-embedding sentence involving factive predicates like *know* does not sound true. However, it turns out that the phenomenon is not restricted to the 'false-belief' sensitivity of factive predicates. We can observe a similar phenomenon with the predicate *agree* in the construction *A agrees with B on....* This is shown in the following example:

(18) **Scenario for *agree*.** In addition to the scenario for *know* in (15), we further assume the following: Sue believes that Newstopia sells an Italian newspaper, but PaperWorld doesn't.

(19) a. John agrees with Sue on where one can buy an Italian newspaper.
b. #Bill agrees with Sue on where one can buy an Italian newspaper.

The contrast in the judgment in (19) is problematic for the Q-to-P reduction. This is so since truth values of sentences of the form ⌜*John/Bill agrees with Sue that p*⌝ doesn't differentiate John and Bill in the scenario. Both sentences in (20) are true while both sentences in (21) are presupposition failures, given that ⌜*x agrees with Sue that p*⌝ presupposes that Sue believes that *p*.

[6] Some native speakers express that the judgment depends on the proportion of the false propositions believed by Bill with respect to the set of all propositions in the question meaning. For example, even if (15b) sounds false in the given situation to these speakers, they feel that the falsity is not clear in a situation where Bill knows a hundred stores that sell Italian newspapers and incorrectly believes for just one store that it does. Note, however, that this judgment is not a problem for the argument here as long as there is a situation in which these speakers too find a contrast in (15).

[7] George's (2011) example above is based on examples that intuitively have a MENTION-SOME interpretation of the complement. Spector (2005), on the other hand, reports a non-reductive judgment of question-embedding *know* embedding a complement with a weakly-exhaustive interpretation (see also Berman 1991, §4.3.2, Groenendijk and Stokhof 1984, 180 for similar observations). See (9) for the distinction between the two interpretations.

(20) a. John agrees with Sue that one can buy an Italian newspaper at Newstopia.
b. Bill agrees with Sue that one can buy an Italian newspaper at Newstopia.

(21) a. John agrees with Sue that one can buy an Italian newspaper at PaperWorld.
b. Bill agrees with Sue that one can buy an Italian newspaper at PaperWorld.

What the above example involving *agree* shows is that the empirical range of predicates that exhibit the non-reductive interpretation of question-embedding is broader than just factive predicates, and includes non-factive presuppositional predicates like *agree (with)*. The general diagnosis of the examples would then be the following: sentences involving certain[8] presuppositional responsive predicates with an embedded question are not true if the subject believes a proposition in the embedded question meaning that does *not* satisfy the presupposition. The existence of such systematic counterexamples is a problem for the Q-to-P reduction approach to responsive predicates.

There have been attempts to analyze the kind of non-reductive examples discussed in this section *within* the Q-to-P reduction approach employing the mechanism of exhaustification (Cremers 2016, cf. Uegaki 2015), drawing on the analysis of 'intermediate exhaustivity' by Klinedinst and Rothschild (2011), or decomposition of a lexical meaning into the assertive and the presuppositional component (Spector and Egré, 2015). Due to space limitations, we are unable to detail such analyses here. Interested readers are referred to the cited works.

3.2 Predicates of relevance

The second problem for the Q-to-P reduction concerns the behavior of PREDICATES OF RELEVANCE (PoRs) (Elliot et al., 2017). PoRs are responsive predicates in that they are compatible with both declarative and interrogative complements, as shown in (22).

(22) a. John cares which students left.
b. John cares that Mary left.

What is going to be crucial is the presuppositions of these examples. Notice that the declarative embedding use in (22b) presupposes that John believes that Mary left. In contrast, (22a) does *not* presuppose that there is a student such that John believes that he/she left.

Note that this is a counterexample to the Entailment Prediction of the Q-to-P reduction in (13b) above. The observation about (22) suggests that $\ulcorner$*x cares that p*$\urcorner$ presupposes that x believes that p, but $\ulcorner$*x cares Q*$\urcorner$ does not presuppose that there is a proposition $p' \in Q$ such that x believes p' . Thus, the observed difference between (22a) and (22b) is difficult to capture under the Q-to-P reduction approach. Under the approach, given the Entailment Prediction, (22a) is incorrectly predicted to presuppose that there is a student such that John believes that he/she left.

[8] I do not generalize this diagnosis to all presuppositional responsive predicates since it is not clear if emotive factives such as *surprise* and *annoy* exhibit non-reducibility.

4 Alternative approaches to responsive predicates

In the last section, we saw two empirical phenomena that are problematic for the Q-to-P reduction approach to responsive predicates: (i) non-reductive interpretations of certain presuppositional responsive predicates and (ii) presuppositions of Predicates of Relevance.

In this section, I will introduce three alternative approaches to the semantics of responsive predicates, i.e., the PROPOSITION-TO-QUESTION REDUCTION (P-TO-Q REDUCTION) approach, the UNIFORM approach, and the AMBIGUITY approach. After outlining characteristics of the three approaches together with short reviews of a concrete analysis from the literature, I will compare the three approaches by considering how they would deal with the two phenomena examined in the previous section.

4.1 Proposition-to-Question reduction

As the name suggests, the P-to-Q reduction approach can be conceived of as the mirror image of the Q-to-P reduction approach. Both approaches posit reduction mechanisms to deal with the complementation pattern of responsive predicates, but in different directions. Unlike the Q-to-P reduction outlined in §2, the P-to-Q reduction assumes that the basic denotation of a responsive predicate is *question*-taking and posits an operation that turns a proposition denoted by a declarative complement into a question. This way, the interrogative-embedding use of responsive predicates is straightforwardly analyzed with their denotation while their declarative-embedding use is analyzed as involving the P-to-Q reduction mechanism. Also, note that the approach adheres to the two basic hypotheses discussed in the beginning of the paper: semantic distinction of clause types and the non-ambiguity of responsive predicates.

Uegaki (2015, 2016) proposes an instance of this approach. According to the analysis, responsive predicates like *know* take a question qua a proposition-set as its first argument:

(23) $[\![\text{know}]\!]^w = \lambda Q_{\langle st,t\rangle}\text{: } \underline{\exists p \in Q[p(w)]}.\lambda x.\ \mathbf{know}_w(x, \mathbf{Ans}_w(Q))$

Such a denotation can be directly combined with a question meaning, as follows:

(24) $[\![\text{John knows who left}]\!]^w = [\![\text{know}]\!]^w([\![\text{who left}]\!])(\mathbf{j})$
$= 1 \text{ iff } \underline{\exists x[\mathbf{left}_w(x)]} \wedge \mathbf{know}_w(\mathbf{j}, \mathbf{Ans}_w([\![\text{who left}]\!])$

As the reader can verify, the truth conditions in (24) are exactly the same as what is predicted in the Q-to-P reduction in (11b) above.

Declarative-embedding sentences involve a reduction from propositions to questions. The is carried out by the **Ident**-type shifter proposed in the domain of NP-interpretation by Partee (1986):

(25) $\mathbf{Ident} = \lambda p_{\langle s,t\rangle}.\{p\}$ (after Partee 1986)

With this type-shifter, a declarative complement can be turned into a question-type object, which in turn serves as an argument of the predicate *know* in (23). As a result, we can derive the intuitive interpretation of *know-that* sentences. This is illustrated in the derivation of the truth conditions of the following sentence:

(26) $[\![\text{John knows [that Mary left]}]\!]^w = [\![\text{know}]\!]^w(\mathbf{Ident}(\lambda w'.\mathbf{left}_{w'}(\mathbf{m})))(\mathbf{j})$
$= 1 \text{ iff } \underline{\mathbf{left}_w(\mathbf{m})} \wedge \mathbf{know}_w(\mathbf{j}, \mathbf{Ans}_w(\{\lambda w'.\mathbf{left}_{w'}(\mathbf{m})\}))$
$= 1 \text{ iff } \underline{\mathbf{left}_w(\mathbf{m})} \wedge \mathbf{know}_w(\mathbf{j}, \lambda w'.\mathbf{left}_{w'}(\mathbf{m}))$

Here, the presupposition triggered by *know* in (23) that the question contains a true answer boils down to factivity, capturing the factive presupposition of *know-that*. The last step of (26) is guaranteed by the fact that, if $\mathbf{left}_w(\mathbf{m})$ is true, $\mathbf{Ans}_w(\{\lambda w'.\mathbf{left}_{w'}(\mathbf{m})\})$ is defined and is identical to the proposition $\lambda w'.\mathbf{left}_{w'}(\mathbf{m})$.

4.2 Uniformity

In contrast to the two reduction approaches, which assume the semantic distinction of clause types, the uniform approach argues that declarative and interrogative complements have the *same* semantic type. Under this approach, then, the selectional restriction of responsive predicates does not pose a problem. Rather, it is something that is *expected* from the semantic uniformity of declarative and interrogative complements, without the involvement of any extra reduction mechanism.

Inquisitive Semantics (Ciardelli et al., 2013) offers a concrete analysis of responsive predicates in the uniform approach (Theiler, 2014; Ciardelli and Roelofsen, 2015; Theiler et al., 2018).[9] According to inquisitive semantics, both declarative and interrogative clauses denote a set of propositions. Here, I will illustrate the treatment in a version of inquisitive semantics without the property of downward closure (referred to as possibility semantics by Ciardelli et al. 2017) in order to make the comparison with other approaches transparent.[10]

In this semantics, both declarative and interrogative complements express sets of propositions, as follows (see Ciardelli et al. 2017 for compositional derivations):

(27) a. $[\![\text{that Mary left}]\!] = \{\, \lambda w'.\mathbf{left}_{w'}(\mathbf{m}) \,\}$
b. $[\![\text{who left}]\!] = \{\, p \mid \exists x[p = \lambda w'.\mathbf{left}_{w'}(x)] \,\}$

Given this uniform semantics for complements, the complementation pattern of responsive predicates can be analyzed with the denotation for *know* we introduced in the discussion of P-to-Q reduction analysis above. I repeat the denotation for *know* below:

(28) $[\![\text{know}]\!]^w = \lambda Q_{\langle st,t\rangle}\text{: } \underline{\exists p \in Q[p(w)]}.\lambda x.\ \mathbf{know}_w(x, \mathbf{Ans}_w(Q))$ (= (23))

By simply applying this predicate denotation to the complements in (27), the truth conditions of *know-wh* and *know-that* sentences are derived in almost exactly the same way as in the P-to-Q reduction approach. The difference between the uniform approach and the P-to-Q reduction approach lies in whether the analysis assumes the set of propositions to

[9] Groenendijk and Stokhof (1984) can be considered as a predecessor of the uniform approach since, for them, both declarative and interrogative complements express propositional concepts, which are selected by responsive predicates such as *guess*. Their treatment of veridical predicates such as *know*, however, involves Q-to-P reduction in the form of 'extensionalization', and thus is unable to deal with the problem of non-reducibility.

[10] See Ciardelli et al. (2017) for a comparison of the semantics with and without the downward closure, and theoretical and empirical motivations for preferring the former.

be the basic semantic type of a declarative complement. In the P-to-Q reduction, a declarative complement denotes a proposition *simpliciter*. Thus, an extra reduction mechanism is needed to convert the proposition into a set of propositions. On the other hand, in the uniformity analysis, declarative complements denote a set of propositions, just like interrogative complements do. Therefore, there is no need for an extra reduction operation. Because of this difference, the P-to-Q reduction and the uniform approach offer distinct analytical possibilities for treating predicates that only embed declarative complements (e.g., *believe*). The interested reader is referred to Uegaki (2016) and Theiler et al. (2018).

4.3 Ambiguity

Instead of rejecting the semantic distinction of declarative and interrogative clause types, the ambiguity approach rejects the assumption that responsive predicates are non-ambiguous. Thus, the ambiguity approach posits distinct denotations for the proposition-taking and question-taking denotations of responsive predicates.

A potential problem with the ambiguity approach in general is the intuitive connection between the declarative-embedding use and the interrogative-embedding use of responsive predicates. As pointed out in the beginning of this survey, this intuition is also empirically motivated by data involving coordinations (see (3-5)).

George (2011) addresses this problem by proposing the TWIN RELATIONS THEORY of responsive predicates. According to this theory, every responsive predicate V is associated in the lexicon with two meaning components V_1 and V_2. Given these two meaning components, there are general schemata that specify the question-taking denotation V_Q and the proposition-taking denotation V_P. Thus, the analysis captures the intuitive semantic connection between the question-taking denotation and the proposition-taking denotation in terms of their relations to the same semantic core, the two relations V_1 and V_2.[11]

For example, the responsive predicates *know* is associated with the two meaning components as shown below.

(29) a. $\mathbf{know}_1 := \lambda p_{\langle s,t\rangle}\lambda x\lambda w\text{: } \underline{p(w)}.\ \mathbf{know}_w(x,p)$

b. $\mathbf{know}_2 := \lambda p_{\langle s,t\rangle}\lambda x\lambda w.\ \mathbf{believe}_w(x,p) \to p(w)$

These meaning components are used to derive the predicates' question-taking and proposition-taking denotations according to the following general schemata (slightly adapted from George 2011 to make the comparison with other approaches transparent).

(30) a. $V_Q := \lambda Q_{\langle st,t\rangle}\lambda x_e\lambda w.\begin{pmatrix} V_1(\mathbf{Ans}_w(Q))(x)(w)\wedge \\ \forall p' \in Q[V_2(p')(x)(w)] \end{pmatrix}$

b. $V_P := \lambda p_{\langle s,t\rangle}\lambda x\lambda w.V_1(p)(x)(w) \wedge V_2(p)(x)(w)$

Instantiating the schemata with $\mathbf{know}_1$ and $\mathbf{know}_2$, we get the following denotations of *know*, one question-taking and the other proposition-taking.[12]

[11] The theory would have to be supplemented with a concrete theory of gapping to account for the fact that the gapping in (5) is licensed given the semantic relationship between V_Q and V_P.

[12] I assume that the factive presupposition of $\mathbf{know}_1$ is existentially projected in $\mathbf{know}_Q$.

(31) a. $\mathbf{know}_Q = \lambda Q_{\langle st,t\rangle}\lambda x\lambda w : \underline{\exists p \in Q[p(w)]}.\left(\begin{array}{c}\mathbf{know}_w(x, \mathbf{Ans}_w(Q))\wedge \\ \forall p' \in Q[\mathbf{believe}_w(x,p') \rightarrow p'(w)]\end{array}\right)$

b. $\mathbf{know}_P = \lambda p_{\langle s,t\rangle}\lambda x\lambda w$: $\underline{p(w)}$. $\mathbf{know}_w(x,p)$

A substantial feature of the analysis is that the denotation already incorporates a solution to the problem of non-reducibility of *know* discussed in §3.1. The denotation in (31a) predicts that ⌜*Bill knows Q*⌝ would be true only if all propositions in Q that Bill believes are true. This is obviously not the case in George's scenario in (14). Thus, the analysis correctly captures the fact that *know* is sensitive to the subject's false beliefs. In fact, George's (2011) ambiguity theory is devised as a direct reaction to the non-reducibility of the question-embedding denotation of some responsive predicates.

5 Comparing the non-traditional approaches

How do the three non-traditional approaches reviewed in the previous section fare with the two problems for the Q-to-P reduction approach? In this section, I go through the two problematic phenomena and examine if the three approaches have resources to account for them.

5.1 Non-reducibility of presuppositional predicates

5.1.1 P-to-Q reduction and uniformity

Both the P-to-Q reduction approach and the uniform approach have a straightforward way to capture the Q-to-P non-reducibility of presuppositional responsive predicates: the denotation of the predicates can simply include the condition that the subject cannot believe any proposition that fails the presupposition of the predicate. For example, *know* and *agree with* in such accounts would look like the following:

(32) a. $[\![\text{know}]\!]^w = \lambda Q_{\langle st,t\rangle}$: $\underline{\exists p \in Q[p(w)]}.\lambda x.\left(\begin{array}{c}\mathbf{know}_w(x, \mathbf{Ans}_w(Q))\wedge \\ \forall p' \in Q[\mathbf{believe}_w(x,p') \rightarrow p'(w)]\end{array}\right)$

b. $[\![\text{agree with}]\!]^w = \lambda y\lambda Q_{\langle st,t\rangle}$: $\underline{\exists p \in Q[\mathbf{believe}_w(y,p)]}.\lambda x.$
$$\left(\begin{array}{c}\mathbf{know}_w(x, \lambda w'.\, \forall p' \in Q[\mathbf{believe}_w(y,p') \rightarrow p'(w')])\wedge \\ \forall p'' \in Q[\mathbf{believe}_w(x,p'') \rightarrow \mathbf{believe}_w(y,p'')]\end{array}\right)$$

The second line of the truth conditions that the denotation of *know* in (32) returns states that all propositions in the question meaning that the subject believes are true. In (32b), the condition is modified so that all propositions in the question meaning that the subject believes are also believed by the comitative ('with') argument.[13] These conditions adequately capture the relevant conditions that are Q-to-P non-reducible.

[13] In footnote 6, I discussed native speaker judgments that are sensitive to the *proportion* of false propositions (or propositions that are not believed by the 'with'-argument) in the set of relevant propositions believed by the subject. Whatever the exact condition of such a proportion is, it can be encoded in the question-taking meaning of the relevant predicates, by minimally modifying the denotations in (32) (e.g., in the case of *know*, by the condition that *most* of the relevant propositions that the subject believes have to be true).

Also, note that there is no distinction between the P-to-Q reduction approach and the uniform approach with regard to the solution to this problem. This is so since the only difference between the two approaches concerns the treatment of declarative complements, and what the solution above hinges on is the question-taking semantics for responsive predicates, which the P-to-Q reduction and the uniform approach share.

5.1.2 Ambiguity approach

George's (2011) ambiguity approach was proposed as a response to the observation of the Q-to-P non-reducibility of factive predicates, and we have already seen in §4.3 how his analysis would account for the Q-to-P non-reducibility of *know*. Here, I will simply show that the analysis can be extended to *agree* by defining appropriate meaning components **agree-with**$_1$ and **agree-with**$_2$ as follows:

(33) a. $\textbf{agree-with}_1 := \lambda y \lambda p_{\langle s,t\rangle} \lambda x \lambda w\text{: } \underline{\textbf{believe}_w(y,p)}.\ \textbf{believe}_w(y,p) \wedge \textbf{believe}_w(x,p)$

b. $\textbf{agree-with}_2 := \lambda y \lambda p_{\langle s,t\rangle} \lambda x \lambda w.\ \textbf{believe}_w(x,p) \rightarrow \textbf{believe}_w(y,p)$

The condition requiring that the subject believes no proposition that fails the presupposition of (the declarative-embedding version of) the predicate is contributed by **agree-with**$_2$. In sum, just like the the P-to-Q reduction approach and the uniform approach, George's (2011) ambiguity approach has resources to capture the Q-to-P non-reducibility of *know* and *agree*.

5.2 Predicates of Relevance

Next, we turn to how the three approaches deal with Predicates of Relevance (PoRs) like *care*, *be relevant* and *matter*. The relevant examples with *care* are repeated below from §3.2.

(22) a. John cares which students left.

b. John cares that Mary left.

The problem lies in the presupposition of (22a): it presupposes that John believes that some student left, but not that there is a student such that he believes he/she left. This cannot be accurately described in a Q-to-P reduction approach. Given the Entailment Prediction (13b) and the fact that the declarative-embedding version (22b) presupposes that John believes that Mary left, the Q-to-P reduction predicts the interrogative-embedding version (22a) to presuppose that there is a student such that John believes that he/she left.

5.2.1 P-to-Q reduction and uniformity

The P-to-Q reduction approach and the uniform approach can accurately account for the presupposition of (22a) by making the denotation of *care* refer to its question argument itself. For example, the denotation of *care* can be analyzed as follows:

(34) $[\![\text{care}]\!]^w = \lambda Q_{\langle st,t\rangle}\text{: } \underline{\exists p \in Q[p(w')]}.\ \lambda x : \underline{\textbf{believe}_w(x, \lambda w'.\, \exists p' \in Q[p'(w')])}.\ \textbf{care}_w(x,Q)$

The presupposition in the second underlined part above states that x believes that some answer of the embedded question is true. This captures the presuppositions of (22a): it only presupposes that John believes that some student left, not that there is a student such that John believes that he/she left.

The denotation for *care* in (34) correctly captures the presuppositions of the declarative-embedding sentence in (22b) as well, given that the P-to-Q reduction approach and the uniform approach assign a singleton-set meaning to declarative complements, either through a reduction operation or as the basic meaning of the complement itself, as in (35).

(35) a. $\textbf{Ident}\ ([\![\text{that Mary left}]\!]) = \{\lambda w'.\textbf{left}_{w'}(\textbf{m})\}$ (P-to-Q reduction)

b. $[\![\text{that Mary left}]\!] = \{\lambda w'.\textbf{left}_{w'}(\textbf{m})\}$ (uniformity)

(36) $[\![(22\text{b})]\!]^w = 1$ iff $\underline{\textbf{left}_w(\textbf{m}) \wedge \textbf{believe}_w(\textbf{j}, \lambda w'.\textbf{left}_{w'}(\textbf{m}))} \wedge \textbf{care}_w(\textbf{j}, \{\lambda w'.\textbf{left}_{w'}(\textbf{m})\})$

Since a belief that some proposition in a singleton-set question is true is equivalent to the belief that the unique propositional member of the question is true, the second presupposition of *care* in (34) boils down to the presupposition that the subject believes the complement.

5.2.2 Ambiguity approach

How would the ambiguity approach deal with PoRs? Interestingly, there is no obvious way in which the approach can capture the problematic presuppositions of PoRs.

To see how George (2011) would deal with PoRs, let us start with the predicted denotations of the question-taking $\textbf{care}_Q$ and the proposition-taking $\textbf{care}_P$ according to his schema:

(37) a. $\textbf{care}_Q = \lambda Q_{\langle st,t\rangle}\lambda x_e \lambda w. \left(\begin{array}{l} \textbf{care}_1(\textbf{Ans}_w(Q))(x)(w) \wedge \\ \forall p' \in Q[\textbf{care}_2(p')(x)(w)] \end{array} \right)$

b. $\textbf{care}_P = \lambda p_{\langle s,t\rangle}\lambda x \lambda w.\textbf{care}_1(p)(x)(w) \wedge \textbf{care}_2(p)(x)(w)$

Of course, the content of these meanings are still unclear unless $\textbf{care}_1$ and $\textbf{care}_2$ are substantiated. However, we already know at this point that the belief presupposition of *care-that*—that the subject believes the complement—has to be encoded in $\textbf{care}_1$ or $\textbf{care}_2$ in (37b). But then, either case, $\textbf{care}_Q(Q)(x)(w)$ is predicted to entail that, for some proposition $p \in Q$, x believes p. Here is why: if $\textbf{care}_1$ triggers the belief presupposition, given the first line of (37a), $\textbf{care}_Q(Q)(x)(w)$ would be true only if there is some proposition in Q that is believed by x in w; On the other hand, if $\textbf{care}_2$ triggers the belief presupposition, given the second line of (37a), $\textbf{care}_Q(Q)(x)(w)$ would be true only if all propositions in Q are believed by x in w. Thus, whether the belief presupposition is encoded in $\textbf{care}_1$ or in $\textbf{care}_2$, $\textbf{care}_Q(Q)(x)(w)$ would entail that there is a proposition in Q that is believed by x in w. What we see here is that the predicted belief presupposition of the question-embedding *care* in George's (2011) theory is too strong, just as in the case of Q-to-P reduction approach.

6 Constraints on the denotations of responsive predicates

In addition to the empirical considerations made in the previous sections, we can compare the approaches based on the *restrictiveness* of theories, i.e., whether each approach places a reasonable constraint on the space of possible denotations of responsive predicates. Spector and Egré (2015) discuss this point, using the fictional responsive predicate **shknow*, which means 'know' in declarative-embedding and 'wonder' in interrogative-embedding. They argue that a semantic theory of responsive predicates should be able to explain why it is hard to imagine a language having **shknow* in its lexicon.

Under the Q-to-P reduction, *shknow* is impossible because $\ulcorner x$ *shknows* $Q\urcorner$ would be analyzed as $[\![\text{shknow}]\!]^w(\mathbf{Ans}_w(Q))(x)$ in the Q-to-P reduction, which in turn would mean 'x knows $\mathbf{Ans}_w(Q)$' instead of 'x wonders Q'. George's (2011) twin relations theory also makes it impossible to define *shknow*. On the other hand, it is *possible* to define *shknow* under the P-to-Q reduction or the uniform approach, as follows:

(38) $$[\![\text{*shknow}]\!]^w = \lambda Q_{\langle st,t\rangle}\lambda x.\begin{pmatrix} |Q| = 1 \rightarrow \exists p \in Q[\mathbf{know}_w(x,p)]\wedge \\ |Q| \neq 1 \rightarrow \mathbf{wonder}_w(x,Q) \end{pmatrix}$$

What this means is that the Q-to-P reduction/uniform approaches *by themselves* are not restricted enough to rule out the unrealistic predicate *shknow* (George, 2011, §4.5.2).

This said, it is possible to posit additional constraints on responsive predicate denotations in the Q-to-P reduction/uniform approaches. One possibility suggested in Uegaki (2015) is to postulate a general lexical-semantic format for responsive predicates, such as the following:

(39) For every responsive predicate V of type $\langle\langle st,t\rangle,\langle e,t\rangle\rangle$ and every world w, there is an entity-question relation $\mathbf{P}$ and an entity-proposition relations $\mathbf{R}$ and $\mathbf{R'}$ such that:[14] $[\![\text{V}]\!]^w = \lambda Q_{\langle st,t\rangle}\lambda x_e$: $\underline{\mathbf{P}(x,Q)}$. $\mathbf{R}(x,\mathbf{Ans}_w(Q)) \wedge \forall p \in Q[\mathbf{R}'(x,p) \rightarrow p(w)]$

This constraint states that the assertive component of the meaning of $\ulcorner x\ Vs\ Q\urcorner$ can always be paraphrased into the conjunction of a relation between x and $\mathbf{Ans}_w(Q)$ and the 'false-belief' sensitivity. This constraint successfully rules out **shknow* since a denotation following this format cannot be sensitive to the cardinality of the question meaning in its assertive component. Theiler et al. (2018, §6) also propose further constraints on the denotations of responsive predicates within the uniform approach. To the extent that it *is* possible to posit feasible constraints on the denotation of responsive predicates in the P-to-Q reduction/uniform approaches, the unrestricted nature of the approaches themselves does not provide a strong argument against them.

It is worth noting that the issue here is reminiscent of the constraints on generalized quantifier denotations (Barwise and Cooper, 1981; Keenan and Stavi, 1986). Natural languages lexicalize only a small subset of meanings that can in principle be expressed as a generalized quantifier. The generalized quantifier theory has sought to formulate empirically feasible constraints on quantifier denotations (e.g., conservativity). At the same time, researchers have investigated the question of *why* such constraints exist from computational and learnability standpoints (e.g., Hunter and Lidz, 2013; Steinert-Threlkeld

[14] Here, one can furthermore state that the relation $\mathbf{R'}$ is a 'non-factive counterpart' of $\mathbf{R}$, following the approach by Spector and Egré (2015).

	Q-to-P reducibility	Entailment Prediction
Q-to-P reduction	Yes	Yes
P-to-Q reduction	No	No
Uniformity	No	No
Ambiguity (esp. George 2011)	No	Yes

Table 1: Comparison of the four approaches w.r.t. whether they make the two problematic predictions: Q-to-P reducibility and Entailment Prediction

and Szymanik, 2018). Following the lead of research in this domain, an imminent task for the theory of responsive predicates is to discover empirically feasible constraints on the denotation of responsive predicates, and seek explanations for the existence of such constraints.

7 Conclusions

In this survey, we reviewed the traditional Q-to-P reduction approach to the semantics of responsive predicates, as well as three non-traditional approaches. The latter three approaches, i.e., the P-to-Q reduction approach, the uniform approach and the ambiguity approach, were compared in view of how they would treat the two phenomena that pose problems for the Q-to-P reduction approach. The non-reducibility of presuppositional predicates can be accounted for in all three approaches by encoding the appropriate conditions in the lexical denotations (or meaning cores) of relevant predicates. On the other hand, when it comes to the other problem with the traditional approach, i.e., Predicates of Relevance, it turns out that only the P-to-Q reduction and the uniform approach, but not the ambiguity approach, have necessary resources to account for their behavior. In Table 1, the comparison is summarized in terms of whether a theory shares the two problematic predictions, i.e., Q-to-P reducibility and the Entailment Prediction, with the Q-to-P reduction approach.

Although the current survey has been mostly concerned with the behavior of English responsive predicates, it is evident that in-depth cross-linguistic investigation of the lexical semantics of responsive predicates sheds additional light on the debate. For example, Roberts (2017) claims that the Estonian verb *mõtlema*—whose meaning is close to 'wonder' when it embeds an interrogative complement while it is close to 'think' when it embeds a declarative complement—can be adequately analyzed only under the P-to-Q reduction/uniform approaches to responsive predicates. At the same time, as discussed in §6, whichever approaches that turn out to be cross-linguistically empirically adequate should be evaluated in view of their predictive powers, in particular, how they can explain cross-linguistically stable generalizations about the interpretations of responsive predicates.

Finally, theories of responsive predicates can also be assessed in view of their predictions concerning the selectional restrictions of other clause-embedding predicates, such as those that only embed interrogative complements (e.g., *wonder*, *inquire*) and those that only embed declarative complements (e.g., *believe*, *hope*). The selectional restrictions of these predicates is an active domain of research in the current semantic literature. In particular, Uegaki (2015, 2016) and Ciardelli and Roelofsen (2015) explain why *wonder* cannot embed declarative complements, based on the following line of analysis of $\ulcorner x$ wonders $Q\urcorner$:

(40) $[\![\text{wonder}]\!]^w(Q)(x) = 1$ only if

  (i) there is no $p \in Q$ such that x believes p

  (ii) x believes that there is some $p' \in Q$ that is true.

This semantics predicts that $\ulcorner x$ wonders that $p\urcorner$ results in a systematic contradiction under the P-to-Q reduction/uniform approach since the two conditions in (40) contradict each other if $Q = \{p\}$.

Theiler et al. (2018) furthermore deal with the selectional restrictions of verbs of dependency (e.g., *depend on*). Theiler et al. (2017) and Mayr (2017) explain the selectional restrictions of neg-raising attitude predicates (e.g., *believe*) and truth-evaluating predicates (e.g., *be true*), drawing on an earlier observation by Zuber (1982). Among non-neg-raising predicates, Uegaki and Sudo (2017, 2018) propose an explanation for the selectional restrictions of non-veridical preferential predicates (e.g., *hope*, *fear*) under the uniform approach.

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