ORIGINAL ARTICLE

Students' Models of Magnetic Interactions: A Comparative Analysis of Accurate and Inaccurate Models over a Ten-Year Interval

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***Abstract**: This research investigates the Models of eighth-grade students in Turkey pertaining to magnets and magnetic interactions, while also examining the consistency of these models within themselves. Additionally, a comparative assessment is conducted by comparing the current data with data collected from eighth-grade students a decade earlier. The study comprises 59 students in the first phase and 45 students in the second phase, all of whom briefly received formal instruction on magnetism during fourth grade. The focus of the analysis centers on identifying the students' Models and evaluating their coherence across diverse contexts in both phases. Surprisingly, despite the passage of ten years, the mental model patterns exhibited by the students in both studies remain remarkably similar. Three primary categories emerged from the students' Models of magnets, including attraction and repulsion, magnetic poles, and the composition and functionality of magnets. However, noticeable distinctions between the two studies are evident. In the earlier study, the students' responses to survey questions displayed a greater variety and detail in comparison to the responses from the later study. Moreover, the second study revealed fewer instances of inconsistent Models concerning the magnetic interaction between magnets and nails, but more instances of inaccurate Models compared to the first study. The findings of this investigation offer valuable insights to educators, guiding them in designing effective lessons and activities aimed at helping students overcome their inaccurate and inconsistent Models.*

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Introduction

PHYSICS concepts are perceived as difficult and inconceivable by many students since physics understanding requires comprehension of different representations such as experiments, equations, math, and graphs, as well as conceptual explanations. Recent research revealed that many physics concepts pose obstacles to students' comprehension as well as their development of accurate models of those concepts (Sederberg, 2012; Thurn et al., 2020). As a result of engagement with physical phenomena, students come to the classrooms with an idea or model of physical concepts which are mostly not complied with definition that scientifically accepted (di Sessa, 1983). Furthermore, those incomplete or incorrect models cause an even bigger barrier to meaningfully understanding current and future concepts. Current literature offers much research to understand the underlying reasons for which students have difficulty learning science concepts. Every researcher has defined terminology to explain these underlying reasons. Some of those terms are misconceptions (Gilbert, 1983; Şengören, 2010); preconceptions (Kucukozer & Kocakulah, 2007); alternative concepts (Şengören, 2010); children's science (Osborne & Freyberg, 1985); and non-normative ideas (di Sessa, 1983). Although some of these terms have been used to refer to the same phenomenon, most of them are slightly or quite different from each other. For example, the term "misconception" is thought to be a synonym for "preconception," but there are subtle differences between the two. Misconceptions could be considered a completely incorrect piece of knowledge. Preconceptions, on the other hand, could be both correct and incorrect ideas. All these terminologies about the reason of students' learning challenges compromise around one common ground: students' existing models which provide a foundation for individual learning process (National Academies of Sciences, Engineering, and Medicine, 2018). Researchers who used the term "model" in their studies came up with their own definitions. For example, Craik's definition of model describes model as a cycle: first, it translates all external data into symbols, pictures, and internal models. Combine and compare those with existing models, and then translate back to these models for external representations (Craik, 1943). Gentner (2001) used the term "mental model" to explain a domain or a case that helps to understand a phenomenon, reason about that phenomenon, or make a prediction. As a cognitive scientist, di Sessa claimed that individuals try to interpret everything around them by rearranging and adjusting their existing ideas to new pieces of information, and they start to understand the external phenomena. He used the term "p-prims" (phenomenological primitives) to describe these knowledge structures, and he used p-primes in a different context than the term "Models."

In this work, I used the term "model" to include early researchers' term "mental model" to refer to individuals' internal representation of everything that they encounter. These models could take the form of a symbol, a scent, a picture, a verb, a graph, a formula, etc. Students' understanding of science concepts is highly dependent on how they construct their knowledge based on their previous knowledge of and experiences with physics phenomena (Ravanis et al., 2010). Constructivist researchers argue that students construct knowledge instead of acquiring it (Von Glasersfeld, 2013). Departing from this theory, science educators have begun to focus on knowledge construction as a process of generating and refining models (Gentner, 2001; Johnson-Laird, 1983), a construct that encompasses students' challenges with science concepts.

Students' Model in Magnetism and Magnetic Interaction

Since models are used to make sense of information by everyone, researchers started to study students' model representations about different topics of science, particularly physics topics, which students mostly struggle to understand. The nature of magnetism is one of these concepts that causes difficulties in students' learning and some scientifically inaccurate models (Kähkönen et al., 2020; Maloney et al., 2001; Sederberg & Bryan, 2010; Thurn et al., 2020). There are studies that have examined students' model representations about magnetism in K–12 classrooms (e.g., Greca & Moreira, 1997; Kähkönen et al., 2020; Ravanis et al., 2010; Sederberg, 2012). These studies revealed that students have both accurate and inaccurate models of magnetism. They also shed light on the students' different model representations of magnetism.

Numerous studies have been conducted to explore the challenges students encounter in comprehending magnetic phenomena. Several models of magnetism, such as the charge model (Borges & Gilbert, 1998; Kähkönen et al., 2020), pulling magnet model (Kähkönen et al., 2020; Voutsina & Ravanis, 2012), emanating model (Erickson, 2013), action-at-a-distance model (Bar & Zinn, 1998), electric polarization, and field models (Borges & Gilbert, 1998; Kähkönen et al., 2020), have been identified as scientifically inaccurate representations of magnetic interactions. However, scant attention has been given to studies focusing on students' conceptualizations regarding the interactions between magnets and objects, with a notable decline in the number of investigations at the K-12 level in recent times.

For instance, Ravanis et al. (2010) examined ninth-grade students' conceptualizations of magnetic fields and observed that many students resorted to the Newtonian model to explain magnetic phenomena. Moreover, Henderson et al. (2019) investigated potential gender disparities concerning electricity and magnetism topics using the Conceptual Survey of Electricity and Magnetism (CSEM), revealing a gender gap favoring male students in their grasp of E&M concepts.

Some other studies focused on improving students' understanding of magnetic phenomena. For example, Kalogiannakis et al. (2018) conducted an empirical study employing the story reading method to assess its impact on preschool students' understanding of magnetism. Utilizing an illustrated fairy-tale storytelling approach, they noted positive changes in both male and female students' perspectives on magnetism. Similarly, Cai et al. (2017) developed an augmented reality (AR) based motion-sensing software aimed at enhancing the comprehension of magnetic fields among 8th-grade students. Through experimental design, they ascertained those students who utilized the AR software exhibited improved learning attitudes and outcomes compared to those who did not.

Numerous scholars have delved into the exploration of students' conceptualizations concerning magnetism, magnets, and magnetic interactions. However, there remains a notable dearth of studies investigating the consistency and accuracy of students' models across diverse contexts pertaining to the same phenomenon. Lemmer et al. (2020) investigated the understanding of basic-level magnetism concepts among 12 secondary students. In this study, the researchers also examined whether students consistently applied their incorrect understandings to answer other questions, revealing that a significant portion of students exhibited inconsistency in their conceptualizations. Departing from the current research findings and considering the gap in the literature, this study aimed to examine 8th grade students' model representations about the nature of magnetic interactions. Within this study, the consistency of the students' models and the logic behind their construction were identified. In their research, Kähkönen et al. (2020) employed the identical survey utilized in the present study, titled as "Magnets and Magnetic Things," to investigate the Models of magnetism among Finnish secondary students. The participants consisted of 12 students who had not received any prior instruction on magnetism before their involvement in the study. The researchers categorized the students' Models of magnetism into six distinct categories, namely the charge model, field model, pole/domain model, field/domain model, magnetism as pulling, and pole/field model.

There are a couple studies conducted to examine Turkish secondary students' misconceptions conducted almost 13-20 years ago (Demirci & Çirkinoğlu, 2004; Kucukozer & Kocakulah, 2007), conceptualizations (Tanel & Erol, 2008; Yurumezoglu & Cokelez, 2010), and models (Saglam, 2010; Şengören, 2010) about electricity and magnetism, particularly about electricity (Başer & Geban, 2007; Turgut et al., 2011) and electromagnetism (Saglam & Millar, 2006). Recently most studies were conducted with college students in Türkiye (Güler & Şahin, 2017; Taşoğlu & Bakaç, 2014; Tereci et al., 2018). Güler and Şahin (2017) used an open-ended questionnaire to examine 77 preservice science teachers (PST)' understanding about electricity and magnetism and they found that although the PSTs knew the concepts of magnetic effect and magnetic field but were insufficient in explaining the effects of these concepts. Tereci et al. (2018), on the other hand, developed an experiment activity based on the TGA (Predict-Observe-Explain) strategy on magnetism to be used in physics courses at upper secondary level and received the opinions of physics teachers and found it useful by the teachers.

Based on the synthesis of the aforementioned studies, it is evident that over time, there persists a prevalence of inaccurate Models regarding magnetic interaction and magnets, particularly among K-8 students. Gaining insight into the content and underlying nature of these entrenched inaccurate Models will provide valuable guidance in devising effective strategies or methodologies for their remediation and elimination.

Research Purpose and Question

In this study, we aimed to investigate the Models of 8th grade students in Türkiye in the subjects of magnets and magnetic interaction and the consistency of their Models within themselves and make a comparative assessment with data collected from 8th-grade students ten years earlier. The first data of the study was collected during the first author's thesis study and the subsequent data was collected for comparison purposes. Magnets and magnetic attraction are concepts that students may encounter in many aspects of their daily lives, and they began to develop ideas about magnets and magnetic behaviors based on these experiences, as well as their existing models of magnetism and similar concepts. Knowing the early development of students' models about the nature of magnets and the interaction between magnets and other objects could facilitate planning an instructional design to help students reconcile inconsistencies and/or strengthen connections between new and old models as they learn about magnetism. In the light of these ideas, the following research questions guided this study: 1) What are the similarities and distinctions between Turkish students' Models of magnets and magnetic interaction a decade ago compared to those developed over the course of the subsequent ten years? 2) What is the consistency of students' models when responding to questions that pertain to the same phenomenon but are presented in different contexts during both phases of data collection?

Method

In this research, we explored students' accurate and inaccurate Models concerning the nature of magnets and magnetic interaction and compare them with data collected from 8th-grade students ten years earlier. Additionally, we seek to ascertain the coherence between students' normative and non-normative ideas within a given context when they explain their models of magnetic interaction for the same phenomenon under two related scenarios: 1) wherein the nail is held stable while the magnet is rotated, and 2) wherein the magnet is held stable while the nail is rotated. As a data source, we used students' written responses and drawings to a survey questionnaire. Concerning the research's objectives, constructivist learning theory and an interpretivist approach were the most appropriate methodological perspectives for this study. Students constructed Models and external representations of their interpretations of the everyday world (Shepardson et al., 2011). Through the application of an interpretive-constructivist methodology, we achieved a comprehensive understanding and clarification of students' models pertaining to magnets and magnetic interactions. The interpretive phase within this framework entailed an exploration of the domain of their experiences (Van der Walt, 2020).

Research Design

In this study, we used a questionnaire that allowed students to use words and drawings to express their understanding and models. Questions from a survey; Magnets and Magnetic Things, designed by Sederberg (2012), were used as the main instrument to examine students' Models of magnets and magnetic interactions. Slight modifications were made to ensure the survey questions that originally were written in English were culturally and semantically appropriate for Turkish students.

Participants and Context

The 2010-11 Sample

The initial phase of the study was conducted during the fall semester of the 2010–2011 academic year. The sample consisted of fifty-nine 8th grade students, aged between 13 and 14 years old, who were attending a private school in Turkey. These students were selected from three different 8th grade classes and represented diverse academic backgrounds. Among the participants, twenty-eight were female and thirty-one were male. The selection of participants was carried out from students enrolled in a public school situated in a small district within the northwest region of Turkey. This particular town is characterized by its abundance of resources and is primarily known for its dominant ironwork industry, which serves as the primary source of income for the local community. The families residing in this area predominantly derive their livelihood from industries such as textiles, ironwork, and steel. Consequently, the participating students were primarily from low- and middle-class socioeconomic backgrounds.

The 2022-23 Sample

The second phase of the study involved the participation of forty-five 8th grade students from a public school in Turkey. These students, aged between 13 and 14 years old, were selected from two distinct 8th grade classes and exhibited diverse academic backgrounds. Among the participants, twenty-four were female and twenty-one were male.

The participants were drawn from students enrolled in a public school located in a small district situated in the northeastern region of Turkey. Notably, one of the schools within this district, where data collection took place, is renowned as the premier middle school in the area. The other school primarily serves students from families with slightly lower literacy levels. Although there is variability in the socio-economic status of the families, tea production is a prevalent source of livelihood in this region.

Despite the revisions of the science curriculum in Turkey over time, it is worth noting that the topic of magnetism remains consistent, as it is included in the 4th grade science curriculum in both phases of the study. Therefore, the selection process aimed to identify students' initial models of magnetism and magnetic interaction, with a particular focus on those who had briefly received formal instruction in magnetism prior to the study. The selection of participants involved a meticulous process that included a thorough examination of the science curriculum across all grades, as well as active collaboration with science teachers. The valuable input provided by these experienced educators played a crucial role in identifying suitable candidates based on criteria such as their grade point average (GPA), voluntary participation, and willingness to submit consent forms. The participant group was intentionally diverse, encompassing individuals with varying levels of academic achievement and learning skills, thereby ensuring a representative sample.

Before commencing the data collection phase, detailed information regarding the study's procedures was conveyed to both the students and their parents or guardians. Informed consent was obtained from the participants' parents or legal guardians, underscoring the importance of ethical considerations, and ensuring that all individuals involved in the study were fully aware of its purpose and procedures. A two-tiered coding system, S1XX and S2XX, will be used to identify the students participating in this study. Students who were enrolled in the study during the 2010-2011 academic year will be assigned codes beginning with S1, while students who were enrolled in the

Q5. Can and Zeynep observe that a nail is attracted to one end of a magnet. Can says that if they turn the magnet around the magnet will pushed the nail away. Zeynep says that the nail would be attracted to both ends of the magnet equally.
Who do you think is more correct? (circle one)

Can Zeynep

Explain why you think this would happen.

Q9. Think about a magnet and an iron nail.
a. Make a drawing to explain what happens when the head of the nail is held close to one end of the magnet.
b. Explain what is happening in your drawing.
c. Now make a drawing to show what you think would happen if you turned the nail around and bring the tip of the nail to the same part of the magnet.
d. Explain what happens between your first and second picture.

Figure 1. Question 5 & Question 9.

study during the 2022-2023 academic year will be assigned codes beginning with S2.

Data Collection

To identify students' models of magnetic interactions, we used questions from a survey called Magnets and Magnetic Things, which was designed for a larger research agenda (Sederberg, 2012). Sederberg (2012) developed the instrument for magnetism studies, which were conducted with 8th grade students in Finland and the USA before this study. This study was conducted in Turkey to find out more about students' Models of magnetism from different educational backgrounds and a decade apart.

The survey questions and consent forms (for the principal, parents, and students) were originally drafted in English. To ensure all translated documents were culturally appropriate as well as clearly composed, the survey questionnaire, consent forms, and a letter for parents were all approved by another native Turkish speaker before being submitted to the principal, parents, and students. Because individual interpretation is a key aspect of constructing models, the participants were asked to answer the questions as individuals, and not to discuss them with each other. Collectively, students' responses and behaviours during the data collection process showed they were comfortable.

This survey consisted of nine questions, including sub-questions. In this study, we focused on three survey questions. One of the questions posed to the students pertained to the "inside and outside features" of magnets. To examine the consistency in students' models about magnetic interactions, we took a closer look at, in particular, two questions: Question 5 (Q5) and Question 9 (Q9) (see **Figure 1**).

These questions allowed us to analyze the students' understanding of the interactions between a magnet and an iron object as well as identify the consistency between their understandings of magnetic interaction toward one phenomenon given in two different ways. Q5 addressed whether a behavioral change happens when the magnet is turned around while the nail is not. On the other hand, Q9 was used to shed light on how students' Models are transferable and durable when asked to anticipate the interaction between a nail and a magnet when the magnet stays stable, and the nail is turned around.

To ensure comparability between the two data collection processes, we employ the same approach utilized in the previous study. The data collection process took place during a normal class period, and students were asked to complete the survey in those 45 minutes. However, the average time for completion of the survey was approximately 30 minutes in both studies.

Data Analysis

The data analysis in both studies followed a two-stage approach. In the first stage, we employed inductive analysis and creative synthesis strategies (Patton, 2014) to explore students' statements about magnets and magnetic interactions. Subsequently, content analysis was utilized as a framework in the second stage. Initially, responses were categorized based on accuracy, and then a content analysis strategy, as described by Strauss and Corbin (1998), was applied to re-categorize responses within each cell of the matrix. For creating the categories, we also drew insights from relevant literature.

Similarly, the same procedure was applied to students' responses concerning the behaviors of nails and magnets when held side by side. Subsequently, a matrix was constructed based on students' accurate and inaccurate Models. The primary objective of segregating students' responses using this matrix was to examine the consistency of models exhibited among students who provided either correct or incorrect answers for both questions, as well as those who provided correct answers for one question but incorrect answers for the other. After categorizing the data, we identified and analyzed the major themes present in students' responses.

Results

In the Turkish science curriculum, students learn the basic properties of magnets only in 4th grade at the primary level for a decade. Other than that, they do not have any learning objectives about magnetism and magnets. Hence, participants in both phases of this study (2020-2011 and 2022-2023 academic years data collection phases) exhibited initial models formed

Table 1. The Most Frequently Possessed Models about the Nature of Magnets.

	2010-2011 Academic Year		2022-2023 Academic Year	
	Frequency	Percentage	Frequency	Percentage
Attraction and Repulsion				
Attracts metal/iron Objects	39	66.1	23	51.1
Attracts magnetic objects	5	8.5	1	2.2
Same poles repel, opposite poles attract	38	64.4	18	40
Helps to find something (e.g., pin, needle, nail)	11	18.6	2	4.4
Magnetic Poles				
Magnets have "+" and "–" poles	17	28.8	15	33.3
Magnets have "N" and "S" poles	31	52.5	11	24.4
Magnets have "+,-" and "N, S"	7	11.9	4	8.9
No sign for the poles	4	6.8	15	33.3
Poles are separated from center	37	62.7	25	55.6
Composition and Functionality of Magnet				
Made of coal	3	5.1	0	0
There are matters/ elements inside a magnet	7	11.9	5	11.1
There are solid things inside a magnet	5	8.5	4	8.9
There is powders inside a magnet	5	8.5	2	4.4
There are atoms/ nanoparticles/ electromagnets inside a magnet	5	8.5	8	17.8
Works even when broken into pieces	52	94.5	36	80

through a combination of their 4th grade science course, personal observations, life experiences involving magnets, and information acquired from external sources (e.g., witnessing parents using tools with magnetic properties or incorporating magnets in their daily activities). Students' answers to the questionnaire were first identified as independent of any category and from each other. Later, the common themes were determined based on current literature as well as unique student ideas. These categories were presented in the first section. We also provide excerpts from the students' drawings and inscriptions to support our assertions.

Students' Models about the Nature of a Magnet

In response to a question about a detailed description of a magnet and its characteristics, students represented their models with their drawings and writings, which demonstrated students' normative and non-normative models. The comparison of students' Models of magnets from the 2010-2011 and 2022-2023 academic years is presented in **Table 1**. Overall, all students were aware of magnetic properties and the behavior of different polarities. However, they often did not articulate the terms and reasons behind those magnetic phenomena. In general, a comparison of the data collected from students during the academic years 2010-2011 and 2022-2023 reveals noteworthy differences in their understanding and articulation of concepts related to magnets. Specifically, the students surveyed in the earlier academic year exhibited a more profound grasp of magnetism, as evidenced by their ability to articulate a greater number of ideas concerning the properties of magnets compared to their counterparts in the later academic year.

In this section, the students' models are described as being very similar to other current research studies about magnetism. The three eighth grade Turkish students' models that emerged from both studies included: a) attraction and repulsion; b) magnetic poles; and c) the composition and functionality of magnets. **Table 1** shows three main concepts that were drawn from literature that focused on students' models of magnetism and from our participants' responses.

Attraction and Repulsion Model

During the initial study, a majority of students (66.1%) demonstrated an awareness of magnets' attractive properties, with a specific emphasis on their ability to attract metal and/or iron objects. In the second study, this proportion decreased, with only half of the students (51.1%) explicitly acknowledging the magnetic attraction towards metal and iron objects. Another prevailing normative model identified among the students was the concept that "like poles repel, while opposite poles attract." In the first study, 64.4% of the students explicitly mentioned this principle in their models, but in the second study, this percentage declined substantially to 40%.

Below are illustrative examples extracted from the students' models in both phases, showcasing their understanding and reasoning related to the attractive feature of magnets,

> *S128: A magnet is a metal structure that has the opposite poles on both edges. It generally attracts some materials, like iron and metals.*
>
> *S204: A magnet is a tool that attracts objects made of metal and iron. The magnet has two different directions: reverse, straight. Both sides of the magnet attract opposite poles.*

Above, we present instances of satisfactory responses provided by the students in both studies. The responses elicited from the participants regarding the question, "How would you elucidate the properties of magnets to an unfamiliar individual?" exhibited a tendency towards restraint and brevity. However, a discernible trend was observed, wherein students encountered greater challenges in providing comprehensive explanations during the latter study. During the initial study, certain students substantiated their responses by drawing upon real-life examples of everyday materials. However, during the subsequent study, with the exception of one student, the majority of participants exhibited a notable decrease in their inclusion of practical applications of magnets in their explanations, thereby evincing a diminished emphasis on illustrating the relevance of magnets in daily life contexts in a decade:

> *S113: ... magnets consist of iron, too. Hence, a magnet attracts iron. For example, it [the magnet] pulls pins, materials, iron, etc.*
>
> *S120: A magnet is a tool that has two poles and magnetic power. A magnet has two poles. One of them is N, and the other is S. Generally, it is used in electrical devices, and it helps us pull things easily.*

A careful analysis of the students' Models in both studies indicates that even though they know magnets attract certain types of objects (e.g., metal, iron, etc.), they did not use any supportive reasoning related to the interior structure of magnets to explain why some materials are attracted by a magnet while others (e.g., plastic, paper, glass, etc.) are not.

> *S224: A tool containing iron powder that attracts metals.*

On the other hand, S113 and S224 stated their reasoning for attraction by indicating magnets' structure ("magnets consist of iron, too"). Presumably, they associated the magnetic interaction between a magnet and a nail with the isomorphic nature of both objects.

An additional distinction between the two studies pertains to the portrayal of the force of attraction or repulsion between two magnets or between a magnet and a nail. The first study observed a prevailing trend where the representation closely resembled the conventional depiction of magnetic field lines found in textbooks. In contrast, the second study did not yield any instances where students utilized this specific representation.

Notably, a majority of students in the first study, similar to the example provided in S109's drawing, depicted the direction of attraction using arrows. In the second study, six students created drawings illustrating attractive or repulsive effects; however, these drawings exhibited considerable diversity, showing no resemblance to either each other or the representations observed in the first study. The drawings provided above serve as examples of this variation. Participant S243 represented the attraction between the magnet and nails by utilizing wavy-shaped lines in her drawing. In contrast,

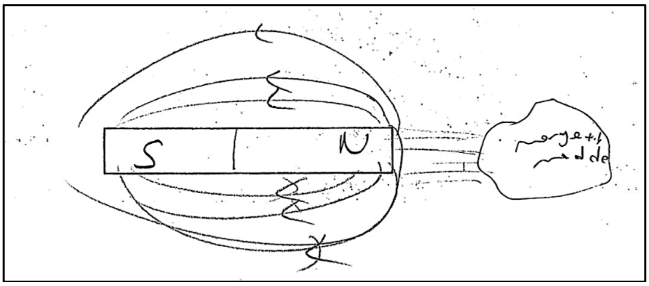

Figure 2. S109's Drawing of Magnetic Attraction/Repulsion Effect *[Magnetic matter]***.**

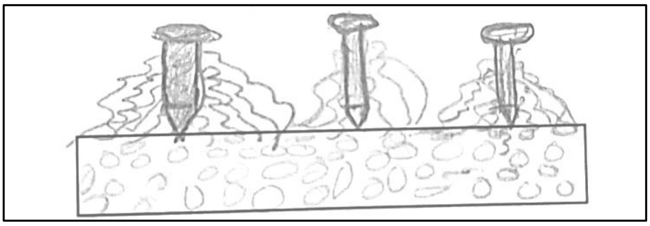

Figure 3. S243's Drawing of Magnetic Attraction/Repulsion Effect.

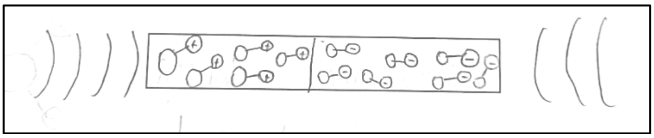

Figure 4. S245's Drawing of Magnetic Attraction/Repulsion Effect.

participant S245 depicted the magnet alone, incorporating half rings that resembled the wave representation at the ends.

Five students in the first study and one student in the second study specifically used the term "magnetic objects" to give examples of substances attracted by magnets. Presumably, iron, metals, nickel, etc. are grouped under that category.

> *S112: A magnet has "N" and "S" poles and attracts magnetic objects. There are different types of magnets, for example, a bar magnet, donut magnet, or horseshoe-shaped magnet. The objects that are attracted by magnets are nickel, cobalt, iron, etc.*

> *S201: A magnet is a tool shaped like an eraser or a horseshoe that attracts magnetic objects.*

S112 initially used the term "magnetic objects" and then listed these objects in his example. This kind of term is generally used by students to both shorten the long list of words and/or make it sound more scientific. S201 did not explain what he meant by a magnetic object.

The preeminence of students' observational experiences and pre-existing knowledge appears to play a pivotal role in the formulation of their conceptual ideas concerning natural phenomena. As children encounter diverse instances involving magnets in their environment, they naturally construct Models through the observational process. Notably, a pronounced distinction between the Models of students emerged between the initial and subsequent studies, particularly with respect to their perceptible association of magnets with toys or household objects, which was conspicuously present in the former but absent in the latter. In the first study, S107 provided additional elaboration on their use of magnets for retrieving specific objects, drawing parallels with the widespread practice of women in Turkish households using "tailor magnets."

> *S107: A magnet is a tool that makes our work at home easy and helps us find something that we are looking for. It holds things like small irons by pulling them toward it. For example, it holds needles and prevents them from spreading out and getting lost.*

Figure 5. S107's Representation of Daily Use of Magnets *[Keeps Needles]***.**

In contrast, during the second study, the students refrained from making explicit references to their toys or household items while describing magnets. Merely two students mentioned that magnets attract needles, pins, and the like, without providing additional elaboration regarding the usage of these items at home. As an illustration, an excerpt from S243's response is provided below,

> *S243: A magnet attracts metal things and nails, pins, needles.*

Poles Model

Despite all students possessing knowledge about the existence of two distinct poles in magnets, their mental model representations concerning the expression of these poles exhibit significant variation (**Table 1**). In the initial phase of the study, a majority of students (52.5%) defined the poles as North and South (N,S), but this proportion notably decreased to 24.4% in the subsequent phase. An alternative prominent mental model employed by students for pole designation involves the use of + and - symbols, which was observed in 33.3% of students during the second phase, as opposed to 28.8% during the first phase.

Two students' responses were given as examples,

> *S104: A magnet has poles. A magnet's (+,-), (-,+) directions attract each other. Moreover, (+,+), and (-, -) directions repel each other.*

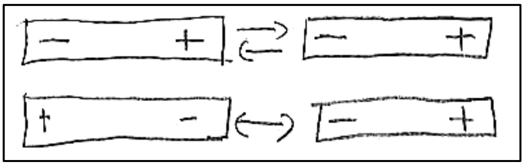

Figure 6. S104's Model Representation of Magnetic Attraction and Repulsion.

> *S124: A magnet is a matter which pulls metal and itself. A magnet has two poles; one side of it is negative (-), and the other side is positive (+). If the same poles come across each other, they repel each other. When opposing poles meet, they pull each other.*

Figure 7. S124's Model Representation of Magnetic Attraction and Repulsion.

> *S244: I think there are + and - atoms inside the magnet. I remember that the + and - sides attract each other, but +,+ and -,- would not attract each other. Opposite poles attract and the same poles repel.*

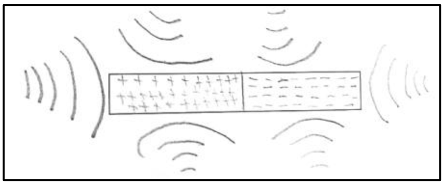

Figure 8. S244's Model Representation of Structure of a Magnet.

S104 employed the term "direction" to describe the poles of the magnets. However, it is important to note that the use of positive and negative direction terms is more commonly associated with kinematics, which defines velocity, acceleration, force, and vector position. As a result, S104's model may indicate a conceptual mixture that goes beyond the conventional charge model. It is plausible that students like S104 constructed their models based on fundamental kinematics concepts, not solely influenced by electricity.

Similarly, in the case of S124, although she presented a model with a "+" and "-" pole, the information provided did not sufficiently warrant categorizing it solely as an electrical charge model. As such, we should be cautious about assuming that these students' Models are always inspired by or influenced by electricity, and we should refrain from labeling them as "charge models." In S124's drawing, she used arrows to depict the repulsive effect when the "+" and "+" or "-" and "-" sides of two magnets are brought together, as well as the attractive effect when the "+" and "-" or "-" and "+" ends of two magnets are brought closer. This representation suggests a more comprehensive understanding of magnetic interactions beyond a simple charge-based model.

In the second study, S244 also indicated the presence of "+" and "-" poles in the magnet by depicting them halved in his drawing. Furthermore, he illustrated the attractive and repulsive effects of these "+" and "-" poles on the external surface of the magnet. This depiction demonstrates a more sophisticated grasp of magnetic interactions that extends beyond a basic charge model.

The students' terminological ambiguity is indicative of the underlying Models they hold, which subsequently influence their representations. Notably, a small subgroup of students (comprising 11.9% and 8.9%, respectively, in the two studies) demonstrated a hybrid approach by employing both N, S and +, - terminology to articulate the concept of magnetic poles.

For instance, in the first study, S103 presented + and - signs during his verbal explanation, but in his drawing, he employed N&S signs to depict the poles. Similarly, S229's drawing depicted both + and - signs, further exemplifying the coexistence of different terminological expressions within individual students' models even a decade apart.

> *S103: A magnet attracts iron. A magnet has two poles. "+" and "–"; plus pulls minus, plus pushes plus.*

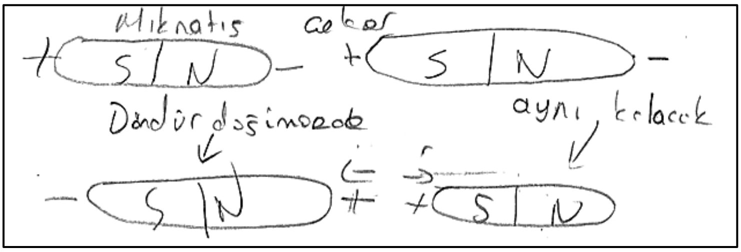

Figure 9. S103's Model Representation of Magnetic Poles *[Above: Magnet Attracts; above: when we turn it around, it will stay the same].*

> *S229: A magnet has two poles. If these poles are brought close to each other, they stick. But when the same pole approaches, they repel each other. The magnet can move and attract anything that is iron.*

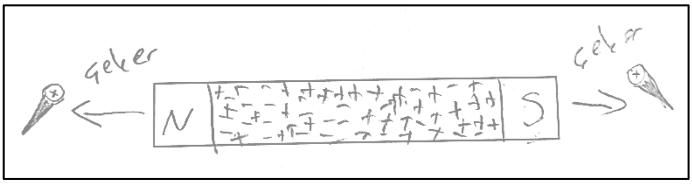

Figure 10. S229's Model Representation of Magnets and Magnetic Poles *[left: attracts; Right: attracts]***.**

These students expressed a conceptual model pertaining to magnetic poles, wherein they employed two distinct symbols to refer to the poles. However, there is a lack of consistent correlation between the symbols and the poles themselves. In other words, these students did not consistently associate the S pole in both phases of the study with either the - or + symbol. An examination of S103's initial drawing, which illustrates magnetic attraction, reveals an association of S with +. However, in S229's drawing, which depicts the distribution of both + and - symbols around the magnet, no clear correspondence is observed. Consequently, it can be inferred that these students lack a coherent model regarding the characteristics and nomenclature of the magnetic poles.

Composition and Functionality of Magnet

The question of what triggers magnets to attract an object and repel another magnet seemed to be a puzzle for students. More than half of the students (64.4%) pointed out the composition of a magnet as the main reason for its attraction and/or repulsion feature in the first study. This rate decreased to 33.3% in the second study. It was observed that 8th-grade students attempted to establish a connection between the atomic structure of magnets and their magnetic behavior.

> *S101: There are matters that have magnetic features inside a magnet. These matters give attraction power to the magnet.*

> *S126: There are matters that have a magnetic feature inside [the magnet].*

For example, S101 and S126 probably used the "matters" term to describe magnetic domains or atoms. Evidently, these students drew upon their understanding that all matter is composed of atoms when attempting to explain magnetic phenomena. However, as exemplified by S106' responses, some students employed terms not commonly used among individuals of their age level, such as nanoparticles, electromagnets, and elements. Presumably, they may not have fully grasped the precise meanings of these terms, but they used them to sound scientific and logical in their explanations.

> *S106: There are electro-magnets inside a magnet.*

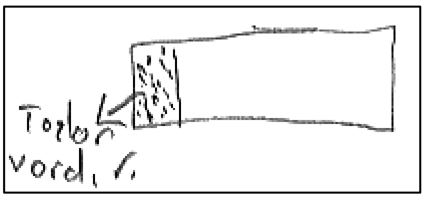

Figure 11. S106's Model Representation of "Magnetic Domains" *[There are powders]***.**

S106 and some others presented more than one term to describe these small particles responsible for magnetic behavior. For instance, S106 mentioned "electromagnets" in her verbal response while using the term "powders" to elucidate the small dots in her drawing.

It is noteworthy that the students in both studies did not mention magnetic domains or the motion of electrons as potential reasons for the attraction and repulsion features exhibited by magnets. Despite being aware of the existence of small particles that constitute a magnet, their responses revealed a degree of ambiguity, indicating that their Models were not entirely clear and comprehensive. Regarding the question about the expected inner structure of a magnet, the responses provided by the students further emphasized the lack of clarity in their conceptualizations and models. The variety in their descriptions of the inner structure of magnets further underscores this point. Notably, it was observed that students in the first study offered more detailed and distinct answers to this question, suggesting potential differences in their conceptualization between the two studies.

In the context of the second study, students exhibited diverse perspectives regarding the internal structure of magnets, which is believed to be responsible for their magnetism. These viewpoints included references to sticky powders, liquid substances, and small magnets as potential components contributing to the magnet's magnetic properties.

> *S217: I think there are sticky powders in it. When they're the same, they repel when they're different, they attract.*

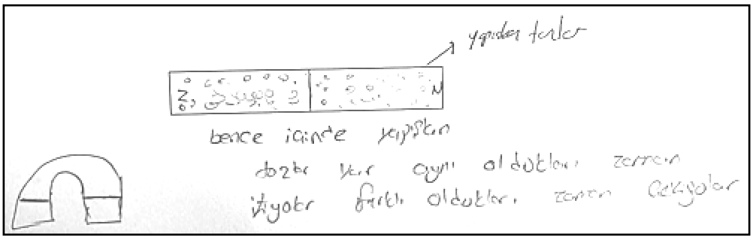

Figure 12. S217's Drawings Demonstrate How They Visualize the Attraction between a Magnet and Objects. *[Above: sticky powders; Below: I think there are sticky powders in it. When they are the same they repel, when they are different they attract.]*

> *S202: There's a substance outside the magnet that will bring things closer together. Inside, there's energy. There's a substance like glue.*

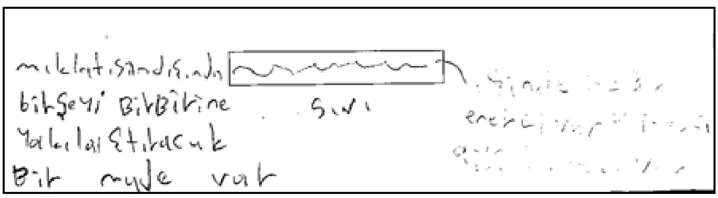

Figure 13. S202's Model Representation of "Magnetic Domains". *[Left: There is a substance outside the magnet that will bring them closer together; Right: There is an energy in it. There's a substance like glue.]*

S205: Magnet is a tool that attracts metal objects. A magnet is needed to find many lost metal objects.

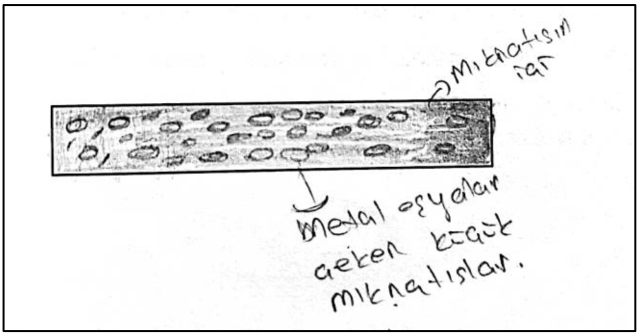

Figure 14. S205's Model Representation of "Magnetic Domains". *[Above: inside a magnet; Bottom: little magnets that attracts metal objects]*

Students' Models about the Nature of Magnetic Interactions

Another significant aspect investigated in this study pertained to the consistency of students' Models concerning magnetic interactions between a magnet and a nail. In this section, the examination revolved around determining whether students' accurate or inaccurate Models exhibited internal coherence when presented with similar scenarios, and it aimed to compare the levels of coherence or incoherence between two distinct groups of students, separated by a ten-year interval. These accurate and inaccurate models provided valuable insights into the coherence of students' comprehension of magnetic interactions and the extent to which their inaccurate Models were ingrained.

Specifically, the students' responses to two distinct questions, Q5 (inquiring about the magnetic interaction between a magnet and a nail when the magnet is turned around) and Q9 (inquiring about the magnetic interaction between a magnet and a nail when the nail is turned around), were analyzed. By probing the magnetic interactions between a magnet and an unmagnetized object in both cases, these responses shed light on the students' understanding of such interactions and the consistency of their comprehension across varying contexts.

Through the analysis of students' responses based on their accuracy levels, three assertions were derived, each further subcategorized according to the students' common Models:

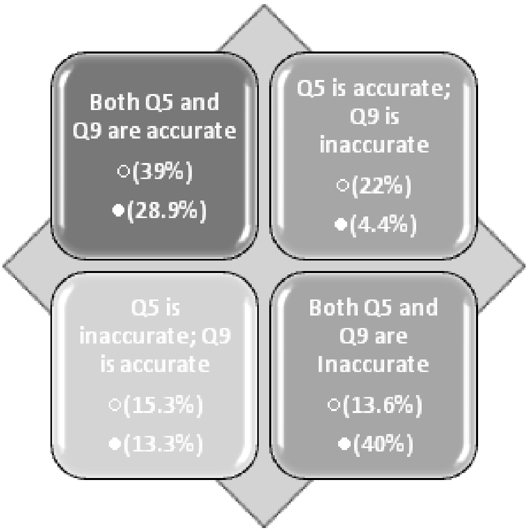

Figure 15. Frequency of Students' Answers to Q5 & Q9. *[○ Data from 2010-2011 academic year; ● Data from 2022-2023 academic year]*

Assertion 1: In the first phase, 23 students (39%) accurately answered both questions, whereas in the second phase, 13 students (28.9%) accomplished the same level of accuracy.

Assertion 2: In the first phase, 13 students (22%) responded correctly to Q5, but they provided incorrect or inappropriate (i.e., non-scientific terminology) responses to Q9. Similarly, in the second phase, only two students (4.4%) demonstrated this pattern. Additionally, nine students (15.3%) in the first study and six students (13.3%) in the second study gave an incorrect answer to Q5 but provided correct answers to Q9.

Assertion 3: In the first study, eight students (13.6%) provided inaccurate responses to both questions, while in the second study, this number increased to eighteen students (40%).

Assertion 1: Students have a full understanding of the attraction between a magnet and a nail in both contexts, i.e., their models are consistently applied across contexts.

Students falling into the first assertion exhibited a coherent model regarding the attraction between a magnet and a nail in both studies, consistently stating that "both sides of the magnet attract the nail." This consistent observation was attributed to the inherent nature of the nail. The responses of these students revealed that their Models of magnetic interactions between magnets and iron-like objects were based on a combination of the magnets' attractive properties and their observational memory. Within this category, we identified two prevalent models:

i. Both sides of a magnet attract a nail

A prevailing response among students to this assertion was that a magnet attracts every side of a nail. However, throughout both phases of the study, students' reasoning exhibited a lack of specificity regarding the nature of this interaction. The following excerpts illustrate that students attributed the equal attraction on both sides to certain characteristic features of the nail.

> *S116: The magnet attracts all sides of the nail equally.*

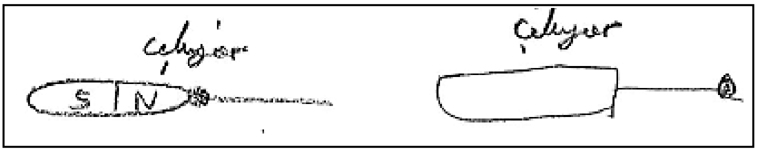

Figure 16. S116's Model Representation of the Interaction between a Magnet and a Nail *[Left: It is pulling; Right: It is pulling]***.**

> *S109: Zeynep is right because all sides of the magnet have the same characteristic.*

> *S245: All sides of the magnet attract with the same force. The gravitational force of the magnet does not change because it has the same feature on the front side as on the back side.*

In this assertion, students emphasized the isomorphic structure and composition of the objects while describing the interaction between a magnet and a nail when held in close together. Another prevalent model was the notion that the attractive force exerted by both sides of the magnet had an equal effect on both sides of the nail. However, in the first study, aside from student S104, none of the students provided further elaboration on the connection between these phenomena and the underlying reason for the observed interaction.

S104:
Q9-a: The magnet attracted the head of the nail because there are many more atoms on the head of the nail.
Q9-b: Nothing has changed. It still attracts.

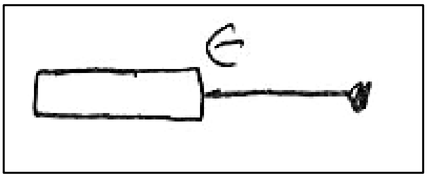

Figure 17. S104's Model Representation of the Interaction between a Magnet and a Nail.

Q9-c: There is no difference between the two cases.

S104 mentioned the atoms of a nail, but his explanation showed some confusion. To three different questions, his answers were that every side of a nail is attracted by a magnet. In the second phase, S242 explicitly stated that the particles within the magnet are responsible for the attraction between the magnet and a nail.

S242:
Q9-a: The particles inside the magnet attract the nail by acting on it.

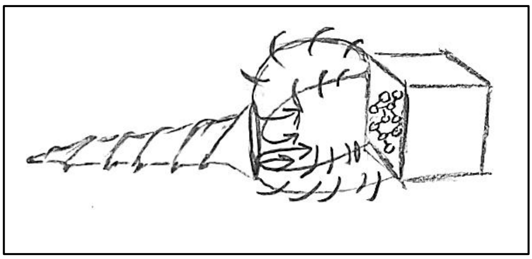

Figure 18. S242's Model Representation of the Interaction between a Magnet and a Nail.

Q9-b: the magnet exerts an attractive force on the nail.
Q9-c: If we turn the nail over, the magnet exerts the same force of attraction on the nail.

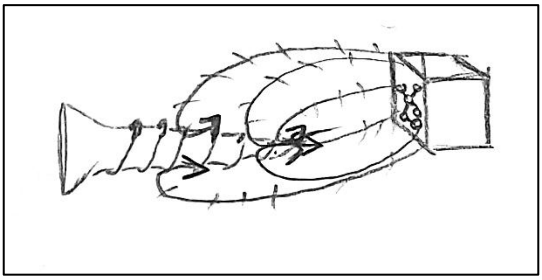

Figure 19. S242's Model Representation of the Interaction between a Magnet and a Nail.

ii. The nail is attracted because of its iron/metal structure.

When we analyzed students' models of magnetic interaction, we found that students distinguished between objects being attracted/repelled by magnetic force, while other objects were not. Throughout both studies, the prevailing reasoning among 8th-grade students for the interaction between a nail and a magnet was attributed to the iron/metal composition of the nail. In the first study, six out of fifteen students, and in the second phase, seven out of nineteen students, offered the rationale that the mere composition of iron was adequate to account for magnetic attraction. Several illustrative examples from the students' responses are provided below:

> *S108: The magnet's attraction towards the nail is attributed to the nail's iron composition.*
>
> *S126: The head of the nail is iron; that's why the magnet still attracts it [the nail].*
>
> *S202: Due to the properties of the magnet, it attracts iron or steel.*
>
> *S205: Since the nail is made of iron, the magnet attracts such objects. In my drawing the magnet attracts the nail.*

In general, the responses from the students revealed a comprehension of the interaction between iron objects and magnets. However, in both the initial phase and the follow-up phase after ten years, the concepts of domain, alignment, and magnetization of ferromagnetic materials were noticeably absent from their explanations. These findings demonstrate children's empirical approach toward scientific phenomena. On the contrary, students tended to limit their understanding to situations in which magnets solely attract iron objects, neglecting the possibility that an iron object could also be magnetized and repel a magnet.

Assertion 2: Students have a partial understanding of the interaction between a nail and a magnet; their models are not consistently applied across contexts.

The students in this category exhibited responses containing inaccurate information to one of the questions among Q5 and Q9. Although both questions necessitated the same conceptual knowledge, a subset of students (N = 16 (27.11%) in the first study and N = 8 (17.8%) in the second study) approached each question with distinct understandings. Consequently, it can be inferred that these students' Models lack internal coherence. In the first phase of the study, nine students demonstrated an understanding of the interaction between a nail and a magnet when the magnet is turned around (Q5), yet this number decreased to only two students in the second phase. Conversely, in the first phase, seven students displayed confusion when asked about the same concept but in the context of the magnet being turned around (Q9), while six students did not provide accurate answers to the question in the second phase.

Nail's two-sided entity model was one of the recurring ideas among students' model representations in early survey questions. However, some students with correct answers held a second belief that the nail will be attracted when one side is near the magnet but repellent when the other side is facing the magnet (Q9). Their logic followed the rule that opposite poles attract and same poles repel. Even though this idea seems to support the magnetized nail feature, they did not mention it, and their answer to Q5 confirms that. Moreover, since these two questions address the same concept, contradictory answers indicate that some students did not understand the mechanism by which attraction between a magnet and a nail occurs. For example:

S131:
Q5: Can's explanation is wrong and does not make sense. Scientifically, it cannot happen.
Q9:
a)

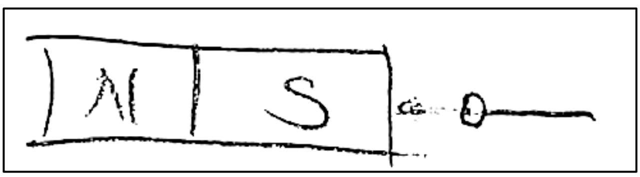

Figure 20. S131's Model Representation of the Interaction between a Magnet and a Nail.

b) The magnet pulls the object.
c)

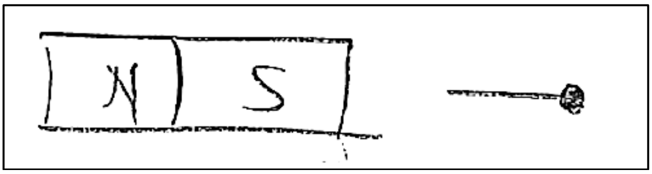

Figure 21. S131's Model Representation of the Interaction between a Magnet and a Nail.

d) It [magnet] attracts the object in the first one, repels the object in the second.

S243:
Q5: Zeynep drives the nail in the right place and the magnet attracts the nail by its tip. So the magnet attracts the nail even if we turn it upside down.
Q9:
a)

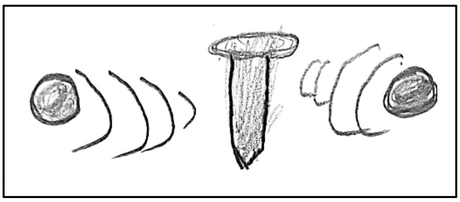

Figure 221. S243's Model Representation of the Interaction between a Magnet and a Nail.

b) If you hold the magnet against the iron, they immediately stick together.
c)

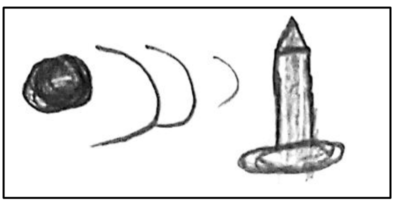

Figure 23. S243's Model Representation of the Interaction between a Magnet and a Nail.

d) Hardly pulls the nail.

The discrepancy in S131's conceptual model became apparent through an examination of his responses to Q5 and Q9. In Q5, he asserted that Can's explanation regarding the interaction when the magnet is turned around was not "scientific." However, in Q9, S131 contended that the magnet attracts one end of the nail and repels the other end.

In contrast, even a decade later, S243's responses to Q5 and Q9 continued to demonstrate divergent perspectives. In Q5, S243 stated that the magnet attracts the nail even when the nail is turned upside down, while in Q9, S243 asserted that the magnet attracts the nail in its original orientation but exerts minimal attraction when the nail is reversed. Much like these students' inconsistent responses, other students may also provide two entirely distinct explanations for the same phenomenon. These observations indicate that these students' Models appeared to revolve around two distinct ideas.

i. Magnets attract the head and repel the tip of the nail.

Within this category, certain students argued that magnets attract the head but repel the tip of a nail. In both studies, a noteworthy finding emerged among students who stated that in the interaction between the nail and the magnet, the nail is repelled by the magnet when it is reversed. These students demonstrated a tendency to associate larger surfaces with attractiveness and smaller surfaces with repulsiveness in their conceptualizations of the magnetic interaction. Below, the students' drawings for Q9 (where the nail is turned around) and their explanations to Q5 from both studies exemplified the emergence of non-normative Models among the students.

> *S117: The head of the nail has the same polarity as the magnet and the opposite direction has the opposite polarity. Therefore, the one with opposite polarity attracts and the other one repels.*

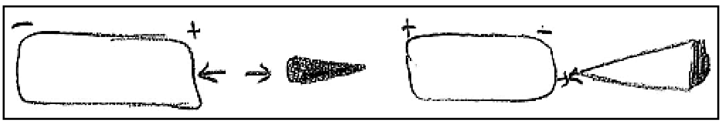

Figure 24. S117's Model Representations of the Interaction between a Magnet and a Nail.

> *S239: The second time the magnet repelled the nail. Since there are fewer electrons at the tip of the nail, the chemical in it decreases towards there. That's why it repels. The head*

and the tip of the nail have different properties. The electrons there are different.

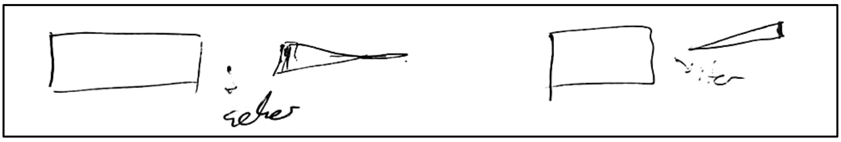

Figure 25. S239's Model Representation of the Interaction between a Magnet and a Nail *[Left: attracts; Right: repels]***.**

The impression that large surfaces are affected by magnetic force more than small surfaces presumably derives from another piece of conceptual knowledge. Students may think that many atoms on the head of a nail increases the possibility of interaction with a magnet's atoms.

ii. The interaction between a magnet and a nail depends on the poles of the magnet.

Most students in this category who provided accurate responses to Q9 (i.e., a nail is turned around) demonstrated awareness of the non-polarized structure of a nail. However, they encountered challenges when attempting to transfer this knowledge to their responses to Q5 (i.e., a magnet is turned around). Notably, five students in the first phase and eight students in the second phase asserted that while one side of a magnet always attracts, the other side always repels. For instance, the inconsistent answers given by students S128 and S228 indicated the existence of an incomplete model regarding the magnetic condition of nails (in the absence of being magnetized).

S115: Because the magnet has two poles. If one pole attracts an object, the other pole does not. That's what Can is trying to say.

S228: Because a magnet has opposite poles. If one pole of the magnet attracts, the other pole repels.

These students may hold the belief that the two poles of the magnet serve distinct functions. Notably, in the second phase of the study, some students explicitly stated that the north or + pole of magnets exhibits an attractive force, whereas the south or - pole elicits repulsion.

S206: Because I think the south side is pushing.

Assertion 3: Students do not have a scientifically accurate understanding of the interaction between a nail and a magnet.

In the first study, ten students and in the second study, eighteen students were identified to possess inaccurate Models of the interaction between the nail and the magnet. These students consistently displayed a particular pattern in their responses to all questions. Initially, in response to Q1, which inquired about the nature of a magnet, all of these students mentioned that magnets attract objects such as iron and metal. However, when presented with Q5 and Q9, which asked about the interaction between a magnet and a nail, these students stated that a repulsion effect would occur when either the magnet or the nail was reversed.

Despite the lack of scientific accuracy in their responses, these students' answers demonstrated consistency across Q5 and Q9. The prevailing model that emerged from the students' responses was based on the notion that unlike poles attracts each other, while like poles repel.

i. Unlike poles attract, like poles repel.

The pole entity is one of the recurring ideas among these age-group students. Despite the absence of references to magnetization of the nail in any of the questions posed, certain students asserted the presence of poles in the nail in both phases of the study. In the first study, seven students (11.9%) and in the second study, six students (13.3%) indicated that the poles of the nails influenced the interaction between the magnet and the nail.

By knowing students' models of polarization of unmagnetized nails, the non-normative models about interaction between a nail and a magnet could be deciphered expressively. One example from each study is given below to reflect the students' models:

S103:
Q5: When the nail is changed [turned around], then the poles will change, too.
Q9:
a) The "+" pole of iron pulls that part of the nail.
b)

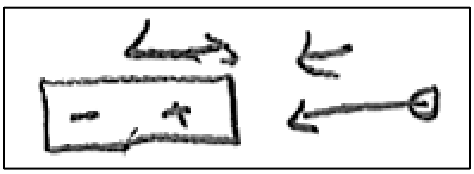

Figure 26. S103's Model Representation of the Interaction between a Magnet and a Nail.

c)

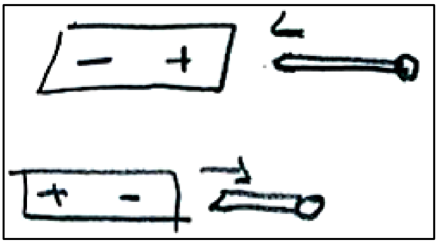

Figure 27. S103's Model Representation of the Interaction between a Magnet and a Nail.

d) The nail is affected by the first pulling force. The influenced nail pushes another pole when this pulling force is applied to it.

S212:
Q5: Because what Can says is scientific and logically convincing.
Q9:
a)

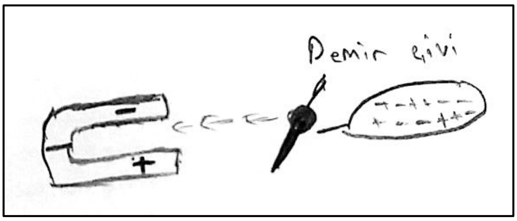

Figure 28. S212's Model Representation of the Interaction between a Magnet and a Nail *[Above the nail: Iron nail]*.

b) The positive and negative poles of an iron nail attract each other
c)

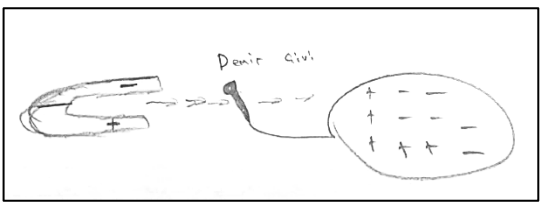

Figure 29. S212's Model Representation of the Interaction between a Magnet and a Nail *[Above the nail: Iron nail]*.

d) Since the iron nail has more negative charges, the negative pole will push the nail.

In the first example, S103 presented several conceptual confusions. For Q5, he asserted that if the nail is turned around, the poles will also change their direction, potentially stemming from the second reasoning mentioned earlier that contributes to the "opposite poles attract, like poles repel" model held by students. He posited that the magnet's "plus" pole pulls the nail, while the "minus" pole pushes it. On the other hand, S212 did not appear to fully grasp Q5; however, the student arrived at a conclusion that Can's idea is more scientific. He also depicted a cross-section illustration that revealed the internal structure of the nail, indicating the presence of both positive and negative charges within, in Q9. These results demonstrate that even after a decade, students maintain the belief that the nail can be "charged" while remaining oblivious to its magnetization property.

Discussion

Modelling is considered and utilized as a common scientific practice (Burgin et al., 2018; Giere, 2004; Schwarz et al., 2009). Models, on the other hand, have primarily two major missions: serving as the cognitive tools that individuals develop in their minds and utilizing them to make sense of the world around them (Gentner, 2001; Johnson-Laird, 1983). Models are used to represent a phenomenon, a concept, or an object as well as for sharing ideas, making predictions, examining, and revising an idea, etc. Scientists take advantage of using model-based understanding to approach and solve a problem (Giere, 2004). Likewise, children use their models to understand and interpret a new piece of information (Greca & Moreira, 1997).

This study gave us the opportunity to examine normative and non-normative Models of Turkish students at 10-year intervals. When we analysed the data, we also focused on identifying if there is a consistency in the students' models regarding questions that have different contexts but address the same phenomenon. In the following sections, we will discuss our findings for these two questions and blend in current studies' findings about students' magnetism models to draw a holistic picture.

Models of Magnets

When the first phase of this study was conducted during the 2010-2011 academic year, it was observed that there existed several investigations dedicated to unveiling K-8 level students' Models related to magnetism prior to 2010 (Borges & Gilbert, 1998; Bradamante & Viennot, 2007; Kucukozer & Kocakulah, 2007; Ravanis et al., 2010; Saglam, 2010; Sederberg & Bryan, 2009; Şengören, 2010; Tanel & Erol, 2008; Yurumezoglu & Cokelez, 2010). However, it was noted that these studies predominantly fell within the scope of electricity-related topics, with a stronger emphasis on basic concepts. Subsequently, in the second phase of the study conducted during the 2022-2023 academic year, a noticeable decline in such studies was observed, indicating a decreasing trend, and the topic of magnetism was mentioned with diminishing frequency (Cai et al., 2017; Erickson, 2013; Henderson et al., 2019; Kähkönen et al., 2020; Kalogiannakis et al., 2018; Lemmer et al., 2020; Sederberg, 2012).

The existing studies, which encompassed students at both higher grade levels and elementary schools, have revealed a significant issue concerning students' meaningful comprehension and Models, particularly when advancing into more complex learning experiences, such as electricity and electronics. Within the scope of this study, we identified numerous non-normative models concerning the nature of magnets, which could potentially pave the way for the development of other non-normative models. Intriguingly, these non-normative Models exhibited relative stability over a span of ten years, despite any curriculum changes in magnetism topic that might have occurred during this period.

We gathered students' Models about nature of magnets and magnetic interactions under three main categories and elaborated them. The first category was about magnets' attractive and repulsive entities. In the two separate studies involving 8th-grade Turkish students, conducted with a ten-year interval, a majority of the students contended that magnets solely attract metal and iron materials. This observation aligns with the findings of prior studies conducted by Sederberg (2012) with American students, Kähkönen et al. (2020) with Finnish students, and Lemmer et al. (2020) with African students.

Magnets, owing to their easy accessibility, affordability, and practical utility, find frequent application in everyday life, prompting students to often depict them in terms of their benefits. Notably, in both studies with a decade apart, certain students asserted that magnets are used for picking up objects such as needles or nails and for keeping these objects together. This noteworthy finding underscores how children construct their Models through direct interactions with objects within their immediate environment, indicating that their conceptualizations are influenced by practical experiences (Kalogiannakis et al., 2018). This aligns with the observations made by Brademante & Viennot (2007) and Lemmer et al. (2020), wherein students also presented real-life examples of magnet applications, such as sticking to needles or refrigerator magnets. However, a salient finding in comparing the results of the first and second studies was that students in the recent study provided fewer examples of daily life applications of magnets compared to students from a decade ago. This discrepancy may imply alterations in the students' social lives, motivational factors, or their interaction with the environment over the intervening decade between the two studies. It is plausible that changes in their experiences and exposure to different contexts contributed to the divergence in their Models. The underlying basis for the robust inclusion of the attraction phenomenon in students' models during the first study could be attributed to their exposure to childhood toys, such as magnetic building blocks and fishing games, as well as daily-utilized magnets like those affixed to refrigerators or used as tool holders and telescoping devices. Further investigation is warranted to better comprehend the intricacies influencing the evolution of their conceptualizations over time.

The second category pertained to magnetic poles, an aspect of considerable interest in both studies conducted a decade apart. The findings revealed that students encountered difficulties in comprehending and describing magnetic poles. Over the ten-year interval, students' representations of magnetic poles fell into three main types. The most accurate representation observed in both studies was the N-S representation, with 52.5% of students in the first study and 24.4% in the second study consistently labelling magnetic poles as N and S. The second most common representation was through charge symbols, with 28.8% of students in the first study using + and - symbols to describe magnetic poles. Remarkably, this percentage increased to 33.3% in the second study, suggesting a notable shift in students' conceptualizations of poles over time. This widely encountered model is commonly referred to in the current literature as the "charge model" (Borges & Gilbert, 1998; Kähkönen et al., 2020; Lemmer et al., 2020; Sederberg, 2012). However, it is crucial to note that there is insufficient evidence to directly associate students' representations with the concept of electrical charges, as none of the children explicitly referenced electrical charges in their responses. Consequently, it remains uncertain whether students were genuinely inspired by electrical charges or simply employed + and - symbols to denote opposites.

The third pole representation was mixed poles. A subset of students, accounting for 11.9% in the first study and 8.9% in the second study, combined + and - signs with N and S labels to describe magnetic poles. These students exhibited scientifically appropriate models yet appeared hesitant to relinquish their pre-existing Models. Saglam and Miller (2006) previously elucidated this paradox by noting that students often associate positive charges with N poles and negative charges with S poles. However, the present study's findings did not confirm this assertion, as students did not establish any direct correlation between + and -, or S and N. Instead, they randomly assigned these symbols to the poles. These diverse findings underscore the complexity of Models among students and the evolving nature of their conceptual frameworks concerning magnetic poles. Further investigation is warranted to unravel the underlying factors that influence the development and transformation of these Models over time.

The third category was composition and functionality of magnets, which appeared to show differentiations in both studies a decade apart. Upon examining the data gathered from students a decade ago and at present in the current study, it was observed that the majority of students in the initial study provided a greater number of properties of magnets (see **Table 1**) and offered more detailed illustrations in their drawings.

In our investigation of students' descriptions pertaining to the properties and internal structure of magnets as viewed through "magic glasses," significant disparities emerged between the responses gathered a decade ago and those from a decade later study. In the initial study, students demonstrated a variety of Models and presented diverse drawings. For instance, certain students in the first study proposed that magnets were constituted of coal or powder, whereas in the second study, none of the students mentioned coal as a constituent of magnets, and two students referred to the presence of powder. Further analysis of the drawings revealed contrasting depictions of magnetic fields between the two studies. In the first study, students employed field lines emanating from N (North) to S (South) poles, incorporating a semi-circular pattern to illustrate the magnetic field. Conversely, in the second study, the field lines adopted a sound wave-like appearance. These findings align with prior research conducted by Sederberg (2012) with American students and Kähkönen et al. (2020) with Finnish students, and Lemmer et al. (2020) with African students which also reported similar outcomes.

Moreover, it was revealed that students in both studies shared similar Models concerning magnets. In both phases, some students asserted that magnets contained matter or elements within. Additionally, certain students in both studies posited that magnets consisted of atoms, nanoparticles, or electromagnets. The presence of such common patterns in both studies correspond with Sederberg's (2012) previous study findings as well.

Models about Magnetic Interactions between a Magnet and a Nail

While many magnetism studies focused on the structure of magnets, we discovered non-normative models about the structure of nails and attributed some of the accuracy of models about the nature of interaction between a nail and a magnet to these fundamental non-normative models. Students' models about interactions between a magnet and an unmagnetized object (i.e., a nail) were examined across two questions. The results indicate a similar pattern with Kähkönen et al. (2020) and Lemmer et al. (2020)'s study that two models predominate in eighth grade students' minds: magnets (and all iron objects, according to some students) have two opposite poles, and opposite poles attract while the same poles repel. In addition to these models, students asserted the idea that one end of a magnet always attracts while the other end always repels.

Students who possessed a sound understanding of the nature of magnetic behavior could effectively utilize their prior knowledge and experiences to describe the outcomes when either the nail or the magnet was rotated. Nevertheless, the findings also indicated that a considerable proportion of students, accounting for 37.3% in the first study and 17.7% in the second study, exhibited difficulty in establishing a cognitive connection between two identical concepts presented in different contexts. Despite a reduction in the percentage of such students in the second study, their models of magnetic interaction remained incomplete and inadequately developed. This confusion arises from both students' limited knowledge of magnet properties and their inconsistency in determining whether the nail is magnetized or not. Lemmer et al. (2020) reported that students are aware of magnets having two poles, but they tend to believe that magnets encountered in their daily lives, like refrigerator magnets, possess only one pole. Furthermore, Kähkönen et al. (2020) observed that students treated nails as if they were magnetized, even though their study did not explicitly mention the magnetization of nails. The same inconsistency in Models was identified in both student groups in our study.

The findings suggest that students often grapple with inconsistent Models when navigating between their informal observations in daily life and the formal knowledge presented in scientific studies. The decline in the number of students exhibiting inconsistent Models in the second study could be attributed to a reduced engagement with magnets in their daily lives, as mentioned earlier.

Finally, a noteworthy percentage of students, comprising 13.6% in the first study and 40% in the second study, demonstrated internally consistent but unscientific Models of the magnetic interaction between the magnet and the nail. These students' non-normative Models appear to stem from the perception that the nail possesses two distinct poles, akin to a magnet. The origins of this model may be attributed to two factors. First, students might generalize that all matter composed of iron, metal, nickel, etc., inherently possesses two poles with similar magnetic effects, even though they may not be aware of the possibility of the nail being magnetized. Second, the concept of magnetic poles might lead students to believe that certain objects (such as iron, metal, etc.) consistently exhibit attraction and/or repulsion, independent of their structural composition or atomic alignments. This observation aligns with the findings of Sederberg (2012) and Kähkönen et al. (2020) in related studies.

Conclusion and Suggestion

The study presented in this paper is framed by the premise that learning and understanding derive from learners' current models and knowledge (Gentner, 2001; Von Glasersfeld, 2013). Therefore, the present study endeavors to unveil the Models of eighth-grade students in Türkiye concerning magnets and magnetic interactions, with a specific focus on identifying both ingrained and nonnormative Models. The research seeks to shed light on the depth of students' conceptualizations and the extent to which nonnormative Models persist in their understanding of the subject matter. In recent years, there has been a scarcity of research investigating K-8 students' Models of magnetism. The prevailing studies often focused on assessing students' Models at a specific time or examined the impact of interventions on their Models. A distinct feature of the current study is its unique approach of comparing Models of students within the same age group at 10-year intervals, employing a consistent data collection tool. This method allowed for the identification of changes in the mental model patterns among Turkish students over the specified time frame. Furthermore, refocusing our attention on the underlying factors that influence the development of students' constructed models holds vital importance in helping students enhance or revise their existing models.

Novice students use Models built via informal education such as personal observation, media, or people, and prior concept knowledge (di Sessa et al. 2004; Shepardson et al., 2007). Hence, it is not surprising that students' explanations were less sophisticated and lacked detail since magnets are parts of daily life and these students have not seen a comprehensive magnetism topic in their prior science courses. However, the findings in this study should suggest teachers how to design their lessons and what their activities should be focusing on to help students overcome their inaccurate as well as inconsistent Models. Additionally, as indicated by the findings of this study, the passage of ten years can significantly influence the formation and development of students' Models on a specific subject. Although all cognitive scientists agree that the construction of models takes place as an internal process for individuals, outside social, cultural, and environmental factors also play a significant role in an individual's modelling process (Moreira, 2000). Therefore, it becomes essential to conduct periodic studies at regular intervals, while also considering the prevailing social and societal context. Such repeated investigations provide valuable insights into the evolution of Models over time and offer valuable guidance for educators to align their instructional practices with the latest research findings.

While the outcomes of this study provide valuable insights for educators as outlined above, it is essential to acknowledge that the data collected through the employed data collection tool may have limitations in fully explicating certain aspects of students' inaccurate and inconsistent Models.

Therefore, it is advisable that future research endeavors be undertaken to explore and elucidate these specific details further.

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