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Reasoning, Representing, and Modeling in Babylonian Astronomy

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Abstract: This paper considers Babylonian astronomical predictive schemes as a source for the study of reasoning and representing via modeling. Two principal questions are addressed: first, whether Babylonian astronomical modeling can be usefully included in the conversation about scientific reasoning with models, and second, how and what the representational value of the practice of astronomical modeling was in ancient Babylonia. It is found that the Babylonian astronomical schemes demonstrate the adaptability and various capabilities of the process of modeling as a powerful tool of representation for scientific knowledge and theorizing.

Keywords: modeling, representing, reasoning, analogy, mathematical systems, Babylonian astronomy

1 Introduction and questions

The following discussion concerns reasoning, representing, and modeling in Babylonian astronomical thought. To paraphrase Geertz (2010: 18) on Malinowski's Trobrianders, such thought is not meant to be generalized or standardized as something "The Babylonian" or "The Mesopotamian" would think by virtue of being a Babylonian or, much less, a "Mesopotamian" (there was no such ancient identification). Such treatments slide easily into talk of mentalities, and I reject the idea of an essential "Mesopotamian" or "Babylonian" mentality. The reasoning and representing here was produced by individuals who identified themselves with a particular literate scholarly tradition. The patterns or modes of reasoning belonging to this tradition are not a function of a "Babylonian" characteristic or habit of mind, but were the product of a world, or worlds, of scholarship of certain times in certain places (discussed throughout this volume). I mean, therefore, to emphasize the particularity, rather than the generality, of reasoning, representing and modeling in the context of Babylonian astronomy.

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Reasoning and representing are operative in the construction of models in science: reasoning to relate a theoretical construct, or "model," to the world, or to some phenomenon in the world, and representing in that very relationship established between the model and the world, or some phenomenon of the world. The cognitive scientist and A.I. researcher, Marvin Minsky, in a paper dealing with the relation between mental and physical events and how models mediate between the mind and the world (Minsky 1965: 1), defined a model in the following terms, that "to an observer B, an object A* is a model of an object A to the extent that B can use A* to answer questions that interest him about A." Minsky saw the intention of the knower (B) as crucial to the use of A* in relation to A. He adds, "If A is the world … A* is a good model of A, in B's view, to the extent that A*'s answers agree with A's, on the whole, over those questions important to B." (ibid.) Therefore, Minsky's definition raises both the question of the relation of a model to the world, that is, whether it provides corresponding structures, and also how well the model can answer some particular observer's—or community of observers—questions about the world by reference to the properties of the model.

To put this relationship between scientific modeling and the empirical world into greater focus, Hughes (1997: S327–29, using as an example Galileo's geometrical diagram, or model, of "Naturally Accelerated Motions" in the Third Day of his *Discourses Concerning Two New Sciences*), identifies *denotation* as the first characteristic of a model in physics. He quotes Goodman (1968: 5, apud Hughes 1997: S329) that "denotation is the core of representation and is independent of resemblance." The elements of a model, from this standpoint, need not replicate or simulate the object of the model in a physical way, but if there is the fundamental relationship of reference, or denotation, between model and world, then that model represents the phenomena of the world.

Two of the key dimensions of this conception of a model are then its ontological status and its use. But what if all we want from our process of modeling is that it gives us access to phenomena of the world without necessitating a heavy ontological burden? This, I think, is consistent with Daniela Bailer-Jones's sense of what a model is, or what it does, i. e. that models "*tell us* something about certain features of the world." (Bailer-Jones 2003: 59–60, emphasis in the original) Modeling, reasoning with models, and representing phenomena with models are thus basic to many domains of science, but usually do come with an identifiable ontological commitment. On those grounds it is difficult to argue that Babylonian astronomy produced models in the modern sense, as the predictive schemes attested in mathematical astronomical texts do not have clear ontological reference. Clearly, however, the astronomers employed the cognitive process of modeling to gain access to the behavior of the phenomena of their interest. The adaptability and various capabilities of the process of modeling make it a powerful tool of representation for scientific knowledge, explanation, and theorizing.

Reasoning, representing, and modeling in Babylonian astronomy is particularly well illustrated by the mathematical predictive schemes in late Babylonian astronomical texts (Neugebauer 1955; Ossendrijver 2012). A wider range of evidence could also be taken into consideration, such as from the nonmathematical astronomy (particularly Goal-Year methods, see the texts in Hunger 2006), or the descriptive astronomy in early Babylonian astronomical texts (in the Astrolabes, see Horowitz 2014; or MUL.APIN, see Hunger and Pingree 1989; Hunger and Steele 2018; or in *Enūma Anu Enlil* Tablet 14, see Al-Rawi and George 1991–92). The present discussion is, however, not aimed at a survey of evidence for the use of modeling, but is rather interested in questions raised by the idea of models or modeling in the cuneiform world, and for that purpose focuses only on the late Babylonian ephemeris tables as illustrative of the place of Babylonian astronomical modeling in the history of scientific model-making. A broader coverage of all such texts that show a similar (or a different) relationship to scientific model-making is a task for future research.

Assigning a place for Babylonian astronomical modeling in the history of scientific model-making is inevitably colored by our own tradition of the use of models in physics to say something about reality, a tradition famously illustrated by James Clerk Maxwell's methods of physical analogy. Our present scientific values follow from a position that the best models, be they mathematical or physical, are true to the structures of Nature, which is to say, they constitute accurate representations of the physical world.[1] From this point of view a model, particularly of a physical feature or an observable phenomenon of the world, attaches to a certain ontological conception of the world to which the model of it relates. As seen in Minsky's statement (Minsky 1965: 1) that "questions about things in the world are answered by making statements about properties of corresponding structures in one's model W* of the world," we want and expect a certain kind of physical relation (representation) to make our model successful (to be able to answer questions). Examples of physical models, such as Maxwell's kinetic theory of gases on the analogy of billiard balls in a box, or Bohr's model of the hydrogen atom on the analogy of a planetary system, seem clearly representative of a different species of model from what is in evidence in Babylonian astronomy on precisely the grounds of the kind of relation they are meant to have to a presumed physical reality. This difference, in major part, has to do not only

1 On the anachronistic transfer of this as the goal of scientific "hypothesis" construction, see Bowen (forthcoming), "Hypothesis and Some Early Hypotheses."

with the kind of structures that describe or theorize phenomena, but also, and more significantly, the relation of those structures to the physical world. The cuneiform astronomical texts to be discussed here present, as F.X. Kugler called them (Kugler 1900, p. 3 and passim), "systems" of calculation for the prediction of astronomical phenomena rather than models that correspond, or are meant to correspond, to planetary motion in a physical sense.

The modern classification and definition of "model,"[2] therefore, is of questionable relevance for Babylonian astronomy. Instead of focusing on models, therefore, we might more usefully speak of modeling in Babylonian astronomy,[3] where the emphasis is on the processes whereby different mathematical schemes were constructed to be able to generate positions and dates of phenomena in accordance with their periodicities. Then, with respect to reasoning and representation in cuneiform science, at least what we call science (the cuneiform scribes did not), we can raise two additional questions: First, can Babylonian astronomical modeling be usefully included in the conversation about reasoning with models, or what is now, after Nancy Nersessian (2006, 2008), regularly termed "model-based reasoning"?[4] And second, was representation the purpose of the Babylonian astronomers' modeling practice, and if so, how and what was the representational value of that practice?

2 Reasoning

Nancy Nersessian (2008: 12) defines a model as "a representation of a system with interactive parts and with representation of those interactions." She points

2 An extensive literature in the philosophy of science (Bailer-Jones 1999 for an overview) has arisen around the character and function of models in science, particularly given the debate around views of theories where a "syntactic/linguistic" view (stemming from Logical Empiricism) has come to be opposed to a "semantic/structuralist" view (stemming from Suppes 1960; developed by Achinstein 1964) and the more recent addition of the "pragmatic view," see Cartwright (1983), who emphasized the important role for models; also Suárez (1999), and Craver (2002).

3 I thank Willard McCarty for this useful suggestion. In his words, "the word 'model' has so often been used in the sense of a mathematical model, a robust formulation with almost the status of a theory, that the singular noun bends our minds to think of one fixed thing when we know we're dealing with a process." (personal communication)

4 Or, is the notion of "model-based" problematic in the present context, again, in McCarty's terms, for the reason that "to say 'model-based' (as in so much thinking about the role of models in science) implies a stable theory-like entity from which one reasons" (personal communication). The Babylonian astronomical texts do not seem to support such an interpretation, i. e. as reasoning from a static model.

out that models can be "conceptual, physical, mathematical, and computational, or combinations of these." Although the representational aspect of modeling, as in Nersessian's definition, can be assumed, the question of what is being represented cannot be so assumed and will be of concern to this discussion below in the section *Representing*. More immediately, the question of what sort of modeling is in evidence in cuneiform astronomical texts will be considered here. The condition of Bailer-Jones' definition of models (cited above) is that they have to do with, describe, give an account of, in short, *represent*, phenomena in the empirical world. Models do not have to be accurate or true to physical reality, but we expect the process of modeling in science to be founded in empirical data and its aim to give some sort of account of the phenomena of interest.[5]

A certain class of structures, in the form of mathematical (or numerical) descriptions of cyclical astronomical phenomena, is extant from the entire chronological span of Babylonian astronomy, from the scheme for the visibility of the moon in *Enūma Anu Enlil* Tablet 14 to the late Babylonian ephemerides of the Seleucid Period. What is distinctive about these mathematical constructs is that their aim in each case is to function as a means for predicting the next phenomenon in sequence, given an initial phenomenon or quantity relating to a phenomenon. The mathematical structures applied to the description or prediction of such phenomena respond in certain ways to empirical data, e. g. the increase and decrease of the length of daylight throughout the year around two points of equal length of daylight and nighttime (when each is 12 hours duration), or that lunar eclipses occur at regular intervals when the moon is in opposition to the sun, or that planetary visibilities also occur at regular intervals depending on a given planet's position relative to the sun. The correspondence to empirical phenomena in these kinds of mathematical constructs, I suggest, is one of denotation, or extension. The quantities from which the mathematical schemes are built have a denotational relationship to some phenomenon of the world, be it a daylight length, a lunar eclipse, or a synodic appearance of a planet. Constraints imposed by presumed underlying empirical data of the phenomena of interest, therefore, even when evidence of empirical data is no longer preserved, are an essential part of the modeling of the phenomena in the context of the Babylonian mathematical astronomy.

As a rule a relationship to empirical data derived from observing phenomena is embedded in scientific models. However, if we insist that models have a one-to-one correspondence with the physical world or a part of it, the Babylonian

5 For a recent exposition of representation via models in science, and in the History of Science, see Van Fraassen (2008).

evidence will not qualify as models as they do not function in that way. Such isomorphism is, however, extremely limiting; moreover, other kinds of relationships between the structure of a model and the phenomena it aims to describe are also admissible into the category of models. Indeed, Margaret Morrison commented (Morrison 2007: 203) on this aspect when she observed that, "the issue isn't simply one of determining the referential features of the models even if we limit ourselves to the 'empirical' data. Because of the kinds of assumptions we typically build into our models, we often are unable to disentangle the truly empirical aspects from the stylized descriptions, produced via a high-degree mathematical abstraction."

One of the principal objectives of Babylonian astronomical modeling was to derive the next phenomenon in a periodic cycle, such as a first or a last visibility of a planet, new or full moons, or a phenomenon such as the length of daylight, and to effect this derivation by computation. As already noted, for the purpose of the present discussion only the two late Babylonian mathematical systems called systems A and B will be used to illustrate this objective, although numerical schemes in other kinds of Babylonian astronomical texts could also be considered as evidence.[6] In the case of the two late Babylonian computational systems A and B two different functions were adopted, specifically the step and the zigzag function, for modeling solar, lunar, and planetary phenomena (see Figures 1 and 2), the purpose of which was to facilitate the aim of prediction of the next phenomenon in a periodic cycle of whatever astronomical phenomenon was in question.

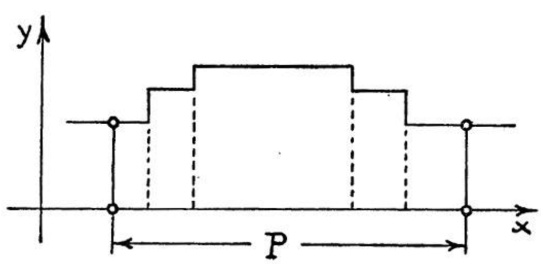

Figure 1: Step function, characteristic of system A.

6 Examples would be the daylight length scheme from the Astrolabes (Horowitz 2014) or MUL.APIN (Hunger and Pingree 1989; Hunger and Steele 2018). Descriptive rather than predictive usage of model-making is also known, such as the rising times scheme, as discussed in Rochberg (2004), Steele (2017). Discussion of description as opposed to prediction in relation to model-making is also not the present concern, but would obviously be important for a more thorough treatment of astronomical modeling in cuneiform astronomical texts.

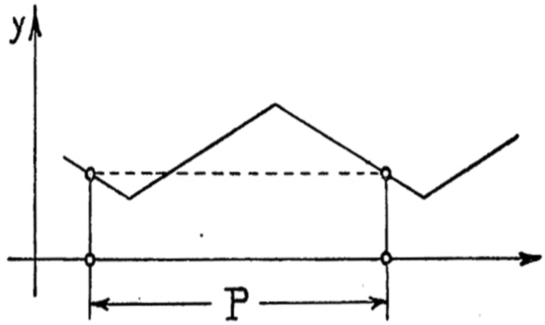

Figure 2: Zigzag function characteristic of System B.

Babylonian astronomical modeling required parameters, the units in which parameters are expressible, as well as available coordinates, such as degrees of longitude. Systems A and B used the step or zigzag functions respectively to account for the difference between a position/longitude (y_n) and the next in periodic sequence (y_{n+1}). In system A this difference was modeled as the progress of a phenomenon around the zodiacal signs subdivided into zones of longitudinal progress, the simplest version consisting of two such zones, fast and slow.[7]

In this way, system A modeled the synodic arc—the characteristic change in longitude between successive synodic events ($\Delta\lambda$)—and modeled the synodic arc directly with a step function of longitude (Aaboe 2001: 44). The object of system A was not to describe the motion of a celestial body in a physical sense, but to use what we describe as “fast” and “slow” arcs of the ecliptic as a mathematical way to deal with the problem of anomaly manifest in real as opposed to mean synodic arcs. In making the computation of consecutive phenomena directly dependent upon the position of the body in the ecliptic, system A’s calculation scheme was tied to the ecliptic so that the change in longitude was a direct function of longitude ($\Delta\lambda = f(\lambda)$). We might say that system A modeled phenomena in the empirical world in a direct way.

System B, on the other hand, was not tied directly to the ecliptic but rather to the serial number (n) of a synodic phenomenon in some sequence of consecutive synodic phenomena in the table (Aaboe 1964: 225).

7 The graphs shown in Figures 1 and 2 for the characteristic functions of the Babylonian astronomical ephemerides are anachronistic conveniences for which there is no cuneiform evidence of such a graphic conceptualization.

The values of synodic arcs ($\Delta\lambda$) increase and decrease between two extrema and thus form a linear zigzag function where the independent variable is the serial number of the consecutive events to which those synodic arcs belong and which are tabulated in the ephemeris, so that the change in longitude is a function of the line number in the table, expressed as $\Delta\lambda = f(n)$. System B's calculation scheme is indirectly tied to the phenomena (or synodic events) via the event number, using Ossendrijver's terminology, in the table, not the body's position in the ecliptic (Ossendrijver 2012: 42).

Despite the fact that the two systems modelled the phenomena differently, each functioned as heuristic devices for analyzing the periodic nature of planetary, lunar, and calendrical phenomena. Thus they are not so different from one another in terms of the employment of the same kind of cognitive tool, namely, modeling. Is this tantamount to what Nersessian termed model-based reasoning?

Reasoning with models is now widely accepted as an elemental part of science. The recognition that science uses model-based reasoning has enlarged the traditional (early to mid-twentieth century Logical Empirical) claim that scientific reasoning was typified principally by the use of hypothetico-deductive reasoning, which was based in logic and assumed a certain relation between theory and observation. In tandem with the change in viewpoint concerning the nature of theories in science from the traditional syntactic/logical approach to the semantic approach, analysis of reasoning in science similarly opened up to the idea that construction and interaction with models was an important part of how scientific reasoning functions to solve problems. As Nersessian (2006: 700) said, "investigations of scientific problem-solving practices lead to the conclusion that logic and argument are not the only forms of making inferences. Inference can be made directly through model construction and manipulation."

Nersessian is the major voice behind the idea of model-based reasoning, especially in relation to conceptual innovation and problem-solving in the history of science. Her cognitive-historical analysis integrates several forms of reasoning strategies, such as analogy and imagery, to provide another way to look at the cognitive basis of science. She calls (2008: xii, 11) model-based reasoning the "signature practice of the sciences." The construction of models, in her analysis, involves several categories of reasoning, including the analogical, simulative, evaluative, and abstractive (involving generalization and idealization). Here I shall focus on the analogical, as it seems particularly key to explaining how models succeed in the representation of phenomena, through a cognitive process in which knowledge from a source domain (in Babylonian astronomy we might say, mathematics and period relations) is applied to a target domain, or target phenomena (say, synodic phenomena of the planets).

Each domain brings certain constraints to the modeling process, the source domain providing its own principles or mechanisms of description, the target in providing features that are specifically characteristic of the empirical data, and consequently the conceptualization, of phenomena to be modelled.

The use of analogy in science has a very long history. North (1981: 116–121) finds the key point of entry in the late 17th C. with Newton, who made an analogy, or correspondence relation (North 1981: 120), between light and sound. In this study of analogy in Newton, Thomson, and Maxwell, North made the following statement (North 1981: 134, emphasis in the original): "The subject of analogy is a large and difficult one, extending as it does into every region of human activity. Analogies have two sides to their nature: they are instruments of *argument*, prediction, and validation, and they are instruments of *cognitive meaning*, understanding, formalization and classification." Newton's use of analogy, according to North, was primarily one of argument.

In the history of physics are also analogical models that render their target phenomena visually, or sometimes as a simulation of the structure and behavior of the phenomena, and not in a merely formal way, but by true physical properties of resemblance, even identity, with the physical world (Nersessian 2008). In the history of Babylonian astronomy, on the other hand, we are not entitled to claim any sort of physical resemblance between the way the planetary positions were modeled and the physical behavior of the planets. The Babylonian systems A and B are not simulations of planetary phenomena, although they succeed in making predictions of successive occurrences of phenomena. The role of analogy, or analogical reasoning, in the construction of Babylonian mathematical models for the synodic behavior of the planets make the behavior of the planets intelligible and predictable, and so have the heuristic function of models known in the history of science.

There is abundant attestation to analogical reasoning elsewhere in the cuneiform world. (Rochberg 2016: 156–163; as a key feature of cuneiform scribal scholarship with its roots in multilingualism and translation, see Crisostomo in this volume). Among other cognitive strategies, analogical reasoning, including deductive inference, worked within the framework of divination to relate and correlate the particulars of phenomena in various meaningful ways.[8] While the content of cuneiform scholarship changed over time, from the seventh to the third centuries B.C.E. and later, analogical reasoning remained a consistent feature of the material over time. Analogy seems to me a fair description of the kind of reasoning at the heart of Babylonian divination, as well as some of

8 Mesopotamian analogical reasoning is also discussed in the contributions of Jay Crisostomo, Eckart Frahm, Enrique Jiménez, and Marc Van De Mieroop to this volume.

the lexical lists built up through semantic and phonological associations within the cuneiform writing system which account for entries in the lexical lists such as Antagal and Diri, or in commentaries such as I.NAM.GIŠ.HUR.AN.KI.A (Livingstone 1986: 17–52).

In terms of the traditional cognitive strategies of Babylonian scholars, then, the use of analogical reasoning in the Late Babylonian astronomy was not new. However, its application in modeling the progress of the moon and planets around the zodiacal circle reached a new level with the planetary and lunar ephemeris tables of the Late Babylonian period, and the mathematical schemes they employed became the vehicle for a new way of representing the same phenomena that had occupied the interest of the scholars since the seventh century and before.

3 Representing

Representation in science is not simply a question of how models function, but is a question at the very heart of the nature of theory. Models, theories, and representation are all equally implicated in one another, but little consensus is to be found. In Mauricio Suárez's description of the syntactic view (Suárez 1999: 75), "theories can be seen to provide the logical form of scientific knowledge while models are responsible for filling in the content." He remarks (Suárez 1999: 75) that in the semantic view, by contrast, "there is no fundamental distinction between theories and models: a theory is in fact nothing but a family of structures … Defenders of the semantic view often refer to the theoretical structures as 'representations'." His own pragmatic view departs from the semantic/structuralist view of models as (merely) heuristic structures, suggesting that the representational aspect of models is not simply about formal resemblance or structural identity with phenomena, but also has to do with the use and purposes of models, which are plural in nature, saying (Suárez 1999: 82) that "models change if and when their intended uses change." An engagement with these statements can be fruitful in characterizing the role of modeling and its relation to theory in the Babylonian astronomical tradition.

Changes in modeling commensurate with changes in the use and the intended purposes of its use is clearly demonstrable in the cuneiform evidence. We need only consider the use of the theoretical structure of the zigzag function, which, in one of its uses, functioned as a description of the change in the length of daylight which exhibits a clear increase and decrease over the period of a year, regardless of how a year is defined or what its length is determined to be.

The purpose for the zigzag scheme for length of daylight in early Babylonian astronomy (Astrolabes, MUL.APIN, *Enūma Anu Enlil*) is a case in point. This scheme was constructed on a 2:1 ratio of longest to shortest daylight, a ratio which, as Brown et al. (1999: 130) pointed out, probably had more to do with "notions of symmetry or numerical simplicity than it did to observation." The scheme was based on the ideal year (12 30 day months = 360 days) where the Vernal Equinox is placed in the middle of the first month, Nisannu 15, and the ratio of longest to shortest daylight is 2:1. Subsequently this traditional scheme was superseded by a scheme for daylight length that used a better ratio of 3:2, in the mathematical astronomical texts of systems A and B as well as in a late Babylonian text concerning the water clock (BM 29,371, see Brown et al. 1999). The way that the length of daylight was modeled by the particular theoretical structure employed (in this example, the zigzag scheme), changed as the purpose of the scheme changed, that is, from, as David Brown suggested (Brown 2000: 113–22), a scheme to tell when phenomena deviated from conceived norms, to one that represented the change in daylight length commensurate with the position of the sun in the ecliptic, or zodiacal circle.

The late stage in the development of astronomical modeling introduced mathematical analogs to the manner in which a body (meaning a planet in a given synodic phase) could proceed around the zodiacal circle. As shown above, system A modeled the body's progress around the zodiacal circle by means of a step function of discontinuous change in longitude ($\Delta\lambda$) according to zones in the ecliptic, the other, system B, by representing a periodic return to a change in longitude ($\Delta\lambda$) by means of a zigzag function of constant incremental and decremental change between two extrema. This is a quite different application of the theoretical structure of the zigzag scheme as compared with that of earlier Babylonian astronomical texts that focused on daylight length. The non-uniform progress of planets in their synodic visibilities was modeled in system A with a step function without purporting to say that the sun or a planet actually moved at various rates or, as we might say, "velocities," slow around one part of the ecliptic and fast in another. Indeed, "fast" and "slow" conjure up the anachronistic sense of moving bodies but the tables were focused not on continuous motion but rather on the positions in the zodiac of discrete synodic events. Where the planet was in between synodic events was either not of interest, or could be derived by interpolation. Even more removed from a description of "physical reality," so to speak, than system A was system B, which modeled synodic time (τ) and synodic arc ($\Delta\lambda$) as functions of the event numbers in the table. What was modeled in system B are not positions of a planetary body but *differences* in degrees of longitude from position to position as that body progresses through the zigzag function.

Systems A and B each produced heuristic analogues, not intended to represent the actual behavior of the body, but to deal with the anomaly discernible in the empirical evidence. That is, to represent the fact that a planet did not perform equal arcs of synodic progress as it traversed the zodiacal circle, the two systems fashioned different ways of mathematically describing—representing—planetary zodiacal anomaly. Representation can then take many forms, physical description being only one possibility. Even when the modeling of phenomena is not aimed at a literal description of the world it can have a connection to the world and thus have representational value. The Babylonian evidence is effective testimony to Bailer-Jones' idea (Bailer-Jones 2002: 108, 124, 2009: 1, 206) that a model's representational value is not only in being a replica or simulacrum of the phenomena, but in the ability of a model to facilitate access to phenomena. This criterion, in my view, is met by the sort of modeling attested in cuneiform astronomical texts.

The representational or analogical nature of Babylonian astronomical modeling depends upon the relationship between the underlying period relations on one hand and the empirical world on the other, without producing models that represent the world in a direct physical way, that is, either in a material or a mechanical sense. From this perspective, Babylonian astronomical modeling can be said to be representational—in Bailer-Jones' sense it was a process that facilitated access to empirical phenomena—without attempting to describe or represent reality materially or mechanically. Because the purpose of the late Babylonian computational systems A and B was prediction, the aim of their astronomical modeling was not to produce replicas or simulacra of (what we regard as) physical reality. Indeed the schemes can be described as having a distinct *dis*interest in cosmology or physical explanation. As they were not aimed at showing something essential or true about Nature's structures and laws, they do not belong, strictly speaking, to the history of natural knowledge. They do, however, belong to the history of scientific modeling and reasoning via modeling.

What Babylonian astronomical modeling affords us is the opportunity to trace the history of the representation of astronomical phenomena to a time before astronomy became part of natural knowledge and before any stakes in physical explanation were developed. Systems A and B were not developed to represent celestial phenomena as parts of a unified Nature, but were nonetheless anchored to the world of observation and experience, whether directly (as in system A) or indirectly (as in system B).

Embedded in the Babylonian astronomical schemes were not only their particular empirical underpinnings, but also the theoretical substructure which utilized mathematical analogues to represent the phenomena. As shown above, however, those analogues were not isomorphic in structure to the behavior of the phenomena but aimed to describe the phenomenon's "behavior" in a way that would obey available parameters and period relations. Accuracy of representation, in the modern sense, was not one of the intended purposes of the Babylonian astronomy.

The Babylonian mathematical modeling to describe and also to predict planetary and lunar phenomena belongs to the vast evidence from the history of science that shows how matters of so-called fact can be in meaningful relation to various conceptual schemes. What is known, or how something is described, modeled, represented, or explained, itself has an impact on the world so described, modeled, represented and explained. Exemplary illustration of this is how the Greek spherical kinematic models of motion in the heavens drew from a conceptual (and heavily philosophical) model of spherical motion and subsequently validated and perpetuated a geocentric spherical finite view of the world that lasted for nearly 1500 years.

Accordingly, in repudiating the scientific realist claim to a mind-independent world, Hilary Putnam (Putnam 1981: xi) offered that "the mind and the world jointly make up the mind and the world." In other words, for science the world is the object of knowledge, but knowledge also makes the known world, which can then take on a variety of aspects. This returns us to the ontological dilemma of the Babylonian evidence, as their modeling efforts did not seem to be directed toward description of the world as a unified entity, but rather of parts of a world whose physical character is difficult for us to define in the familiar language of naturalism or mechanism.

4 Conclusion

I can now return to the two questions with which I began, namely (1) can Babylonian astronomical modeling be usefully included in the discussion about reasoning, and (2) was that modeling aimed at representation of the world? For much of the twentieth century, in service to the goal of philosophy to provide the foundations of knowledge for science, an important criterion became accuracy of representation, that is, the aim of scientific modeling was to provide an accurate representation of physical phenomena in the empirical world. Rorty (1979: 6) suggested abandoning this notion of "knowledge as accurate representation." He saw (Rorty 1979: 3) the central concern of traditional philosophy to be "a general theory of representation, a theory which will divide culture up into the areas which represent reality well, those which represent it less well, and those which do not represent it at all (despite their pretense of doing so)." He saw the question of how the mind constructs representations as a legacy of the Enlightenment, in which the metaphor of "the mind as a great mirror" took hold. He rightly pointed out (Rorty 1979: 12) that "without the notion of the mind as mirror, the notion of knowledge as accuracy of representation would not have suggested itself." Rorty dismantled the mind-as-mirror metaphor and with it the false dichotomy between, on one hand, epistemology, or the inquiry into how we know what is "out there," and on the other, hermeneutics, or interpretation, that is, what is not simply "out there," but rather is "made up" by human beings.[9]

These are important points for understanding a Babylonian (or perhaps, better, a cuneiform-cultural) epistemology, where representation in cuneiform astronomical texts did not perform the same function as it did later in Greek astronomy, or other chapters in the history of astronomy and physics. This, however, is no measure of how well or poorly the Babylonian scribes understood or could represent "reality." The structure of the Greek cosmos, itself a thoroughly cultural construction, which lent itself to spherical kinematic models, was no more accurate or better a representation of reality than were the Babylonian systems of calculating planetary synodic progress. When this is recognized, then Rorty's critique of the consequences of the old philosophical theory of representation becomes extremely important, as it exposed a distorted anthropology of science that divides up and makes a hierarchy of cultures by their representations of "reality."

In the context of knowledge of heavenly phenomena, modeling played a continuous role throughout the history of Babylonian astronomy, from the Old Babylonian descriptive astronomy to the Hellenistic period predictive astronomy. In all of this prodigious span of time the question of the mind mirroring Nature would have been unintelligible and incomprehensible and thus the representational nature of that modeling has nothing whatsoever to do with the kind of accuracy of representation of the physical or natural world that has been at stake in the last several hundred years of philosophical discourse concerning knowledge and representation. Babylonian astronomical modeling was not the product of thinking about Nature, or of a physical kind of reality, but of solving astronomical problems—theorizing—with mathematical relationships produced by reasoning analogously to events in the empirical world, and by making use of parameters derived from observational experience with the

9 He said, "From this point of view, then, the line between the respective domains of epistemology and hermeneutics is not a matter of the difference between the 'sciences of nature' and the 'sciences of man,' nor between fact and value, nor the theoretical and the practical, nor "objective knowledge" and something squishier and more dubious." (Rorty 1979: 321).

empirical world. I do not think it is too bold to claim that this is scientific theorizing on a continuum with Ptolemy, Copernicus, Kepler, and Newton. That claim has nothing to do with charting success, nor with the linear progressive reconstruction of old, now outmoded, histories or their implied anthropologies of science. While continuous with Ptolemy et al in terms of the process of modeling in the construction of theory, unlike their later kin, the representing that Babylonian modeling effected had no conceptual connection to a physical or a mechanical framework, but existed within a different (ontological and epistemological) framework in which phenomena were not parts of Nature but rather placed celestial phenomena in a matrix with gods and their phenomena. Gods and signs did not occupy an instrumental place in Babylonian mathematical astronomy *per se*, but belonged to the fabric of understanding and interpreting the world that later would be replaced by the celestial sphere and God.

In separating the style of reasoning from the construal of the world that is modeled, described, predicted, or explained by whatever reasoning is employed, the character of Babylonian astronomical modeling can be seen in relation to other kindred forms of scientific reasoning as exemplified by models. And whereas, it seems to me that it is possible to separate the process of modeling from multiple ways of theorizing the world's structure, it is not possible to separate modeling from reasoning; indeed a certain analogical form of reasoning seems to be at work in this process, but, of course, the analogies will refer to the parts of a world in whatever way it is construed, and will bear the signature of that construal, and therefore of its particular perspective.

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