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Children Thinking About Models: Analyzing a Globe

The purpose of this study was to explore to what extent 87 grade 5 (10-12-year-old) children, supported by instruction about scientific models, could engage in thinking beyond a naïve realist level about a globe. A qualitative framework allowed analysis of children's responses to worksheet questions in which they identified analog-target correspondence and how models act as tools for thinking. Children's responses were further analyzed using visual factors (Goldsmith, 1984) and interacting components (Mathewson, 2005) organized to highlight semiotic challenges associated with the models. The data demonstrated a beginning sophistication in thinking about models that for more than half the children was beyond a naïve realist level. Further research with children working with models of less familiar targets and multiple models of the same target is recommended.

Cette étude avait comme objectif d'explorer dans quelle mesure 87 élèves de la 5e année (10 à 12 ans) appuyés par un enseignement sur les modèles scientifiques, pouvaient réfléchir au sujet d'un globe au-delà du niveau du réalisme naïf. Un cadre qualitatif a permis l'analyse des réponses qu'ont fournies les enfants à des questions portant sur l'identification de la correspondance analogique et les modèles en tant qu'outils de réflexion. Les réponses des élèves ont également été analysées selon des facteurs visuels (Goldsmith, 1984) et des composantes interdépendantes (Mathewson, 2005) organisées de sorte à faire ressortir les défis sémiotiques associés aux modèles. Les données ont démontré un début de réflexion sophistiquée sur les modèles qui, chez plus de la moitié des enfants, dépassait le niveau du réalisme naïf. Nous recommandons de poursuivre la recherche avec des enfants qui travaillent avec des modèles de cibles moins connues et avec plusieurs modèles de la même cible.

Introduction

Models have consistently played a role in the professional practice of science and in how scientific concepts are represented to students (Duit, 1991; Gobert & Buckley, 2000; Mathewson, 2005; May, Hammer, & Roy, 2006; Pittman, 1999). Research conducted primarily with middle and high school students has demonstrated, however, that many students do not think beyond a naïve realist view of models (Grosslight, Unger, Jay, & Smith, 1991). Given these findings, researchers have speculated that students would probably benefit from guided instruction about the epistemology of models before interacting with models designed to teach scientific concepts (Boulter & Gilbert, 2000; Harrison &

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Treagust, 2000a, 2000b; Snir, Smith, & Raz, 2003; Treagust, Chittleborough, & Mamiala, 2002). Unfortunately, few studies have focused on the implementation of these recommendations for practice.

In addition to studies with middle and high school students, a smaller number of studies have examined young children's abilities to think about models, and these studies have raised questions about the developmental progressions of thinking about models that are presented in the literature (Abell & Roth, 1995; Gobert, 2000; May et al., 2006). In particular, they question findings suggesting that models are too complex for young children. Researchers wonder if children may be capable of reasoning about models in ways that could lead to a reconsideration of their capabilities in this area.

In this study, we explore the implications of recommendations for teaching students about models before engaging them in learning science concepts through the use of models. Our goal is to explore whether this progression will provide evidence of younger children thinking beyond a naïve realist view of models. The results of this study may provide evidence to support new model-centered teaching practices and identify productive pathways for scaffolding students' thinking about and through scientific models.

Theoretical Framework

In recent years, much research has focused on defining and describing models, considering how models are used in science education, and thinking about how to teach students through models (Buckley & Boulter, 2000; Duit, 1991; Gilbert, 1997; Glynn, 1991, Treagust, Harrison, & Venville, 1998). It has been shown that models can act as a tool for thinking about science, and researchers have speculated that students would benefit from guided instruction intended to help them consider the nature of models themselves (Grosslight et al., 1991; Snir et al., 2003; Treagust et al., 2002).

This research has also included efforts to define exactly what is meant by the term *model*. In this study, we began with the definition developed by Gilbert (1997): Simply, "a model is a representation of an idea, object, event, process or system" (p. 2). This definition recognizes two aspects of a scientific model: (a) the underlying concept, process, or idea, and (b) the object, analogy, or description that represents the concept, process, or idea. Glynn (1991) uses the terms *analog* and *target* to identify these two components where the term *target* identifies the underlying concept, process, or idea, and analog refers to the representation. Glynn argues that in general, an analog is a familiar concept, and a target is an unfamiliar concept. Analogs are frequently in the form of tangible models (scale models, 3D models, pictorial models). It is the analogies embedded in these models that permit comparison between the analog and the target and highlight common properties between the two, allowing complex ideas to be simplified and abstract ideas to be rendered visible (Duit, 1991; Gobert & Buckley, 2000; Ingham & Gilbert, 1991; Mathewson, 2005).

Researchers acknowledge that as students interpret the analog and target, they create personal, internal, cognitive representations called mental models (Coll & Treagust, 2003; Gentner & Stevens, 1983; Gilbert & Boulter, 2000; Glynn & Duit, 1995; Johnson-Laird, 1983). Expressed models are the words, writing, and drawings students use to communicate their mental models to others

(Buckley, 2000; Ergazaki, Zogza, & Komis, 2007). Buckley and Boulter (2000) conclude that when students perceive their mental and expressed models to be adequate, these models then become part of the repertoire of the students' conceptual ecologies (Toulmin, 1976).

Models as Tools for Thinking

Researchers maintain that the creation and use of models has played a critical role in the historical development of scientific knowledge and continues to be a key part of the professional practice of science (Duit, 1991; Gobert & Buckley, 2000; Mathewson, 2005; May et al., 2006; Pittman, 1999). Scientists are continually involved in generating, refining, and validating models to share with the scientific community (Clement, 1998; Duit; Mathewson; May et al.). Consensus models that are agreed on as central to explaining certain phenomena become scientific models that are widely shared throughout the scientific community and serve as a vehicle to communicate ideas. These scientific models, therefore, represent a "perceptual pathway" (Mathewson, 1999, p. 46) to understanding that can be used with other modes of communication to explain and describe scientific phenomena. Similarly, May et al. summarize that scientists use models in the generation, analysis, and synthesis of new knowledge and that models also serve as a vehicle for communicating this knowledge to a wider audience.

In the educational context, researchers have described how models can act as tools for thinking and how they can facilitate learning and promote conceptual change (Abell & Roth, 1995; Brown, 1993; Duit, 1991; Francoeur, 1997; Gilbert, Boulter, & Rutherford, 1998; Glynn & Takahashi, 1998; Grosslight et al., 1991; Hall & Obregon, 2002; Harrison & Treagust, 2000a, 2000b; Hodgson, 1995; Justi & Gilbert, 2002a; Mathewson, 2005; May et al., 2006; Treagust et al., 2002; Yerrick, Dosster, Nugent, Parke, & Crawley, 2003). Models are tools for thinking in that they can be used to make predictions, test hypotheses, interpret evidence, explore conjectures, construct explanations, and communicate ideas (Erduran, 1999; Harrison & Treagust, 2000b; Mathewson, 2005; Treagust et al.). Models also act as tools for visualizing in the mind (Duit; Harrison & Treagust, 2000a). They can help in the visualization of abstract ideas and provide insight into the nature of these ideas (Bhushan & Rosenfield, 1995; Duit; Treagust et al.).

Although many researchers have argued the merits of models, these merits have frequently been couched in language that cautions against an uncritical belief in the efficacy of models as teaching tools (Ainsworth & Loizou, 2003; Harrison & Treagust, 1996, 2000a). It is recognized that in order for analogical reasoning to be successful, students must be familiar with the analog domain (Duit, 1991). Familiarity, however, does not guarantee that students have a complete and correct understanding of ideas represented by the model, and these misconceptions could play a role in students constructing unintended, incorrect interpretations (Duit). Misconceptions can lead to selective attention, a dismissal of key aspects of the model, a resistance to conceptual change, a retention of models beyond their use-by date and increasing frustration with learning (Duit; Harrison & Treagust, 2000b; Mathewson, 2005; Yerrick et al., 2003). Holton (1986) concludes that models can become "handicaps for students, who inherit all of the troubles and none of the rewards" (p. 240).

One of the key areas of difficulty is in the construction of mental models of the relationship between the analog and the target (Duit, 1991; Eliam, 2004; Franco & Colinvaux, 2000; Glynn & Takahashi, 1998; Harrison & Treagust, 2000b; Johnson-Laird, 1983; Justi & Gilbert, 2002a; Vosniadou, 1994), sometimes called mapping (Buckley & Boulter, 2000). During this cyclical and iterative process, students are engaged in perceiving, retrieving, connecting, and evaluating analogies, a process that can be challenging when students attend to divergent aspects of the models or retrieve information that may or may not be helpful to them.

Teaching About Models

In attempting to address these difficulties, studies of students' ideas about models and their attempts to learn science through models (conducted primarily with middle/high school students) have led researchers to argue that before using models to teach specific science content, students should first receive guided instruction about models (Grosslight et al., 1991; Snir et al., 2003; Treagust et al., 2002). Instruction about models should include thinking about the epistemology of models (e.g., What is the nature and purpose of models? What are the connections between models and reality? How do analogies operate?), developing visual spatial skills, practicing analog-target mapping, identifying the strengths and limitations of models, and thinking about how models are human inventions. Furthermore, teachers should encourage students to understand the importance of evaluating the power of individual models and viewing models as tools for thinking rather than as representations of reality.

Gobert and Discenna (1997) have shown that students with more sophisticated understandings of the epistemology of models are better able to use models as a tool for thinking. Other researchers concur that students need many opportunities to reflect on the nature of models and think about the role and purpose of scientific models in science (Duit, 1991; Grosslight et al., 1991; Treagust et al., 2002). This type of preparatory work can lead to students understanding that models are a meta-concept in science and using this knowledge to take a critical approach to using models to learn science (Snir et al., 2003).

An important aspect of teaching students about models includes providing them with practice in analogical thinking, specifically, the mapping between the analog and the target described above. Students first need to work with familiar analogs and targets and practice identifying the strengths and limitations of the analog (Boulter & Gilbert, 2000; Cosgrove, 1995; Glynn, 1991; Harrison & Treagust, 2000a, 2000b; Snir et al., 2003; Treagust et al., 1998). Discussion should focus on assumptions underlying the model and how these assumptions limit the power of the model (Snir et al.). Later work could include the more complex challenge of using familiar analogs to analyze unfamiliar, abstract targets. Some researchers speculate that using multiple models (e.g., diagrams, text, scale models) of the unfamiliar target may help students to overcome misconceptions and focus on relevant features of the target (Kozma, 2000; Mayer & Moreno, 2003; Schnotz & Bannert, 2003). Other researchers have suggested instructional sequences that begin with questions and then support students to invent their own models to understand unfamiliar targets (Reiser et al., 2008; Schwarz et al., 2008).

This body of literature has established the importance of instruction about models for middle and high school students. More research is needed, however, to ascertain the extent to which young children can learn about models and whether this base knowledge can assist them to analyze and interpret models commonly used to explain scientific phenomena.

Progression in Thinking about Models

In addition to exploring how to support student learning about models, some researchers have argued that there is a developmental progression to students' abilities to analyze and interpret models (Grosslight et al., 1991; Harrison & Treagust, 2000a). This progression may be influenced by the students' abilities to interact with abstract phenomena, the sophistication of their visualization skills, and their epistemological view of models - factors that hint at the complexity of defining a progression to thinking about models (Ferk, Vrtacnik, Blejec, & Gril, 2003; Grosslight et al., 1991; Mathewson, 2005).

Grosslight et al. (1991) worked with grades 7 and 11 students and a small group of experts and explored participants' conceptions of models and how they think models are used in the professional practice of science. Their analysis suggested an epistemological progression in thinking about models that they sorted into three levels. Most of the grade 7s scored at Level 1, reflecting a belief that models were a simple copy of reality (a naïve realist view). The remainder scored at Level 2 (e.g., able to distinguish between the ideas motivating the model and the model itself; realize that the purpose of the model influences the form of the model) or a mixed Level 1/2. Only the experts were able to approach Level 3 (e.g., models are created to develop and test explanations). Although these three levels of epistemological progression provide a fruitful scheme for grouping students' ideas about models, researchers were less certain about assigning ages to levels and were unconvinced that students' epistemologies developed unilaterally across domains. They did, however, speculate that during the elementary years, students tend to retain a naïve realist epistemology (Level 1).

Little research, however, has explored whether young children are capable of practicing the analogical thinking necessary to interpret models beyond the naïve realist level. Certainly descriptions of progression in analogical reasoning coupled with studies of the intellectual demands of various models paint a daunting picture for young children's potential engagement with models. A few studies, however, provided promising examples of elementary students' use of models.

May et al. (2006) studied grade 3 children and observed that they could spontaneously generate analogies at varied levels of sophistication, and some could generate analogies to illustrate an entire mechanism. Some children were able discuss and critique analogies and identify limitations of analogies. Other children were able to extend and refine analogies spontaneously generated by classmates. In reference to their larger study with K-8 children, May et al. described additional examples where grade 5 children used their own analogies during science discussions. They concluded that children's use of

Table 1
Anchoring Questions from the Understanding Models in Science Teaching Resource

Anchoring Question	*Purpose*
How is the model like the real thing?	Exploring the extent to which grade 5 children can engage in analog-target mapping, and identify and describe the strengths of a model.
In what ways is the model not like the real thing?	Exploring the extent to which grade 5 children can engage in analog-target mapping, and identify and describe the limitations of a model.
What incorrect ideas could people have if they believed that this model was the real thing and not the model?	Exploring the extent to which grade 5 children can assume the perspective of a naïve realist and engage in thought experimentation about the model. Exploring the extent to which grade 5 children can express how a model represents limited aspects of the real thing.
In what ways does the model help you understand the real thing?	Exploring the extent to which grade 5 children can express how a model can act as a thinking tool and how it may promote conceptual understanding.

from the "emotional impact of entering strange territory" (p. 48), a factor we attempted to diminish through the choice of familiar analogs and targets.

It was also important to understand a globe in the context of the challenges that it may pose for children. Buckley and Boulter (2000) used Goldsmith's (1984) analytical framework to help examine the communication value of models and analyze challenges that may arise in interpreting particular models. Briefly, Goldsmith lists semiotic levels (syntactic, semantic, pragmatic) and visual factors (unity, location, emphasis, text parallels) that when presented in a matrix, help to identify aspects of a model that might present difficulties and exemplify potential semiotic challenges. Buckley and Boulter claim that Goldsmith's analytical framework "is particularly helpful when considering what the learner makes of the particular aspects of the phenomenon represented" (p. 126). In addition, Mathewson (2005) has examined representations shared by the scientific community and has identified what he calls master images (e.g., structure, setting, boundary) that recur in these representations. These master images or interacting components also provide a way of analyzing the visual aspects of models and identifying what stands to hinder or facilitate model interpretation. To better understand the globe as a model, we analyzed it using a combination of these two frameworks. This analysis is presented in Table 2 in which the strengths and weaknesses of the globe are summarized in the context of these visual components. The analysis foreshadowed the elements of the globe that could arise during the children's efforts at analog-target mapping.

Briefly, to define the terms, Goldsmith (1984) describes *Unity* as any area of a model "that might be recognized as having a separate identity" (Buckley & Boulter, 2000, p. 126). Graphic elements contributing to unity would include lines between countries that indicate borders. Mathewson's (2005) master im-

Table 2
Visual Factor Analysis of a Globe

Visual Factors	*Strengths* *A globe includes:*	*Limitations* *A globe does not include:*
Unity	• boundaries between land and water	• flow between boundaries
	• groups of countries on continents	• indications that some boundaries (e.g., borders) are human inventions
	• groups of provinces and states within countries	• the complexity of life forms that characterize these landforms and water features
	• external shape provides an overall arrangement of interconnecting parts	• change over time • overall magnitude • atmospheric context • the materials that make up land, water, living and non-living things
Location	• points identifying singular locations	• indication that lines of latitude etc. are human inventions
	• areas of denser and sparser human habitation	• Earth's location in space
	• lines of longitude and latitude	
	• equator signifying a mid-point	
	• poles signifying end-points	
Emphasis	• color coding to show different countries; land versus water areas	• indication that some colors are false (human inventions) and some are true
	• motion to draw attention to rotation	• direction of motion, rate of motion or planetary path
	• tilt	
Text Parallels	• names of human settlements (cities, countries) and landforms (mountains)	• indication that names are human inventions • topographical gradients
	• names of water features (oceans, seas, rivers)	

ages of boundary, branching, groups, and surface also generally describe themes of unity. *Location* as used by Goldsmith describes spatial relationships among images and serves as an organizer for Mathewson's master images of point, setting, structure, and path. Goldsmith describes *Emphasis* as addressing the hierarchical relationships among aspects of the model, and in the context of a globe, was seen to include Mathewson's master images of color and motion. Goldsmith's final visual factor, *Text Parallels*, highlights relationships among images and words and appeared close to Mathewson's master image of signs. The blending of Goldsmith's and Mathewson's work draws attention to the complexity of ideas that are represented by models and helps to reveal semiotic challenges associated with a given model.

In the process of addressing our research questions, we were interested in whether children could identify a globe's strengths and limitations and if so, what factors they would use to identify analog-target correspondence and what messages this would have about young children's abilities to interpret models. Table 2 illustrates possible strengths and limitations as analyzed from the blending of Goldsmith's (1984) and Mathewson's (2005) frameworks.

Development of the Analysis Schemes

The students' worksheets were analyzed in two ways. First, we paid attention to the specific strengths and limitations that students identified for the globe and categorized these ideas using the visual analysis outlined in Table 2. Then in the second analysis, we reviewed the students' overall responses and assessed whether the children had engaged in thinking beyond a naïve realist level about the globe (see Appendix B for a sample worksheet analysis).

The first level of analysis began with a detailed reading of the students' worksheets with special attention paid to the students' analysis of the strengths and weaknesses of the globe. After the detailed first reading of the data, a second reading was conducted during which segments of text (phrases, sentences, or single words) were categorized with preliminary code names. As subsequent segments were analyzed, they were categorized either using one of the existing preliminary codes or using a new code created to describe the segment. Note that the worksheet was organized around the four anchoring questions described above and a separate analysis was conducted for the students' responses to each of the questions.

When one of us had completed the cycle, the other read the worksheets and examined the codes that had been assigned to each segment of text. This process was used to establish inter-rater reliability and ensure a trustworthy analysis of the data (Glesne, 1999). The reanalysis resulted in our coding of 95% of the segments in the same way. The remaining segments were discussed until consensus was reached on the coding.

The final stage of the first-level analysis involved examining the emergent themes from the children's worksheet responses (e.g., incorrect ideas about the magnitude of the earth, incorrect ideas about signs and markings) for alignment with the visual analysis outlined in Table 2. Each of us individually proposed connections between the student themes and the visual factors. These were discussed until we reached consensus.

The second level of analysis involved comparing students' responses to the first two levels of thinking about models described by Grosslight et al. (1991, see Table 3). Grosslight et al.'s Level 3 criteria were not addressed in this study and thus were not applicable to the second level of analysis. The aim of this analysis was to sort each student's responses and provide insight into whether they were engaging beyond a naïve realist view of models (Level 1). In a process similar to that used during the first level of analysis, one of us conducted the initial analysis, and then the other reviewed and critiqued the levels that had been assigned to each of the students. Disagreements were discussed until a consensus was reached.

Findings

Analog-Target Mapping

The initial lesson from *Understanding Models in Science* began with the opportunity for the students to share their existing ideas of the word *model*. Students

Table 3
Levels of Thinking about Models from Grosslight et al. (1991)

Level of Thinking About Models	*Description*
Level 1*	Models are toys or simple copies of reality. Models are useful because they provide copies of actual objects or actions. Models may vary from the real thing in size or materials. No reasons provided for why parts of the real thing can be left out of the model or why any differences could be important.
Level 2**	Models no longer must exactly correspond with the real-world object being modeled and identified strengths and limitations provide insight into the real-world object. Tests of models are not tests of underlying ideas but of the workability of the model itself.

*Level 1 category has been adjusted to include study responses that focused on simplistic aspects of models such as size and materials. Although Grosslight et al.'s work did not include these examples, in the present study such responses were judged to indicate a preliminary understanding of the nature of models.
**Level 2 category has been adjusted to include responses that showed a consistent recognition that there were aspects of the model that were important to providing information about the real-world object.

were told that scientists use models to explain ideas and make predictions, and several examples of models were discussed (e.g., model of the solar system, picture of a life cycle). The teacher provided a definition of a model (*A model is a representation of something that is real that helps us to understand more about the real thing*) and introduced the idea that every model has strengths and limitations. The four anchoring questions listed in Table 1 were discussed, and then the students worked in small groups to examine a globe and complete the worksheet questions. In the following analysis, we present the themes that emerged from analyzing the students' responses to each of the four questions. They are labeled in the tables in relation to the visual factors described in Table 2.

Table 4 illustrates the visual factors children attended to when asked to describe how the globe was like the real thing.

The data show that many children used ideas associated with unity, location, and to a lesser extent emphasis to identify perceived similarities between the globe and the real thing. Some children, however, struggled with the question. Five appeared to misread the question and provided answers unrelated to the task at hand. Eight others had difficulty responding to the question with five writing that the globe was "like the real world" or "like the real thing." Three of the eight children wrote that the globe was simply a smaller version of the earth. These responses lacked sufficient detail to allow sorting and showed a lack of focus on the globe's detailed and interacting visual components. In addition, one student appeared challenged by the idea that the globe was a model with strengths and limitations and wrote that the globe "shows everything on the real world and is accurate."

Table 4
Summary of Student Responses to Question 1:
How is the model like the real thing?

Visual Factors	*Number of Responses**	*Sample Written Responses*
Unity	64	*Surface features, landforms, boundaries, shape:* Shows water, continents, land, mountains, islands; Both (the globe and the Earth) are round
Location	51	*Human locations:* Shows cities, countries, provinces, places, states, equator
Emphasis	20	It rotates; it is tilted
Text Parallels	2	*Names of places:* names of the oceans

*For all questions, children's responses could feature ideas that could fit in more than one category.

For the most part, the children were able to identify and describe the model's strengths. A view from space would show the overall shape and movement of the earth, major landforms, and large urban areas. Indications of human inventions, however, such as the equator, borders between countries and provinces, and place names would not be evident from space. But what did the children visualize as the real thing? If a child understood the real thing to be their surrounding world, then it would be reasonable to write that certain human inventions (e.g., place names) *were* visual factors shared by the model (place names on the globe) and the real thing (place names on signs found throughout the world). The second anchoring question was designed to explore children's ideas about the limitations of the model and stood to provide further insight into how the children were visualizing the real thing.

Table 5 shows that when answering the second anchoring question, the children addressed a range of visual factors, with unity once again proving most popular.

Three children did not provide a specific answer to the question and simply wrote that the model is "not the real thing" whereas four other children misread the question and could not be categorized. Although response numbers listed in Table 5 reveal that children's responses could feature ideas that fitted more than one category, instances remained when children wrote ideas that did not align with the visual factor analysis of the globe. For example, three children wrote that a limitation of the globe was that it lacked a core: an idea that does not appear in the visual analysis. Also, two children wrote responses that showed incorrect perceptions of the limitations of the globe (e.g., "the model is at an angle," "doesn't say the population"). Overall, children's responses showed that they used existing ideas about the appearance of the earth from space ("it is not in space," "no one lives on the Earth") and the surrounding world ("it is not made of mud") to visualize the real thing. Many children shared accurate ideas about the limitations of the model and included a variety of visual factors.

Table 5
Summary of Student Responses to Question 2:
In what ways is the model not like the real thing?

Visual Factors	*Number of Responses*	*Sample Written Responses*
Unity	57	*The model includes incorrect ideas about the magnitude of the Earth and materials:* It is really tiny; It is not that small or light; It's cardboard; it's plastic; It is not made of mud, dirt or anything like that; it has borders; no borders between countries
Location	37	*The model includes incorrect ideas about position and human inventions:* It is not in space; You can't see the equator; No longitude or latitude; No lines on the Earth; does not show every town and city; does not show streets, schools, or houses
Emphasis	28	*The model includes incorrect ideas about colors:* China isn't yellow; it doesn't move like the real one
Text Parallels	29	*The model includes incorrect ideas about signs and markings:* It has words on it

Table 6 shows the children's responses to an anchoring question intended to explore whether they could assume the perspective of a naïve realist and engage in thought experimentation about the model.

Similar to Table 5, many students wrote responses that showed that they were able to identify a range of visual factors that could lead to people having incorrect ideas about the real Earth. Ten children, however, misread the ques-

Table 6
Summary of Student Responses to Question 3:
What incorrect ideas could people have if they believed that this model was the real thing and not the model?

Visual Factors	*Number of Responses*	*Sample Written Responses*
Unity	42	*Incorrect ideas about the magnitude of the Earth, materials, and boundaries:* The Earth is really tiny; Countries are small; It is plastic; World is hollow; World is made of paper; The boundaries and borders are really there; You can see countries
Location	16	*Incorrect ideas about position and human inventions:* Equator, longitude, latitude, countries, has lines on it; does not show all cities and countries
Emphasis	23	*Incorrect ideas about earth motion and colors:* It is going to spin when they put their hand on it; Some places are pink, orange, and blue
Text Parallels	24	*Incorrect ideas about signs and markings:* They would think it has letters on the earth; It has words on it; There are names of countries on the place; They would think it says "North America" on the continent

tion, and two more wrote "it is like the real thing," an answer that prevented categorization. Three more children provided imaginative answers, with one taking the perspective that only aliens could think that a globe was really the Earth because if they were human they would be on Earth ("They're aliens because they're not on it"), another reasoning, "If the globe was destroyed the world would blow up," and a third writing, "If they set it on fire, the apocalypse would happen." These imaginative responses (and all other students' responses) are indicators of how the students used existing knowledge to shape their worksheet responses. Although these imaginative responses could not be categorized using the framework in Table 6, they still provided insight into how experiences from outside the classroom (e.g., TV, movies, books) influenced students' thinking. In the lesson, the teacher was advised to begin by exploring the children's existing ideas about the word *model* and cautioned that students frequently share ideas from outside the classroom.

In summary, children's responses ranged from those that contained a range of visual factors (both accurate and inaccurate) to those that prevented categorization. Probably most impressive was many children's abilities to identify at least some of the globe's strengths and limitations. These responses, however, showed a range of sophistication, with some children writing modest answers (the model is like the real thing because "it is round") and others writing more extensively (the model is like the real thing because "it shows the tilt of the earth, it rotates, it shows the oceans, seas, lakes, rivers, land and it shows the earth is round").

Using the Globe as a Tool for Thinking

The final worksheet question was asked in order to explore the extent to which the children could write about how a model could act as a thinking tool. Table 7 shows that many children thought the globe represented the Earth and was a valuable tool for showing and telling details about the Earth. A smaller group wrote that the globe helped them to learn and understand because the model allowed them to do things (plot distances) and construct a more meaningful understanding of existing ideas (about topography, movement, and relationships among countries).

Table 7
Summary of Student Responses to Question 4:
In what ways does the model help you understand about the real thing?

Category	*Number of Responses*	*Sample Written Responses*
Represents the Earth	62	Shows you the cities; Shows where everything is; Shape of countries; Shows all the places; Tells you what the world is like; Earth is round and the globe is round; Explains where places are; Shows the tilt; Says stuff; Shows where the equator is; Gives us an idea where countries are
Assists with Learning and Understanding	27	Understanding the textures (topography); Helps to figure out where everything is; Helps to understand the angle (tilt); Helps us to understand shape and location; Helps to understand that the Earth spins; Helps to understand where countries are in relation to each other; Helps to figure out how far away you are from somewhere

One child does not appear in Table 7 as he wrote that the model helped to understand the real thing because it "looks like one," and four other children misread the question and could not be categorized.

Overall, the children's responses to the anchoring questions showed that they believed the globe to have a variety of strengths and limitations. They were able to use a wide range of visual factors to analyze the globe, and many agreed that the globe could act as a thinking tool for representing the Earth.

Levels of Thinking About Models

Children's responses to the anchoring questions allowed a second level of coding that involved alignment with Grosslight et al.'s (1991) levels of thinking about models (see Table 8).

Students grouped in Level 1 persisted with naïve realist views of models throughout the worksheet: they described the globe as copy of the Earth or just a smaller version of it. They offered few explanations of the differences between the analog and the target or why those differences could be important. In identifying limitations of the model, they tended to focus on simplistic aspects such as size or materials. Students who were grouped into Level 2 offered some consistent recognition that there were aspects of the model that were important for giving information but were not copies of reality. These were visual factors such as position, human inventions, signs, and markings that were important for understanding the Earth.

Table 8 shows that about half of the grade 5 children wrote answers consistent with Level 2 descriptors. These children were confident that the globe did not correspond to the Earth and supported their views by writing about a variety of visual factors that highlighted the strengths and limitations of the globe.

Table 8
Grosslight et al.'s (1991) Levels of Thinking about the Globe

Level of thinking about models	**Number of participants*	*Example criteria*
Level 1	42	Models are toys or simple copies of reality (e.g., just different sizes or "it's just not the real thing"). Models are useful because they provide copies of actual objects or actions (e.g., "it shows every country and city," "it shows the shape"). No reasons provided for why parts of the real thing can be left out of the model.
Level 2	37	Models no longer must exactly correspond with the real-world object being modeled. Focus on aspects of the model that do not replicate reality (e.g., markings, colors, material, size) and not a focus on the ideas portrayed. Tests of models are not tests of underlying ideas but of the workability of the model itself.

*Eight children could not be categorized due to missing answers or their misreading worksheet questions.

Discussion

The intent of this study was (a) to identify visual aspects of the globe that children use during analog-target mapping; (b) to identify visual aspects of the globe that may in particular facilitate this mapping; and (c) to explore to what extent children engage in thinking about a globe beyond a naïve realist level.

Research with secondary students suggested that younger children would find it challenging to engage in the analogical thinking that underpins analog-target mapping and that they would struggle to move beyond a naïve realist view of models. To explore this claim, the lesson was designed to provide direct guidance in model analysis, and the anchoring questions were explicitly written to highlight and teach the analogical thinking necessary for making connections between the analog and the target. We assumed that this approach to model analysis would act as a necessary precursor to later work with analyzing models of small, unseen particles.

Children Identifying Visual Aspects of the Globe

Visual factors and interacting components were presented as a way to analyze the globe visually. This analytical framework provided a way of organizing children's written responses to worksheet questions and held the potential to show what caught the eye. Research with secondary students had not featured a similar analytical framework, but had hinted that many secondary students viewed models as being alike except for scale, an answer that does not identify the many limitations revealed by our visual analysis (Grosslight et al., 1991). Similar to these secondary students, some of the grade 5 children provided limited answers to questions intended to engage them in thinking about the globe's strengths and limitations (e.g., "The globe is a smaller version of the Earth").

Also evident in the children's responses is that they identified a wide variety of interacting components to illustrate the strengths and limitations of the models. These interacting components could be grouped under all four visual factors, and analysis showed that Unity proved most common with Location, Emphasis, and Text Parallels also garnering much support. We speculate that some students' abilities to notice a variety of visual factors contributed to their successful negotiation of the model. Students identifying a narrower selection of visual factors (i.e., a narrower band of strengths and limitations) could be indicative of a struggle to engage in thinking analytically about the model. Visual factors, therefore, are promising indicators of the potential communication value of the models, and children's abilities to determine the strengths and limitations of these factors could help explain the variable effectiveness of models.

Another interesting question is why Unity appeared such a popular visual factor. The design of the globe was intentional, and design decisions involved trade-offs between the needs to be met by the model (e.g., illustrating important features and interconnections) and design constraints (e.g., cost, size, and graphical constraints). In part, design decisions set the stage for how students interacted with the models. Design decisions to include selectively only some information and to highlight this information using a selection of graphical techniques in part set the context for unity responses. For example, globe designers chose to include much information about boundaries between land

and water and between countries, states, and provinces. These design decisions contributed to the popularity of Unity responses and played a role in the nature of the analytical thinking in which children could engage for any given model.

Children's Levels of Thinking About the Globe
Grosslight et al.'s (1991) levels of understanding about models were presented as a way to sort the children's responses and determine whether these grade 5 children were capable of moving beyond a naïve realist view of models (Level 1). Grosslight et al.'s research had focused on secondary students and presented a persuasive picture of their epistemological beliefs about models. Along with other researchers, however, they did suggest that teaching students about models could potentially help them progress in their beliefs about models. To start students on the path to thinking about models, we selected a model linked to the mandated curriculum. Although we selected a familiar model, we did not believe that this guaranteed that the children would think beyond Level 1. In a pre-lesson survey unreported in this article, about three quarters of a subset of 24 children who responded to questions about the globe as a model for the Earth were judged to be in Level 1. After their work in Lesson 1, fewer than half of the children remained at Level 1. Although we make no claims to have conducted an intervention study, it was clear that some children were constructing more sophisticated ideas about models. We speculate that the children's prior knowledge and familiarity with the analog and target, their conversations with the teacher about models, their opportunities to revisit the anchoring questions, and their social negotiation of the strengths and limitations of the models all contributed to a progression in some children's ideas about models. This grounding in thinking critically about models represented a promising initial pathway to teaching children about models of small, unseen particles.

Conclusion

Findings from this study are compatible with earlier research on young children's analogical thinking, namely, that children are capable of analogical reasoning and that they can show variable sophistication in their thinking. The study illustrates that direct instruction about models and opportunities to interact with a familiar model provides a context in which many grade 5 children can identify some of the model's strengths and limitations. Children who were able to identify a range of visual factors understood that a model did not need to correspond exactly with the real thing and were categorized as having a Level 2 understanding. Analyzing the visual factors and interacting components of models provides a useful framework for helping to judge the degree to which children are able to negotiate a given model successfully.

Ideas for Future Research
The research reported here raises ideas and questions with respect to children's thinking about and with models that is in need of further investigation. These ideas and questions include:

- What is the nature of visual factors identified by children analyzing models of less familiar targets? Multiple models of the same target?
- What teaching strategies can be used to help children continue to progress in their meta-conceptual knowledge about models?

- How does the opportunity to think about models influence children's interactions with models used to teach science?
- How should teachers introduce students to models of small, unseen particles? Should teachers first teach about models before introducing these scientific models?

These questions are all based, however, on the important recognition that young children can move toward sophisticated thinking about models. The important outcome of this study is to illustrate the range of analysis in which students can be engaged and the important function of guided instruction focused on understanding and critiquing models.

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Appendix A
Lesson #1: What is a Model?

Concepts
- A model is a representation of something else.
- All models have strengths and limitations.

Skills
- Observing scale models and pictorial models.
- Analyzing the strengths and limitations of models.
- Communicating ideas about models.

Attitudes
- Flexibility in thinking about different ways to model a real thing; open-mindedness in regards to listening to other students; communicating different ideas.

Materials: scale model (e.g., globe), pictorial models (e.g., pictures of life cycles, maps of familiar areas); Worksheet #1

Introduction:
1. Begin the lesson by exploring the children's ideas about the word *model*. Children can record their ideas in their notebooks or a class chart of ideas about *model* can be compiled. (Note: children will frequently share ideas about fashion models, model toys, etc.)
2. Tell children: In science, scientists use models to help explain ideas, help people understand their ideas, and make predictions about ideas. For example, scientists draw pictures of life cycles to help us understand more about life cycles, scientists build skeletons to help us understand more about bones, and scientists build models for the solar system to help us understand more about planets.
3. In general: *A model is a representation of something that is real that helps us to understand more about the real thing.*
4. Relate back to children's existing ideas about the word *model*. Which existing ideas are representations of something that is real that helps us to understand more about the real thing?

Activities
1. Scale Models (e.g., globe): Distribute globes to small groups of children. Tell children that when looking at and thinking about models you should always ask questions about the model because no models are perfect. Instead they are "good enough" for helping to understand certain aspects of the real thing. Every model is a "good enough" model. (Write the following questions on chart paper)

> How is this model like the real thing?
> In what ways is the model not like the real thing?
> In what ways does the model help you to understand about the real thing?
> What incorrect ideas could people have if they believed that this model was the real thing and not a model?

2. Have children work in groups to analyze the globes and answer the above questions using Worksheet #1. Review children's answers with the whole group.
3. Tell children: A globe is a scale model. It mostly looks like what it represents. Other models do not look like what they represent but are still useful for helping to understanding something.
4. Pictorial models (e.g., picture of a life cycle, map of a familiar city or area): Picture models are another type of model used by scientists to help us understand

something. Provide children with pictorial models and have them work through the same above questions.

5. Whole class sharing: How is the picture model like the real thing? In what ways is the picture model not like the real thing? In what ways does the picture model help to understand about the real thing? What incorrect ideas about streets could people have if they believed everything in the picture model? How do you have to use your imagination when you see and use the picture model?

Closure: [whole group discussion]

1. How would you describe what a model is to someone who has never even heard the word before? (anticipate a variety of answers such as "something that represents something else")
2. Is it possible to make a perfect model? (No.) Why or why not? (models are human inventions; all models differ in some way from the real thing; some models are designed to highlight just one aspect of the real thing)
3. How can models help you to understand about the real thing? (models make something easier to see and imagine; models can provide a smaller model of a really large real thing)
4. How can models result in you misunderstanding the real thing? (not everything about the model may be accurate)
5. Why do scientists create models? (to help us see things; to help us understand and explain things)

Worksheet #1: Thinking About Models

Name: ____

Part 1: Thinking about a Globe

1. How is this model like the real thing? ________________________
____
____
____

2. In what ways is the model not like the real thing?________________
____
____
____

3. In what ways does the model help you to understand about the real thing?
____
____
____

4. What incorrect ideas could people have if they believed that this model was the real thing and not a model?
____
____
____

5. How do you have to use your imagination when you see and use a globe?
____
____
____

Appendix B
Sample Worksheet Analysis—Lesson 1
Models That Look Like What They Represent

Fill in the following chart as you look at and talk about the globe.

How is this model like the real thing?	Child A: It's smaller [*unable to categorize*] Child B: It's like the angle of the globe is the same as the earth, the real earth because it shows the shape of countries, borders and it shows where the water is and where the land is [*focusing on human location—Unity; Location*]
In what ways is the model not like the real thing?	Child A: It is not the real thing [*unable to categorize*] Child B: The countries aren't actually that small and the countries aren't labeled or colored and the earth doesn't actually have an equator [*focusing on incorrect ideas about size—Unity; incorrect ideas about color—Emphasis; incorrect ideas about human inventions—Location*]
In what ways does the model help you understand about the real thing?	Child A: It shows you the cities [*focus on human location—Location*] Child B: It helps because it gives us an idea of where the countries are and which were beside. The world spins [*focusing on location and movement—Represents the Earth*]
What incorrect ideas could people have if they believed that this model was the real thing and not a model?	Child A: It's like the real thing but is not [*unable to categorize*] Child B: They could think the countries are actually colored and that is what the world actually looks like [*focusing on colors—Emphasis*]

Child A Categorized with a Level 1 (naïve realist) Understanding (Grosslight et al., 1991)
Child B Categorized with a Level 2 Understanding (Grosslight et al.)