A Cognitive Linguistics Approach to the Layperson's Understanding of Thermal Phenomena.

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1. Introduction

The central objective of this paper is to provide a language-based characterization of the English speaking layperson's idealized cognitive model (Lakoff, 1987) of thermal phenomena. The focus is on characterizing the core causal schema that can be expected to apply across all such phenomena. This work constitutes part of a larger study aimed at understanding the mechanism of conceptual change implicated in the transition from novice to expert in the domain of thermal physics (Wiser, 1995; Wiser & Amin, 1998). From the perspective of this larger study the analysis presented here contributes to the characterization of the layperson's understanding of thermal phenomena prior to formal instruction. I make use of the framework of cognitive linguistics (see e.g., Fauconnier, 1997; Lakoff, 1987; 1990; 1993; Langacker, 1987) to achieve this characterization. First, on the basis of an analysis of the syntactic contexts of the lexical items *heat* (as verb), *heat* (as noun) and the noun *temperature*, as well as metaphors implicit in everyday language, a conceptual schema can be characterized, what I will call the "minimal cognitive model" of thermal phenomena. Second, the process of "conceptual integration" (Fauconnier, 1997; Turner & Fauconnier, 1995), claimed to take place as discourse unfolds, provides a useful analytical tool for research on conceptual change in science. In particular, the framework of conceptual integration is applied to a student's conceptualization of the ontology of 'heat.' The suggestion will be that this conceptualization is not part of the layperson's minimal cognitive model of thermal phenomena but rather emerges in specific contexts of explanation.

2. A Language-based Characterization of the Minimal Cognitive Model of Thermal Phenomena.

In this section I examine aspects of the syntactic contexts of *heat* (as verb), *heat* (as noun) and *temperature*, and identify the corresponding semantic components that make up a minimal cognitive model of thermal phenomena. First, an argument is developed for classifying the verb *heat* as an accomplishment verb. This will suggest a basic semantic structure as a starting point for characterizing the minimal cognitive model sought. This is then followed by an analysis of the syntactic contexts of the nouns *heat* and *temperature* suggesting further semantic elaboration of the model.

2.1 The Syntax and Semantics of the Verb *Heat*

The starting point for this analysis is the classification of the verb *heat* with respect to the four verb classes: states, achievements, activities, and accomplishments (see Dowty, 1979). Dowty suggested that verbs can be classified in terms of the basic aspectual structure implicit in their meaning. That is, verbs in each of the four aspectual class share a small set of basic units of meaning such as DO, BECOME, and CAUSE. State verbs are specified simply in terms of what Dowty called "stative predicates" where some entity is specified as being in some state (e.g., knowing). Achievement verbs involve elaborating the basic predicate with some sense of coming into being or becoming (e.g., notice). Activity verbs involve elaboration of a predicated entity with some sense of agency or doing (e.g., walk). Finally, accomplishment verbs share an aspectual structure which can be thought of as an agentive act causing the becoming of some state. The following table[1] from Foley and Van Valin (1984) summarizes these four aspectual structures.

[1] The accomplishment verb entry is modified slightly for clarity.

Verb class	Logical structure
State	predicate (x)
Achievement	BECOME predicate (x)
Activity	DO (x, [predicate (x)])
Accomplishment	(causal event) CAUSE (BECOME [predicate (x)])

Dowty (1979) lists a set of syntactic and logical entailment tests that establish the membership of a verb in one of these aspectual classes. In what follows, I summarize the application of these tests, establishing *heat* as an accomplishment verb. First, I quickly exclude the classification of *heat* as an achievement or state verb. Excluding the classification of *heat* as an activity verb is less straightforward and will require a slightly more extended discussion of the relevant tests.

Three tests met by state, activity, and accomplishment verbs are met by *heat*, but exclude its classification as an achievement verb. All three tests reflect the fact that state, activity and accomplishment verbs refer to events that are extended in time: (i) *heat* takes adverbial prepositional phrases with *for,* as in (1) below, (ii) *heat* can occur with *spend an hour*, as in (2), (iii) *heat* can appear as a complement of *stop*, as in (3).

(1) John heated the soup for an hour.

(2) John spent an hour heating the soup.

(3) John stopped heating the soup.

A series of tests exclude the classification of heat as a state verb. First, in contrast to state verbs *heat* has a habitual reading in the simple present tense.

(4) John heats the soup (for every meal).

In addition, *heat* meets an additional five "non-stative" tests listed by Dowty (1979, p. 55): (i) *heat* appears in the progressive, as in (5), (ii) *heat* appears as a complement of *force* and pe*rsuade,* as in (6), (iii) *heat* appears as an imperative, as in (7), (iv) *heat* appears with the adverbs *deliberately* and *carefully,* as in (8), (v) *heat* appears in Pseudo-cleft constructions, as in (9).

(5) John is heating the soup.

(6) John forced/persuaded Harry to heat the soup.

(7) Heat the soup!

(8) John deliberately/carefully heated the soup.

(9) What John did was heat the soup.

The tests surveyed thus far narrow down the classification of *heat* to one of two classes, activity and accomplishment verbs. A series of tests were listed by Dowty (1979) that distinguish these two classes. Applying these tests indicates that *heat* should be classified as an accomplishment verb (with a slight qualification to be noted below). Semantically these tests reflect the fact that accomplishment verbs designate goal directed events. This is reflected in the following contrasts between *heat* and the activity verb *walk*:

(10) a. *John walked in an hour.

b. John heated the soup in an hour.

(11) a. *It took John an hour to walk.

b. It took John an hour to heat the soup.

(12) a. *John finished walking.

b. John finished heating the soup.

In addition, two logical entailment tests were listed by Dowty (1979) as distinguishing activity and accomplishment verbs. On applying these tests *heat* is found to behave as an activity verb, in apparent contradiction to the classification suggested by (10) – (12), as shown in (13) and (14) below. For each, I list three cases incorporating in turn an activity verb, *heat,* and an accomplishment verb.

(13) a. John walked for an hour.
Entails: John walked at all times during that hour.

b. John heated the soup for an hour.
Entails: John heated the soup at all times during that hour.

c. John painted a picture for an hour.

Does not entail: John painted a picture at all times during that hour.

(14) a. John is walking.

Entails: John has walked.

b. John is heating the soup.

Entails: John has heated the soup.

c. John is painting a picture.

Does not entail: John has painted a picture.

The tests in (13) and (14) result in the classification of *heat* as an activity verb in contrast to the classification indicated by tests (10) – (12). In (10) – (12) the behavior of *heat* as an accomplishment verb reflects the goal directedness of the event it designates. It is precisely this goal directedness that is supposed to preclude the logical entailments in (13b) and (14b), as it does for *paint a picture* in (13c) and (14c). I suggest that the behavior of *heat* as an activity verb in (13) and (14), reflects a semantic property of the event designated by *heat,* where the goal is defined on an ordinal scale that is internally homogeneous. The abstract semantic structures of *heat the soup* and *paint a picture,* differ in the degree of internal homogeneity of the designated event. Indeed it is this homogeneity that distinguishes prototypical activity verbs (e.g. walk) from prototypical accomplishment verbs (e.g. build). What distinguishes *heat* from activity verbs is a goal directedness that results, not from a fundamentally distinct final state, but from the existence of a series of distinct states along an ordinal scale. Thus, the goal is defined in relative terms allowing the entailments expressed in (13b) and (14b).

This aspect of the semantics of *heat* is implicated in another test mentioned by Dowty (1979): the different effects of the adverb *almost* on activity and accomplishment verbs. (15a) and (15c) incorporate prototypical accomplishment and activity verbs, respectively.

(15) a. John almost painted a picture.

b. John almost heated the soup.

c. John almost walked.

Dowty (1979, p.58) points out that (15a) has two possible readings: either that the idea of painting a picture was entertained but no painting took place, or the painting of the picture was begun but was not completed. In (15c) only the first reading is possible. Now in (15b) I suggest that there are two readings, classifying *heat* as an accomplishment verb. The second reading in the case of *heat*, while less likely than in (15a), can be reinforced by the context (e.g. dinner is being prepared). That is, *heated the soup* refers not to *any* increase in the hotness of the soup but an increase that makes it ready for dinner. This can be seen in the common co-occurrence of the verb *heat* with certain prepositional phrases as a complement suggesting that a unique state (or at least a limited range of states) along the ordinal scale is often entertained. Consider (16a-c):

(16) a. Heat gently *until the sugar has melted*.

b. I could heat up the rest of the chicken *for supper*.

c. She heated up a kettle of pool water *to do the washing up*.

To conclude, the results of applying a series of syntactic and logical entailment tests indicate that *heat* should be classified as an accomplishment verb. This classification justifies characterizing a semantic structure designated by the verb *heat* in terms of a state predicate, HOT, and the appropriate string of operators corresponding to the class of accomplishment verbs. Following Dowty, this may be expressed as [causal event] CAUSE [BECOME HOT(X)]. The discussion above, however, suggests that we interpret the predicate HOT as specifying some state along an ordinal scale. Moreover, (16a-c) suggest an additional semantic component: a unique point (or limited range) along the ordinal scale made unique by virtue of its functional consequences. Therefore, the semantic structure may be elaborated as follows:

[causal event] CAUSE [BECOME HOT_i(X)]
where: $HOT_{i-1} < HOT_i$,
HOT_c **= a critical degree of hotness**

The following two sub-sections examine syntactic properties of the nouns *heat* and *temperature* and the implied semantic elaboration of the core structure just described. The sentences used to illustrate these syntactic properties were obtained from the British National Corpus, a 100 million word data-base of current English usage. This is a corpus of English sentences compiled so as to be representative of current English usage from a broad spectrum of domains: novels, newspapers, TV programs etc.

2.2 The Syntax and Semantics of the Noun *Heat*

The semantic structure expressed above includes an unspecified causal event as the causal source of a change in the state of hotness. I will suggest in this section that the noun *heat* is used to designate a spatially localized entity that is the causal source of hotness, elaborating this unspecified causal event. In addition, the noun *heat* occasionally designates the state of hotness itself.

That heat designates a causal entity is reflected in the prepositions that take *heat* as a complement as in (17).

(17) a. It was Rosie, red-faced from running, and *from* the heat of the kitchens.

b. The contents and décor of the kitchen were severely damaged *by* heat and smoke and the rest of the ground floor suffered smoke damage.

This causal entity is spatially localized as seen in the prepositional phrases that the noun *heat* takes as a complement, as in (18), and the prepositional phrases in which *heat* participates, as in (19)

(18) a. The heat *in the room* was already intensely humid.

b. The excitement was there, the burning heat *inside her*, but also there was peace, belonging.

c. Once, she caught Chrissie with her head down, drying herself in the heat *from the fire* with her hair hanging over her eyes.

(19) a. As soon as the thigh meat is ready, remove it *from the heat*.

b. For a few moments the clouds open and we lie *in the heat of the hazy sun*, our efforts justly rewarded.

c. Connelly, barely conscious now, felt as if his blood was boiling, as if his bones were calcifying *under the incredible heat*.

d. Some washed under the pump before cooking rice and vegetables, while others seated *by the heat of the cooking fire* then washed before eating.

In addition to the causal and spatial properties of the entity designated by *heat* reflected in the linguistic evidence just cited, the syntactic behavior of *heat* as a mass noun, as in (20), indicates that the entity designated is un-individuated.

(20) a. With the tent flap closed, the *heat* had been building up under the canvas.

b. *With the tent flap closed, the *heats* had been building up under the canvas.

In (17) - (19) the noun *heat* is being used to designate a spatially localized causal entity that is independent of the object whose hotness is in question. In contrast, participation of *heat* in the prepositional phrases in (21) below, suggests that it is designating the state of hotness itself, and making reference to the consequences of that state of hotness.

(21) a. I was giddy *with the heat* and a little flown with the wine.

b. Go home dear girl, you will die *of heat* on your bicycle.

The contrast I refer to can be seen by comparing the sentences in (17) to those in (21). There seems to be a difference between the entity designated by *heat* in (17a) and (17b), on the one hand, and (21a) and (21b) on the other. In (17a) there is a distinction implied between the external entity 'heat' and the 'state of hotness'. This is reflected in the possessive preposition *of* marking the association of 'heat' with 'the kitchen' marking it as distinct from the 'state of hotness' of 'red-faced Rosie'. Moreover, in (17b) the preposition *by* marks the entity 'heat' as an agent, suggesting an independent entity, not a passive 'state of hotness' that simply results in damage. In contrast, the prepositions *with* and *of* in (21a) and (21b) respectively, suggest that the 'state of hotness' itself is designated by the noun *heat*. These considerations support the inclusion of two distinct semantic components in the cognitive model to be proposed (see section 2.4): an entity 'heat' that is the causal source of hotness, and the 'state of hotness' itself.

Finally, in the sentences in (17) and (21), *damage*d, *red-faced*, *giddy*, and *die* all refer to consequences (especially undesirable) of the state of hotness. This reinforces the inclusion of 'a critical degree of hotness' as a component in the semantic structure described in subsection 2.1 above.

2.3 The Syntax and Semantics of *Temperature*

The linguistic properties of the noun *temperature* differ markedly from that of the noun *heat.*

Temperature participates in locative prepositional phrases suggesting that temperature is conceived as a location in space.

(22) a. Stir thoroughly, then allow to cool *to room temperature.*

b. Maintain the water *at a temperature of 19-24°C* and feed the fish on flake, tubifex, insects and earthworms.

Moreover, the possible locations are limited to a single, vertical dimension and *temperature* can designate an entity moving along it, as in (23).

(23) a. With almost clear skies and very little wind, the *temperature will fall* sharply this evening.

b. Although the days were still warm and sunny, the evenings closed in early and the *temperature soon began to dip* as darkness approached.

In contrast to *heat*, *temperature* is a count noun, indicating that it designates an individuated entity.

(24) There is a large range of temperatures suitable for human life.

2.4 A Minimal Cognitive Model of Thermal Phenomena

The results of subsections 2.1-2.3 suggest the components of a conceptual structure that underlies the use of *heat* (as verb), *heat* (as noun) and *temperature*. This minimal cognitive model underlying the usage of *heat* and *temperature* as discussed above is represented in figure 1. This is a *minimal* model in the sense that it incorporates only those semantic elements that apply to a variety of specific thermal phenomena. The model can be described in terms of its basic components as follows: There is an un-individuated entity occupying an extended region in space (shaded circle). Its spatial contiguity with an object is the causal source of the increased hotness of that object (the square in the diagram). This hotness, conceptualized as a location along a vertical dimension, can range in intensity (represented by HOT_i). One point (or a limited range of points) are singled out as critical (HOT_c). The suggestion here is that the lexical items *heat* (as verb and noun) and *temperature* designate different aspects of this model. The verb *heat* designates the whole model. The noun *heat* may designate the spatially localized entity that is the causal source of hotness, or occasionally the state of hotness itself. *Temperature* designates the degree of hotness, conceptualized as a location along a vertical scale.[2]

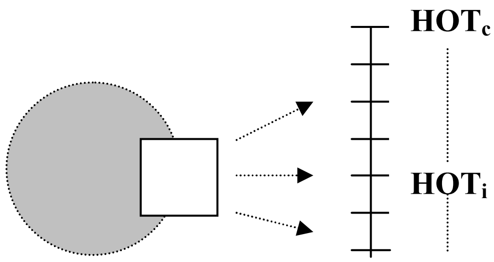

Figure 1: The minimal cognitive model of thermal phenomena

The cognitive model just described models the phenomenon of an object becoming hotter at a fairly schematic level. That is, emphasis has been placed on characterizing it in terms of conceptual notions like space, cause, states and linear scale. This is not surprising since the model was characterized by performing a grammatical analysis and it is precisely such notions that are encoded grammatically (Slobin, 1997). Thus this characterization turns out to have emphasized what Lakoff and Turner (1989) have called the event (or "generic-level") structure of the conceptual domain. This model can be described purely in generic terms as follows: spatial contiguity between two entities is the cause of a change of state where that change occurs along a vertical scale with a certain point singled out as functionally significant

Lakoff and Turner (Lakoff, 1993; Lakoff & Turner, 1989) have suggested that generic-level structure is what is preserved across metaphorical mappings from one conceptual domain to another. Therefore, the accuracy of the above characterization can be checked by examining whether the generic-level structure of the model proposed is indeed preserved across mappings from the source domain of heat to other domains. I address this point next.

2.5 Two Sets of Conceptual Mappings as Corroborating Evidence

In this subsection I discuss two sets of conceptual mappings found in English implicating the domain of heat as a source domain. The first involves an extension of the use of the noun *heat* in American slang, in particular, language in use in the criminal world. The second is a coherent

[2] The distinction between the whole cognitive model and the designations of the individual lexical items correspond to Langacker's (1987) domain/profile distinction.

set of metaphorical expressions, unified by the conceptual metaphor ANGER IS HEAT, identified by Lakoff and Kövecses (Kövecses, 1990[3]). In both cases the mapping preserves the generic-level structure described above.

I begin with the first set of mappings underlying the use of the noun *heat* in the slang of the world of crime. The sentences that are used to develop the argument are compiled from dictionaries of American slang.

Consider the sentences in (25) - (27).

(25) a. If you pack heat, you've got to know what you're doing. (pack heat = carry a gun).

b. Drop the heater and leave the jewel case where it is, I don't want any unpleasantness. (heater = gun)

c. I was packing about as much heat as you find in an icicle. (heat = gun)

d. Try operating an American city without the heat. (heat = police)

(26) a. We better stop purse-snatching while the heat is on. (heat = pressure of police)

b. The heat is on dope. (heat = pressure of police)

(27) a. He will soon feel the heat of their threats.

b. I had to take the heat for his mistake.

c. He gave him the heat. (= He shot him.)

I suggest that these three groups of sentences reflect the role of generic-level schema in motivating the mapping between the domain heat itself and the criminal world.

In (25) *heat* either designates a gun or the police in analogy to the use of heat to designate the entity heat which is the causal source of hotness as discussed earlier. A gun (or the police) and the entity heat constitute counterparts, both being instantiations of an entity that is spatially localized and is causally relevant to a change of state.

In (26a) and (26b) *heat* designates the pressure applied by the police on a particular target. While this applied pressure is the effect of police presence, it plays a distinct semantic role. So the suggestion here is that 'degree of hotness' and 'applied police pressure' are counterparts, both instantiations of another aspect of the generic level schema: the effect of one entity on another is conceptualized with respect to an intensity scale.

Finally, the uses of *heat* in (27) implicate the final component of the generic level schema contrasting slightly with (26). In (27a), *heat* designates

[3] Chapter 4, "Anger," was co-authored with George Lakoff.

'that point at which gradually intensifying threats become particularly troubling'. In (27b) it designates 'repercussions of a mistake by one person intense enough to negatively affect another'. In (27c) the 'threat by a gun culminated in the threatened being shot'. Thus, the claim is that the usage of the noun *heat* in (27) involves designations in the criminal domain that are counterparts of 'a critical degree of hotness' in the domain of heat, both instantiating a critical degree of intensity with significant functional consequences. I say that the usage "involves" this designation implying a slight qualification. Notice that in (27b) and (27c) the constructions *to take the heat for* and *gave him the heat* suggest that *heat* designates a localized entity. In both cases there is the conception of transfer of an entity to a recipient who comes to possess that entity. These usages need to be distinguished from those in (25), however. This is because the constructions in (27b) and (27c) are examples of the EXPERIENCES ARE POSSESSIONS metaphor (see Lakoff, 1990). It seems reasonable, therefore, to emphasize that the usage of *heat* (certainly in conjunction with the grammatical constructions in which it is embedded) involves a designation that involves a critical degree of intensity with functional (experiential) significance.

The second mapping that I will consider here is one that underlies much of the language about anger in English. Lakoff and Kövecses (Kövecses, 1990) identified a conceptual metaphor that renders coherent many English sentences about anger. They point out that the combination of the metaphor ANGER IS HEAT when applied to fluids, with the metaphor THE BODY IS A CONTAINER FOR THE EMOTIONS, produces the central metaphor ANGER IS THE HEAT OF A FLUID IN A CONTAINER. What is of particular interest here is the specific aspects of the source domain (i.e. HEAT OF A FLUID IN A CONTAINER) that participate in the mapping. We find Lakoff and Kövecses (see Kövecses, 1990; pp. 54-56) organizing their examples into the following groups (I give one example from each. For more examples see Kövecses, 1990, pp. 54-56).

i. WHEN THE INTENSITY OF ANGER INCREASES, THE FLUID RISES:

(28) His pent-up anger *welled up* inside him.

ii. INTENSE ANGER PRODUCES STEAM:

(29) Billy's just blowing off steam.

iii. INTENSE ANGER PRODUCES PRESSURE ON THE CONTAINER:

(30) I could barely contain my rage.

iv. WHEN ANGER BECOMES TOO INTENSE, THE PERSON EXPLODES.

(31) When I told him, he just exploded.

v. WHEN A PERSON EXPLODES, PARTS OF HIM GO UP IN THE AIR

(32) She flipped her lid.

vi. WHEN A PERSON EXPLODES, WHAT WAS INSIDE HIM COMES OUT

(33) His anger finally came out.

The groupings identified by Lakoff and Kövecses can be further collected into two more schematic groups: those referring to points on the intensity scale and those referring to a limit having been reached. Hence we find the following comment in Kövecses (1990), summarizing the central metaphor:

> In the central metaphor, the scale indicating the amount of anger is the heat-scale. But, as the central metaphor indicates, the anger scale is not open-ended; it has a limit. Just as a hot fluid in a closed container can only take so much heat before it explodes, so we conceptualize the anger scale as having a limit point. We can only bear so much anger, before we explode, that is, lose control. (p. 56)

This mapping between the source domain, HEAT OF A FLUID IN A CONTAINER and ANGER is structured according to the components of the abstract schema mentioned at the beginning of this subsection. I have pointed out the fundamental role played by the intensity scale and the critical point of this intensity scale as reflected in the two groups of metaphorical expressions. In addition, *anger*, in analogy to *heat*, plays the dual role of designating an entity that is a spatially located causal source of intense agitation as implied in (34), and the state of intense agitation itself as in (35).

(34) Try to get you anger out of your system.

(35) She was shaking with anger.

Thus in the two mappings discussed the generic level schema extracted from the minimal cognitive model proposed in section 2 are preserved. This constitutes corroborating evidence for the existence of that model.

3. The Ontology of Heat as an Emergent Product of Conceptual Integration

I consider the model proposed to be a good starting point for a characterization of the core of the layperson's understanding of thermal phenomena. Certainly people have a lot of other related specific knowledge (e.g., that water boils when heated for some time and that we sweat under intense sun). The model proposed incorporates the basic causal structure of the layperson's understanding that can be applied across contexts. Another aspect of what might constitute such generalizable knowledge is the ontology of the entity 'heat', what type of thing heat is. In this section I will argue that a stable assignment for the ontology of 'heat' is absent from the layperson's core understanding, but rather emerges in specific explanatory contexts.

I develop this argument by examining two segments of an interview where an experimenter (I) was interviewing a high-school student (S) with the purpose of revealing the student's pre-instruction understanding of thermal phenomena. These segments come from interviews that form part of a series of studies conducted by Marianne Wiser (see Wiser, 1995) in which she has been examining the relationship between high-school students' pre-instruction knowledge and textbook knowledge about thermal phenomena and its implications for characterizing the process of conceptual change involved in this domain.

Segments (i) and (ii), quoted below, reflect the same student's understanding of insulation and conduction, respectively (these segments occur within minutes of each other). The first suggests that the student believes the entity heat is a material substance. The second segment contradicts that conclusion. I present these segments below, then address the question of how these apparently contradictory conceptualizations can be interpreted given the minimal cognitive model described in section 2 above and the process of "conceptual integration" described by Fauconnier and Turner (see Fauconnier, 1997; Turner and Fauconnier, 1995).

Segment i - Insulation:

I: … Do you know how insulation works?

S: Not really.

I: What does that word mean to you when you hear "insulation"?

S: Keeping stuff at the same temperature. Warming something up.

I: All right. So keeping stuff at the same temperature or warming something up. OK, say I have two cups of water, one of them is made of out of Styrofoam and one of them is made out of cardboard. Well, what I want to ask is: we use Styrofoam cups to keep things warm, what do you think it is about Styrofoam that keeps what's inside warm?

S: I don't know. Maybe it's like thicker material that has a better insulation, or something. 'Cause, if you keep it at the same temperature, it's insulated.

I: OK, but what is it about the Styrofoam itself? I mean, water inside the Styrofoam cup stays hotter than water which was, in the beginning, at the same temperature inside the cardboard cup.

S: The Styrofoam can keep it heated better.

A few exchanges later …

I: … Do you think that insulation has anything to do with molecules.

S: Yeah.

I: In what way?

S: The molecules are more smushed, so the heat can't escape.

Segment ii - Conduction:

I: Now this is a copper bar and we've got a candle here at one end, and there's a blob of wax, or a pellet of wax, at the other end. The wax is eventually going to melt, right, do you think that's true?

S: Yeah.

I: OK. How does the heat get from one end of the bar to the other. We've got this little candle heating up this end. How does it get to the end of the bar?

S: Well, this end would probably be hotter, 'cause that's where it started, but the molecules would just, the heat would just keep pushing down onto the molecules after a while, but this end would probably be hotter, but eventually this end would get pretty hot and it would melt the wax.

A few exchanges later …

I: …Do you think water would be able to pass through the bar in the same way?

S: No, I don't think so. Water could pass through the bar? No.

I: No? What about a gas for example? Would that be able to pass through the bar?

S: I don't think so.

I: What about air?

S: I don't know. I don't think it could go through. I don't think so.

I: OK, so water and a gas and air would not travel through the bar, but heat would. What's different about heat, that would make it travel?

S: I don't know, it kinda just spreads through, I don't know why it would travel, I just think it would.

I: So, what kind of a thing is heat, then, it's different from those other things, like water and air?

S: I don't know, you can't really see it, it just heats up the particles and then, it's not like the fire is inside the bar, but it gives it the hotter temperature.

In the first segment in which the student's understanding of insulation is explored, the student displays an understanding of the entity heat as a material substance, which "can't escape" because molecules of Styrofoam, the good insulator, are "more smushed". The student's responses seem to be based on a cognitive model in which the water stays hot because the material entity heat is unable to pass through a substance made of tightly packed molecules. In contrast, in the second segment of the interview the student resists granting material substances like water or gas the ability to pass through a copper bar, an ability granted to heat. Moreover, she does not describe a process in which heat travels *between* molecules of the conductor, it "just spreads through". The understanding of the process of conduction and the melting of the wax is expressed in terms of spatial location of the entity heat, the gradually increasing temperature at points along the bar and the eventual melting of the wax when that end gets hot enough. That is, the explanation of conduction is formulated in terms of the minimal cognitive model with a rejection of a material substance interpretation of the entity heat.

Fauconnier and Turner's account of "conceptual integration" and "emergent" meaning in blended conceptual spaces can help make sense of the apparently conflicting observations mentioned above (see Fauconnier, 1997; Turner and Fauconnier, 1995). Figure 2 illustrates how the framework of conceptual integration can be used to understand how the material substance ontology of heat can emerge in the context of a student's explanation of insulation. Input space 1 includes the minimal cognitive model proposed earlier. Input space 2 corresponds to specific knowledge about insulation: that some insulating substance (I) maintains the hotness of a contained liquid (L). The integration of the conceptual content of each of these two spaces is motivated by correspondences established by the generic space. The projected structure from input spaces 1 and 2 to the blend can be characterized as: the insulator maintains the desired temperature of the liquid by preventing the spatial dislocation of the entity heat that is responsible for the desired state of hotness. I suggest that this projected structure is further elaborated by a force-dynamic frame that is part of our early developing knowledge in which a solid object blocks the passage of another solid object. This elaboration is a result of the process of "completion" described by Fauconnier (1997) where elements in a blend can prompt the conceptualizer to elaborate the conceptual structure in the blend with background knowledge frames. The resultant emergent structure in the blend will contain the conceptualization of heat as a solid material substance unable to pass through the solid insulator and it is this that explains why the hotness of the liquid is maintained.

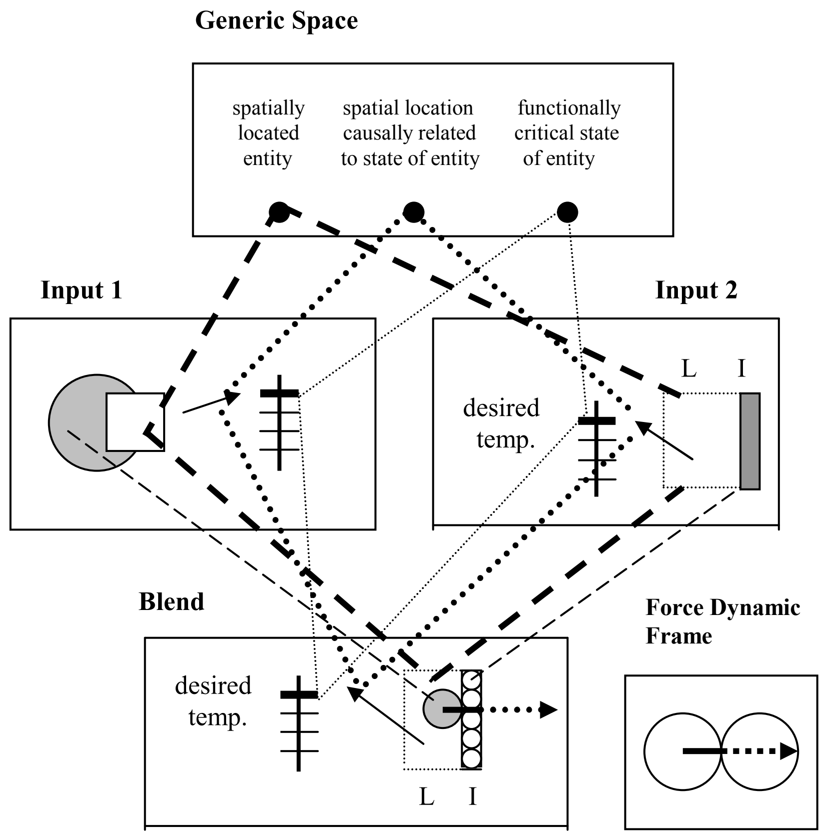

Figure 2: Emergent material substance ontology of heat as a result of conceptual integration. (L = liquid, I = insulator)

Thus, within the context of discussing insulation, the schemas that are evoked and integrated result in an emergent conceptual structure in which the entity heat is interpreted as a material substance. However, the material substance ontology is a temporary component of the cognitive model dynamically constructed by the student while reasoning about insulation. Its lack of entrenchment allows the ontologically unelaborated minimal cognitive model to drive reasoning in response to questioning about conduction a few minutes later.

Interpreted thus, the apparently contradictory findings regarding the student's understanding of thermal phenomena turn out to be quite consistent, as far as cognitive theorizing is concerned. Much of the research on conceptual change in science has, however, assumed that the task is to identify static knowledge structures. For example, Chi and colleagues (e.g. Slotta, Chi & Joram, 1995) have suggested that an important source of difficulty in learning science concepts (including heat) is the pre-instruction classification of these concepts within the material substance ontological category. A static view of this pre-instruction classification does not accord with the kind of variability observed in the interview segments presented above. It is the assumption that it is static knowledge structures that are driving student responses which makes the above segments appear to constitute contradictory findings regarding the student's knowledge. Granting the possibility of the dynamic construction of cognitive models through online conceptual integration provides a framework within which to interpret the absence of stability in pre-instruction understanding of physical phenomena.

4. Conclusion

I hope to have illustrated how the framework of cognitive linguistics can contribute to the characterization of a layperson's core understanding in a physical domain. This contribution can be seen as twofold. On the one hand, cognitive linguistic tools for the analysis of semantic structure implicit in language use can help characterize particularly stable aspects of conceptualization. On the other hand, fluctuating conceptualizations can be understood as dynamic constructions at the moment of use interpreted within the framework of conceptual integration and the emergence of conceptualization in blended spaces. Together these can prove to be a useful set of tools for characterizing pre-instruction knowledge in science.

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