# COMMUNICATION THROUGH DIAGRAMS:
# DIVISION OF LABOR BETWEEN GESTURES AND ARROWS

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**COMMUNICATION THROUGH DIAGRAMS:**
**DIVISION OF LABOR BETWEEN**
**GESTURES AND ARROWS**

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# ABSTRACT

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In this study, we aim at studying the relation between arrow production and gesture production in various multimedia teaching environments. Twenty-four participants, who were all experienced educators, were asked to teach a topic of their choice, as if he teaches to a learner audience. They taught the same topic in the same way in three experimental conditions: (i) Teaching on the board, (ii) Pen-and-paper teaching, (iii) Teaching by a tablet. All experiment sessions were videotaped. For the analysis, gestures and arrows were annotated. Arrows were classified into three groups: deictic arrows direct attention to the specific area, relational arrows connect two representations, and iconic arrows present motion, force, physical representations, and processes in a depiction. Gestures were also divided into three groups: deictic gestures point to entities, iconic gestures present picturable aspects of semantic content, and finally beat gestures are speech-related rhythmic hand movements. The results indicated that speakers produced more gestures and fewer arrows in the board session. This difference decreased in the paper session and reversed itself in the tablet session. Similar trends were also found in the relation between deictic and iconic gestures together compared to all arrows, and iconic gestures compared to iconic arrows. These results support the hypothesis that there is a trade-off between arrow and gesture production. These results also suggest that arrows and gestures are used for similar communicative purposes in different modalities.

Keywords: Gesture Production, Arrow Production, Multimodal Communication, Diagrams

# ÖZ

DAYAGRAMLAR ARACILIĞIYLA İLETİŞİM: EL HAREKETLERİ VE OKLAR ARASINDAKİ İŞBİRLİĞİ

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Bu çalışmada çeşitli multimedia öğretme ortamlarında kullanılan oklar ile el hareketleri arasındaki ilişkiyi incelemeyi amaçlıyoruz. Eğitim alanında deneyimli 24 katılımcıdan seçtikleri herhangi bir konuyu öğrenmek isteyen dinleyiciler varmış gibi öğretmelerini istedik. Aynı konuyu üç farklı deney koşulunda aynı şekilde anlattılar: (i) Tahtada, (ii) Kağıt-Kalem kullanarak, (iii) Tablet kullanarak. Tüm deney oturumlarının video kaydı alındı. Analiz kısmında, kullanılan el hareketleri ve oklar belirlendi. Oklar üç grupta sınıflandırıldı: işaret eden oklar dikkati belirli bir alana yönlendirirler, ilişkisel oklar iki temsili ilişkilendirirler ve ikonik oklar hareket, kuvvet, fizikle ilgili gösterimler ve işlemsel gösterimleri temsil ederler. El hareketleri de üç gruba ayrıldı: işaret eden el hareketleri varlıkları gösterirler, ikonik el hareketleri içeriğin resmedilebilir bileşenlerini gösterirler ve son olarak vurgu el hareketleri konuşmanın ritmiyle ilişkili el hareketleridir. Sonuçlar gösterdi ki konuşmacılar tahtada ders anlatıkları oturumda daha çok el hareketi ve daha az ok kullandılar. Bu fark kalem-kağıt kullanılan oturumda azaldı ve tablet kullanılan oturumda daha çok azaldı . Benzer eğilimler ayrıca işaret eden ve ikonik el hareketleri birlikte tüm oklarla karşılaştırınca ve ikonik oklar ikonik el hareketleriyle karşılaştırılınca da bulundu. Bu sonuçlar ok ve el hareketi kullanımı arasında bir işbirliği (takas) olduğu hipotezini destekliyor. Ayrıca bu sonuçlar ok ve el hareketlerinin aynı iletişimsel amaç için farklı tiplerde kullanıldığını öneriyor.

Anahtar Kelimeler: Gesture Kullanımı, Ok Kullanımı, Farlı Tiplerin Etkileşimi

*To my family;*
*mom and dad,*
*my husband, Fırat*
*Dilara and Barış*

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# CHAPTER 1

## 1. INTRODUCTION

Gestures are an integrated part of speech. (Goldin-Meadow, Kim & Singer, 1999; Valenzeno, Alibali & Klatzky, 2003; Goldin-Meadow & Wagner, 2005; Rauscher, Krauss & Chen, 1996; Alibali & Nathan, 2007). People typically produce gestures when they convey spatial information. Alibali (2005) exemplifies it with the following instance: a man holding two bags with his hands, needs to drop the bags and free his hands when a conversation starts. Gestures complete meaning by representing information which is referred to by speech or enrich communication by supporting information in a second modality. Beside communication, gestures help thinking; reduce cognitive load in visuospatial working memory hence it is supposed that in that way they help the speaker to retrieve words and speak fluently about the visuospatial content (Rauscher, Krauss & Chen, 1996). Moreover, congenitally blind infants produce gestures even when they know that the listener is blind as well (Iverson & Goldin, 1998). Gestures enable the speaker to represent information which is not sufficiently mature to express in a verbal way. For instance, learners externalize new acquired knowledge with gestures when they cannot describe it with speech (Alibali & Goldin-Meadow, 1993).

Overall, gestures promote communication by supporting information in a second modality or complete meaning by conveying information which is not represented in speech. Moreover, they promote communication by reducing the cognitive load of the speaker and help the speaker to externalize thoughts which are not formed well enough to express verbally.

How do gestures represent meaning? Gestures are in many forms and play many roles. The most common gesture types are iconic, deictic and beat gestures (McNeill, 1992). Beat gestures are merely speech-related rhythmic movements. On the other hand iconic and deictic gestures are related to the semantic aspects of speech. Deictic gestures are pointing movements that indicate concrete or virtual entities. They construct a bridge between speech and the entity which is referred to by speech. Iconic gestures visualize picturable aspects of speech, hence they bear some resemblance to what they represent.

Deictic and iconic gestures can represent meaning by drawing virtual diagrammatic elements (e.g., lines, dots, boxes, arrows) in the air (Tversky, Jamalian, Giardino, Kang & Kessel, 2013). In one study, participants were asked to explain diagrams which involve one of three types of diagrammatic elements. Diagrammatic elements in a graph highlight specific aspect of the information represented in line graphs; a point-like circle highlights a punctual state, a vertical arrow highlights a process, a bidirectional horizontal arrow highlights a durative state (Acartürk & Alaçam, 2012). The participants more frequently produced deictic gestures to point to punctual states. They frequently produced vertical gestures while explaining diagrams with vertical arrows. In a similar manner, they produced horizontal gestures while explaining diagrams with bidirectional horizontal arrows. This study indicates the relation between conceptualization of diagrammatic elements and their externalization through gestures where processed information through diagrammatic elements is represented in similar form through gestures. In another study, the participants worked in pairs on a map to find the most efficient route to rescue a certain number of injuries. They produced gestures in a typical diagrammatic element form; pointing a place (e.g., dot), tracing a path between places (e.g., line), and tracing a place (e.g., box) (Heiser & Tversky, 2004).

The studies mentioned above suggest that gestures visualize thought by using simple content-free geometric forms as diagrams do. However, gestures, like speech, are momentary actions; they are produced and appear in a limited time. On the other hand, diagrams are relatively permanent visual representations. This advantage provides diagrams to be inspected without being dependent on time (Tversky et al., 2013). Hence, a wide range of perceptual processes (e.g., compare; contrast; highlight similarity, distance, direction, shape, and size; rotate, group) may play role on the comprehension of diagrams (Tversky, 2009). Gestures can be viewed as virtual diagrams in the air whereas diagrams are the permanent traces of gestures on the surface (Tversky et al., 2013). Diagrams, like language, have developed some conventional forms. They convey actually (e.g., maps, architectural plans) or inherently (e.g., organizational charts, flows) visible spatial relations by using space, diagrammatic elements and their spatial relations.

Diagrammatic elements such as dots, lines, boxes and arrows are simple content-free geometric forms; they represent meaning through their geometric and gestalt properties. Arrows are asymmetric lines (Tversky, 2001). They represent myriad of meanings such as causal or temporal relation, motion or forces, direction, label, focus attention. In one study, students are asked to interpret diagrams, either with or without arrows, of a mechanical system. Students who saw diagrams with arrows gave functional descriptions about the mechanical system whereas the diagrams without arrows are explained by structural descriptions. In the second study, students were asked to sketch a description which involves either structural or functional information about a mechanical system. In similar manner, students produced arrows to illustrate functional aspects of the system whereas they did not for structural descriptions (Heiser & Tversky, 2006). Although diagrams are static by their nature, arrows in a diagram can represent dynamic aspects of the content (Tversky 2009). Gestures are dynamic by their nature hence they can be used to represent actions in a diagram. In another study, students watched one of two videos about how an engine worked (Tversky et al., 2013). Except for gesture types, videos were identical with their diagrammatic representations and verbal explanations. In one video, gestures gave information about the structure of the engine; in another, gestures represented the behavior of the parts of the engine. In one of the post-tests, students sketched the engine according to what they learn from the video. Those who watched videos with gestures represented function of the engine through more arrows which represent action in the diagram. From the perspective of gesture comprehension, this study suggests that gestures, like arrows, have advantages over verbal explanation and static diagrams by means of representing dynamic aspects of the content. From the visuospatial transformation perspective, this study gives evidence about the representation of the same knowledge in different modalities; the transformation of the visuospatial information from one modality to other modality, from gestures to arrows.

A working assumption in cognitive science research has been that internal representations are knowledge or structures that are stored in memory and retrieved from memory by cognitive process. On the other hand, external representations are the knowledge and structure in the environment and although sometimes internal representations may facilitate or speed up processing, information in the environment can be picked up by perceptual systems (Zhang, 1997). External representations are transformed into internal representations by comprehension processes when they have reasonable complexity or not necessarily if external representations are always available. In the same manner, internal representations are transformed into external representations by externalization (e.g., production of gestures, diagrams) (Zhang, 1997).

Humans are better in complex cognitive tasks when they interact with external representations. External representations are used as memory aids because working memory have limited storage and limited process capacity (Zhang & Norman, 1994; see Acartürk, 2010, for a review). For instance, one can multiply two-digit numbers mentally whereas pen-and-paper is required to multiply four-digit numbers. External representations do not just perform as memory aids but also have further functions. In the study of mental images and external pictures, Reisberg (1987) stated that externalization of a representation gives people to access knowledge which are otherwise unavailable. From the perspective of graph comprehension Larkin and Simon (1987) stated that graphs facilitate three processes: search, recognize, and reasoning. Well-designed graphs convey necessary information together thus avoiding search effort to make problem-solving reasoning. They put same group of elements together hence preventing symbolic label requirement. Finally, diagrams support a large amount of perceptual features hence they enable reasoning directly.

Reasoning is a cognitive phenomenon which is a part of daily life and complex activities. A wide range of concepts from simple generalization or recognition activities to complex problem solving tasks require reasoning (Tversky, 2005). In terms of Tversky (2005), reasoning is going beyond to the given information. Transforming information based on the rules is one of the proposed ways. More specifically, visuospatial reasoning allows us to make inferences about what we see and when we see. It is essential to survive; recognize things and places, imagine and perform mental transformations on them (Tversky, 2013). Kleinmuntz and Schkade (1993) stated that the design of diagrams strongly influences decision making strategies. He noted three design principles: form (e.g., verbal, numerical or pictorial), organization (e.g., hierarchy, organization, patterns) and sequence (e.g., sorting items based on frequency in descending order) (see **Figure 1.1.**). Although design principles have an impact on perceptual processes, an expert graph-reader may be aware that the represented information is the same among graphs through visuospatial reasoning.

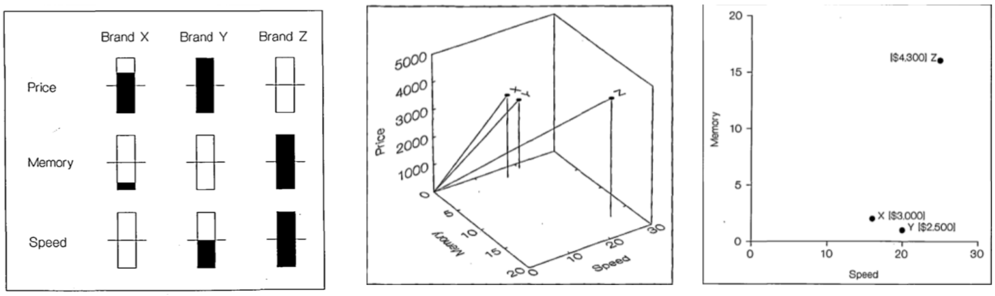


*Figure 1.1. The same information is represented in different graphical displays*
Reprinted from Information displays and decision processes (p222-224), by Kleinmuntz, D. N., & Schkade, D. A. 1993, Psychological Science, 4(4)

The term "visuospatial" refers to visual and spatial properties of objects. The term "visual information" refers to static (e.g., color, shape and texture) and dynamic properties (e.g., direction, path, and trajectory of motion) of objects. On the other hand, "spatial information" is related to spatial arrangement of objects (Tversky, 2004). Visuospatial representations reserve at least some of the spatial structural relations and visual aspects.

To sum up, representations of visual modalities take advantage to convey meaning directly for some content through its visuospatial aspects compared to purely symbolic verbal ones. The interaction between visual and verbal modalities has been subject to many studies. However there are few studies which investigate the relation between the external representations of nonverbal modalities (e.g., Flavers, 2001; Acartürk & Alaçam, 2012). This thesis focuses on the relation between nonverbal modalities, namely gestures and arrows. To examine this issue, gesture and arrow production is investigated in instructional environments which are rich in representation of different modalities.

Instructors provide target knowledge for learners to comprehend ("Instructional explanation", 2011). They frequently use representations of nonverbal modalities (e.g., gestures, diagrams), beside verbal ones (Flavers, 2001). The meaning is expressed as a result of interaction across different modalities rather than a single one (Pozzer-Ardenghi & Roth, 2007). For instance, the teacher traces the edges of rectangle with his hands while explaining the calculation of its area (Alibali & Nathan, 2005). Because instructional settings are rich in representation of different modalities, to examine this issue gesture and arrow production is investigated in three instructional environments:

(i) Teaching on the board

(ii) Paper-and-pencil teaching

(iii) Teaching by a tablet

The term “multimodality” is used for a wide range of meanings in literature. In Human-Computer Interaction, the term is used for representing information to humans or agents in multiple ways (e.g., tables, maps, beeps) in a physically realized form (Bernsen, 1997). In cognitive psychology the term is used for multiple sensory channels. This thesis focuses on two modalities; gestures and arrows.

In summary, gestures are integrated part of speech. They were investigated based on both communicative and cognitive aspects. They contribute the speaker to express himself by reducing cognitive load, help the speaker to retrieve words or enrich communication by supporting or completing meaning. There is a consensus on the gesture classification in the literature; deictic and iconic gestures are semantically rich gestures (McNeill, 1992). Deictic gestures indicate the entities which are referred to by speech, hence construct a bridge between speech and its referent and can direct attention towards the entity. Iconic gestures depict visuospatial aspects of the content. Arrows are asymmetric lines they can represent a wide range of meaning as gestures do and these meanings may overlap with those of gestures. Arrows can point to an entity, represent the relation between the entities hence construct a bridge between them. Finally, arrows can also depict visuospatial aspects of the content. Gestures and arrows convey the same information in different modalities by using similar diagrammatic features. This study aims to investigate whether there exists a trade-off between gesture and arrow production through instructional communication settings. Particularly the following questions are the focus of this thesis.

- Is there any trade-off between gesture and arrow production by means of representing the same meaning? In other words, will gesture production influence arrow production or vice versa in live communication settings?
- Is it possible to classify arrows based on their semantic roles in content like gestures?
- If so, is there any interaction between specific subtypes of arrows and gestures.

This thesis is composed of five chapters. In chapter 2, gestures and arrows are investigated with respect to relevant work in the literature, chapter 3 presents an explanatory analysis to understand the use of arrows in various written material. Chapter 4 presents the interaction between gesture and arrow production is experimentally investigated in three instructional environments. Finally chapter 5 presents discussion on findings of experiments and concludes the thesis with respect to suggest future work.

# CHAPTER 2

# 2. GESTURES ARROWS AND RELEVANT WORK IN THE LITERATURE

## 2.1. Does gesture communicate?

There has been a debate on whether gestures help communication. Krauss et al. (1995) argues that gestures have little communicative effect, whereas Kendon (1994) supports the view that gestures may have impact on a listener's understanding. Goldin-Meadow and Wagner (2005) stated that gestures have little effect on communication when gesture and speech convey the same information. On the other hand, listeners could glean information from gestures when gestures convey information which does not exist in speech.

In communication, gesture and speech are in an integrated form. However, they may serve different aspects of the same message. Goldin-Meadow, McNeill and Sigleton (1996) proposed that speech and gesture convey the meaning differently due to their different structures. Speech has segmented and linear form whereas gestures are in nonsegmented and multidimensional form. For instance, to verbalize that someone is sitting on the chair, each word should be selected accordingly and organized into hierarchical form to build up this sentence; "somebody is sitting down on a chair." On the other hand, gestures can represent the same information analogically by using space, time, form and trajectory (Goldin-Meadow et al., 1996).

In summary, speech and gestures have different characteristics; however, they are also considered to be in relation to each other during the course of communication. Below, a snapshot of the research on gestures and relevant domains is presented.

### 2.1.1. Taxonomy of Gestures

There are several taxonomies for classifying gesture types in the literature (see Roth, 2001 for a brief review). Most researchers build their work upon the taxonomy which was proposed by McNeill (1992). McNeill classified gestures into four classes:

- Iconic
- Metaphoric
- Deictic
- Beat

Briefly, iconic gestures illustrate picturable aspects of speech which are concrete objects or events. He exemplified the description with this example: the speaker acts as if he is gripping something and moves his hand back as he is uttering "bends it way back." In this way the speaker provides the listener the illustrated form of the utterance (see **Figure 2.1.**).

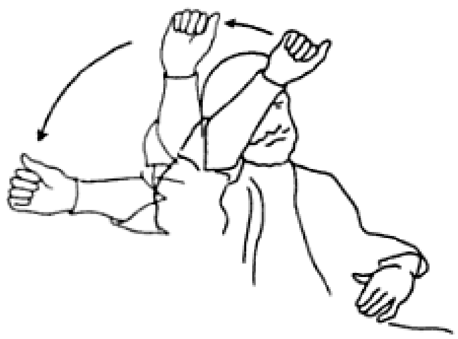

*Figure 2.1. The illustration of iconic gesture.*

The speaker moves his hand back as he is uttering "bend it way back". Reprinted from *Hand and mind: What gestures reveal about thought* (p. 12), by D. McNeill, 1992, University of Chicago Press.

Metaphoric gestures represent abstract concepts rather than concrete concepts, in contrast to iconic gestures. In McNeill's illustration, the speaker raises his hands up and offers the listener to hold an object; meanwhile he is presenting his ideas about the genre of the cartoon. In this way, the gesture represents the ideas of the speaker (see **Figure 2.2.**).

*Figure 2.2. The illustration of metaphoric gesture.*

The speaker raises his hands up and offers the listener to hold an object. In this way, the gesture represents the ideas of the speaker. Reprinted from *Hand and mind: What gestures reveal about thought* (p. 14), by D. McNeill, 1992, University of Chicago Press.

Deictic gestures are pointing movements that indicate concrete or abstract entities and events. McNeill exemplified deictic gestures which gestures which point to abstract entities with the following example: the speaker points to empty space to refer to a city rather than the physical space as he is asking the listener where he is from (see **Figure 2.3.**).

*Figure 2.3. The illustration of deictic gesture.*

The speaker points to empty space to refer to a city rather than the physical space as he is asking the listener where he is from. Reprinted from *Hand and mind: What gestures reveal about thought* (p. 18), by D. McNeill, 1992, University of Chicago Press.

Finally, beat gestures are the speech-related rhythmic movements that occur independently from the semantic aspects of speech. For instance the speaker moves his hand while he is stressing a particular part of speech and drops his hand back at the end of the stressed segment. In McNeill's illustration, the speaker raises his hand while showing an upward palm and drops back down as he is uttering the word "whenever" (see **Figure 2.4.**).

*Figure 2.4. The illustration of beat gesture.*

The speaker raises his hand while showing an upward palm and drops back down while uttering the word "whenever". Reprinted from *Hand and mind: What gestures reveal about thought* (p. 16), by D. McNeill, 1992, University of Chicago Press.

In this thesis, gestures are investigated with the respect to McNeill's gesture taxonomy which is mentioned above and it should be noted that metaphoric gestures are combined into iconic gestures. The following part presents the literature on the effect of gestures on learning.

### 2.1.2. Gestures in Learning

Gestures are an indispensable aspect of instructional communication. Goldin-Meadow, Kim and Singer (1999) identified two functions of gesture in classroom interaction: (a) gestures can inform a listener about the motivation and attitudes of the speaker during the communication between teacher and pupils and (b) gestures play a role in the acquisition of the content of the lesson itself. The first function of gestures may affect a student's attitude towards learning, whereas the second function of gestures has a direct impact on cognitive aspects of learning. More generally, many findings support the idea that gestures are crucial for learning. These studies suggest that gestures promote learning (Goldin-Meadow, Kim & Singer, 1999; Valenzeno & Alibali, 2003; Goldin-Meadow & Wagner, 2005); gestures facilitate retrieving words from memory (Rauscher, Krauss & Chen, 1996); gestures scaffold understanding of learning (Alibali & Nathan, 2007); gestures provide subsequent learning (Cook, Mitchell & Goldin-Meadow, 2008); and gestures help in understanding speakers' current cognitive state (Goldin-Meadow & Singer, 2003; Goldin-Meadow, Alibali & Church, 1993).

Research by Goldin-Meadow, Kim and Singer (1999) examined whether gestures that accompany speech contributed to learning and teaching. Teachers were asked to instruct students individually on the topic of mathematical equivalence. The results of this study indicated that teachers' gestures had an effect on what children learn from teachers' instruction. Children were more likely to reiterate teachers' strategies when the speech was supported by gestures. However, it should be noted that this finding suggests that the presence of gesture-speech matching contributes to comprehension. In other words, the comprehension of speech is enhanced when gesture and speech convey the same strategy about the task. The findings of Goldin-Meadow et al. (1999) also showed that gestures negatively influenced comprehension when they represented information that is incompatible with the content of the speech. In particular, children were less likely to reiterate teacher's strategies when speech and gesture conveyed different strategies than when the teacher did not produce gestures. Goldin-Meadow et al. (1999) assessed the effect of gestures on communication as well as on comprehension. Overall, these findings suggest that supporting teaching with a second modality revealed beneficial effect on children's uptake.

According to Goldin-Meadow (2004), gestures promote communication as well as learning in two ways: direct and indirect. In the direct manner, gestures are supposed to reduce the cognitive load of the learner and in this way help the learner allocate resources to the task. In the indirect manner, gestures are supposed to provide information about the speaker's cognitive state to a listener and lead a listener to alter responses accordingly. Gestures provide crucial cues to the teacher about the level of understanding of a student (Goldin-Meadow and Wagner, 2005) as well as unspoken thoughts of the speaker (Goldin-Meadow, 1999).

Another study, which examined whether teachers' gestures facilitate learning for a listener, was conducted by Valenzeno and Alibali (2003). Preschool children viewed one of two video tutorials on the concept of symmetry. In the verbal-plus-gesture lesson, the teacher produced pointing and trace gestures with her speech. In the verbal-only lesson, the teacher did not produce any gestures. The results showed that children who viewed the verbal-plus-gesture lesson learned more than children who viewed the verbal-only lesson. Valenzeno and Alibali (2003) proposed two likely reasons for their findings. First, gestures had more ability to capture a listener's attention because the findings showed that children who watched the verbal-plus-gesture lesson were more attentive to the videos. Hence, the attentive children learned more from the tutorial. The second reason was that gestures provided a linkage between abstract concepts in speech and the physical environment. For instance, the teacher traced a line by uttering "imagine a line." In this way, gestures depicted the related part of the speech and helped the listeners in their acquisition of new information.

In summary, all of these studies suggest that gestures promote learning when a teacher reinforces his or her speech with gestures. On the other hand, limited consensus has been found regarding the likely reasons for the experimental findings. Relevant work about the role of gestures from the speaker's perspective is presented below.

### 2.1.3. Gestures Help Thinking

Gestures not only facilitate learners' comprehension but also aid the speaker himself in various ways. Iverson and Goldin (1998) focused on the reasons why humans produce gestures and suggested two hypotheses. First, humans produce gestures because they learn gesturing from other humans who also produce gestures. Secondly, humans produce gestures consciously or intuitively to provide a listener with useful information. These hypotheses were examined using congenitally blind children. Interestingly, the findings indicated that blind children produced gestures even they knew that the listener was also blind. These findings suggest that gestures are an integrated part of speech, which humans do not learn from others. This also reveals that gestures comprise an intuitive way to express thoughts.

Rauscher, Krauss, and Chen (1996) investigated the effects of gestures on speech production. Participants were asked to describe animated cartoons in two conditions: (i) gestures were allowed, (ii) gestures were not allowed. The findings indicated that the speakers produced more gestures with spatial content compared to nonspatial content. Another important finding was that preventing gestures reduced the speed of speakers when the content of the speech was spatial. In other words, spatial features of the content led the speakers to require more gesturing, and restricting gestures caused more dysfluencies in the speech of the speaker. These findings suggest that gestures play a role either in formulation or conceptualization of spatial knowledge. As a result, preventing gestures interrupts the process of spatial content production.

Overall, these studies suggest that gesturing is an intuitive way of expressing thoughts and that it is an integrated part of speech, not only from the listeners' perspective but also from the speakers' perspective. In other words, gestures play a significant role both in comprehension and production of speech.

### 2.1.4. Learning Subsequently

The studies mentioned above revealed that gestures facilitate listeners' comprehension and help speakers in expressing thoughts in a fluent manner. The previous work also reveals that gestures have a significant role on learning not only in the short term but also in the long term. Cook & Goldin-Meadow (2008) tested whether gestures provided children learning subsequently. The term learning subsequently is used by these researchers to mean the ability to retrieve the information which was learned during the instruction for at least one month. They observed the effect of gestures on learning a novel mathematical concept in an experimental setup. Children were instructed in three ways: (i) gestures with accompanying speech, (ii) speech alone, (iii) gesture alone. After the instruction children in all groups improved their performance. The crucial finding was that children who produced gestures were more likely to retain knowledge gained during the instruction after four weeks compared to the ones who did not produce gestures. These findings indicate that gestures may help retain knowledge. The researchers proposed three explanations for the reason behind these findings. First, representing knowledge in a second modality may aid in learning by reducing demands on working memory (Goldin-Meadow, Nusbaum, Kelly, & Wagner, 2001; Wagner, Nusbaum, & Goldin-Meadow, 2004). Secondly, gesture itself may be effective to store knowledge in long-term memory by producing strong and robust memory traces. Finally, gesturing, particularly pointing gestures, may affect learning by providing a link between mental representations and the external world.

To sum up, from the perspective of comprehension, it appears that gesture is an indispensable part of communication which has not only short-term influence but also a long-lasting one in retaining knowledge in the long term.

### 2.1.5. Provide Information about Speaker's Insight

Previous research has also investigated the specific conditions under which gestures are produced by the participants. Gestures represent information in a second modality; they can be either a supplement or a complement of the knowledge which is conveyed in speech. Students can extract information from teachers' gestures. Teachers deduce the comprehension of students from their gestures and vary the communication behavior accordingly. Gestures may play a crucial role in adjusting this communication (Alibali & Nathan, 2007). Alibali and Nathan (2007) found that teachers were likely to produce more gestures in certain states, such as when new instructional material was introduced, when the instruction material was complex and abstract, and when responding to students' questions or comments. These findings suggest that teachers are consciously or intuitively aware of the role of gestures in learning and support their teaching with gestures, particularly when children are acquiring new and complex knowledge. An alternative explanation is that teachers' gestures reflect his or her opinion about the student's difficulty in comprehension of the instructed material.

From our perspective, these findings suggest that instructional settings are appropriate domains of research on gesture because the speaker introduces novel concepts which are usually abstract and complex. Therefore, frequent production of gestures would be expected in instructional settings.

### 2.1.6. Gestures and Other Visual Modalities

The literature research so far has studied gestures either in isolated or in its relation to speech comprehension and production. On the other hand, there are few studies which investigate the relationship between non-speech modalities, for instance between gesture and depictive illustrations. Flevares (2001) found that teachers use combinations of visually-based modalities rather than in isolated form. In particular, teachers produced gestures and illustrations while explaining critical concept of mathematics or while responding to students' questions. Flevares' study supports the view that gestures as well as other visual representational modalities reflect the thought of the speaker in a similar way. Teachers supported or completed their instruction, especially on critical content, by using other modalities. Teachers may be aware of the ability of visual modalities or this may reflect the awareness of the teacher as to the student's level of understanding (Alibali & Nathan, 2007). Both possibilities support the view that visual representations which are not restricted with gestures help students' understanding. However, another finding of the study was that teachers more frequently produced gestures than the other visual representations (picture, symbol and objects). This finding suggests that gestures are easier to produce compared to other visual modalities.

When we look at the communicative elements in instructional settings, arrows appear to be a frequently used non-speech element type, in addition to gestures. The following section discusses arrows as a visual communicative element along with a study of arrow use in written materials.

## 2.2. Arrow as a Visual and Communicative Element

The arrow symbol is one of the most ubiquitous elements of visual communication. It is used in a variety of such as instructional materials, academic journals, magazines, and traffic signs. They easily capture a wide range of concepts such as motion, direction, transformation, sequence, and relation through their geometric and gestalt properties. For instance, an arrow between two items intuitively represents the connection between them.

It is not known how long arrows have been used in diagrams, but it is known that they were used in diagrams to show direction by the 18th century (e.g. Gombrich, 1990).The relation between arrow and direction depends on two analogies: the direction of an arrow shot from a bow and the arrow-like points in events such as liquid flowing downhill (Tversky, 2001).

Tversky (2001) defined an arrow as a special asymmetric line which indicates an asymmetric relationship. As a consequence, if an arrow is used between two elements they are naturally ordered. An arrow consists of three parts. Kurata and Egenhofer (2008) named them *tail slot*, *body slot*, and *head slot* (see **Figure 2.5.**).

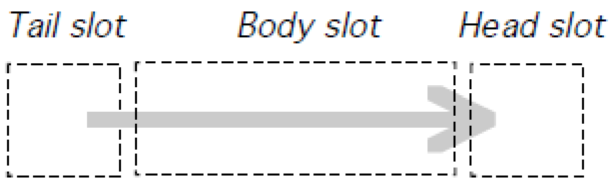


*Figure 2.5. The parts of arrow symbol*

Reprinted from “The Arrow-Semantics Interpreter.” by Y. Kurata and M. J. Egenhofer, 2008, *Spatial Cognition & Computation*, 8(4), p. 313.

Frutiger (1989) suggested that the expression of an arrow is altered by the degree of the arrow head. Angles greater than 45° are seen as resistance against forces whereas angles smaller than 20° produce the effect of a weapon and reaction of danger. Although, this assumption makes sense analogically, it is a fact that an arrow alone does not convey any message. However, it has a remarkable ability to communicate in context. Beside its versatility, an arrow may have several possible meanings in the same context. This ambiguity may cause some difficulties in interpreting arrow-containing diagrams especially for novice readers and computer agents who lack background (Kurata & Egenhofer, 2005a).

Horn (1998) counted 250 possible meanings for arrows such as direction, linkage, and motion. Kurata and Egenhofer (2005b, 2008) proposed systematic investigation of the arrow classifications based on the number of entities required by the arrow-containing diagram and whether an arrow modifies the entity itself or represents connection between individual entities (see **Figure 2.6.**). They divided arrows into four classes: *orientation*, *behavioral description*, *annotation*, and *association* (Kurata & Egenhofer, 2008). An arrow in the orientation class modifies the entity itself by representing the vector or the direction of the entity. Secondly, an arrow in the annotation class connects two dependent entities by labeling. Thirdly, an arrow in the behavioral description class represents the motion of the entity towards the other entity. Finally, an arrow in the association class connects individual entities and represents the relation between them such as causal relation and ordered relation. Based on the entity count that a given arrow-containing diagram requires, an arrow in the orientation class requires a single entity; an arrow in the annotation and association classes requires two entities, and, finally, an arrow in the behavioral description class requires two or more entities.

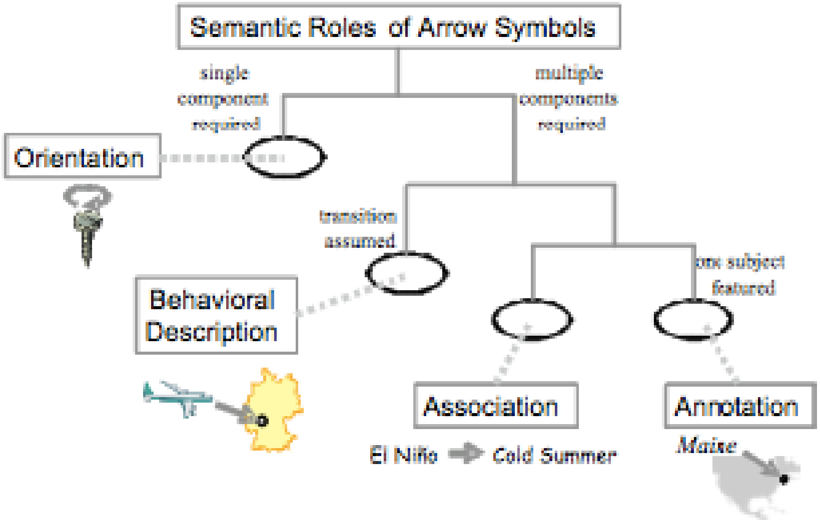


*Figure 2.6. Arrow classification proposed by Kurata and Egenhofer (2008).*
Kurata and Egenhofer (2005b, 2008) proposed systematic investigation of the arrow classification based on the entity count which the arrow-containing diagram requires and whether an arrow modifies the entity itself or represents connection between individual entities. Reprinted from The Arrow-Semantics Interpreter (p. 313), by Y. Kurata and M. J. Egenhofer, 2008, *Spatial Cognition & Computation*, 8(4).

Another study which points out the potential of an arrow in a diagram is by Heiser and Tversky (2006) which shows that diagrams with arrows and without arrows convey different messages. Diagrams, such as the ones that show how a bicycle pump works, show its structure if no arrows are used. However, diagrams with arrows point out its function and temporal sequences of events.

From the perspective of cognitive science, arrows have the potential to represent asymmetry and direction in space, in motion, in time and in causality. Arrows are basic communication modalities that accompany speech, much like gestures. Arrows have context-dependent use and particular functions that can be presented at a closed-set level. Nevertheless, the previous research reveals no consensus on the classification of arrows. Therefore, we decided to conduct an explanatory analysis to understand the use of arrows in various types of written material. In this study, an analysis which provided an opportunity to determine ontology was conducted to examine how arrows are used in different instructional domains. This analysis will be presented in the following chapter.

# CHAPTER 3

# 3. AN ANALYSIS OF ARROW USE IN INSTRUCTIONAL MATERIAL

In this study, a variety of samples from various resources was collected in order to create a proposal for a classification of arrows. We classified the samples into groups based on their semantic roles. Finally, arrows were evaluated according to whether or not they had a common syntactic structure. If so, the syntactic representations of arrows in each group were formulated by using node-link diagrams.

## 3.1. Data Collection and Analyses

Arrow samples were collected from a total of nine resources: five books, two academic journals and two weekly magazines. Each book was selected from the following domains; physics, psychology, engineering, chemistry, and biology. The journals were selected randomly without considering its domain.

## 3.2. Classification System

First, all pages of the books and journals were scanned and each arrow sample was photographed. In this way, 1015 arrow samples were collected from all resources (see **Table 3.1**).

Table 3.1

*The distribution of collected arrow samples according to the resources*

| | Iconic | Relational | Deictic | Other | Total |
|---|---|---|---|---|---|
| Physics: Principles And Problems Teacher Wraparound Edition. | 355 | 28 | 5 | 11 | 399 |
| Holt Biology Texas: Student Edition | 64 | 99 | 0 | 0 | 163 |
| Chemistry the Central Science International Edition | 134 | 173 | 5 | 1 | 313 |
| The Cognitive Control of Motivation: The Consequences of Choice and Dissonance. | 0 | 12 | 0 | 0 | 12 |
| Modelling in Mechanical Engineering and Mechatronics: Towards Autonomous Intelligent Software Models. | 11 | 30 | 0 | 0 | 41 |
| Cognitive Science | 8 | 18 | 0 | 0 | 26 |
| NewsWeek | 21 | 1 | 2 | 4 | 28 |
| TLS | 0 | 0 | 1 | 0 | 1 |
| topiCS in Cognitive Science | 12 | 17 | 1 | 2 | 32 |
| Total | 605 | 378 | 14 | 18 | 1015 |

After that, each sample was classified into groups based on its contextual function. In this way, we identified 34 classes in the first pass. In the second pass, the groups were compared to each other to detect whether any functional similarity existed between them and if this similarity was adequate to combine groups into an upper level. The following groups which were identified in the first pass are presented below as an example (see Error! Reference source not found.).

- Sequence: Arrows that represented a temporal order between the entities were classified into the sequence class.
- Transform: Arrows that represented a change in the form of the entity were classified into the transform class.
- Zoom: Arrows that represented a close-up and detailed view of the particular part of the entity were classified into the zoom class.

These three classes (sequence, transform, and zoom) were combined into the relational class because the presence of relational representation was identical for these arrows although they convey different relational aspects in the details.

Sequence Transform Zoom

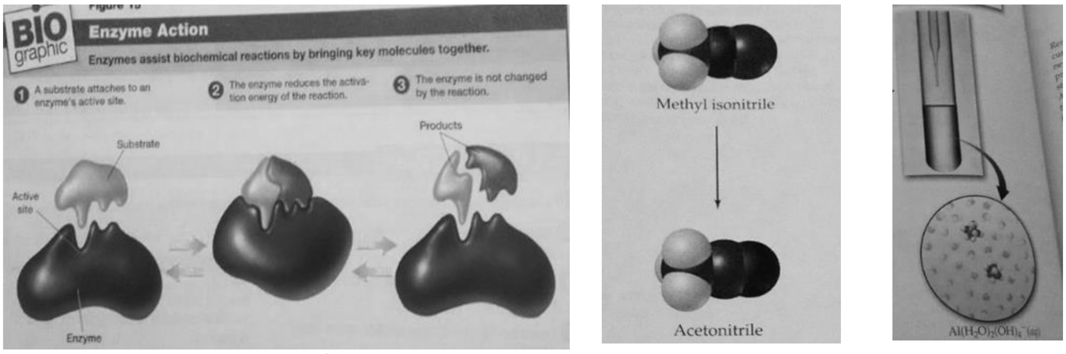


*Figure 3.1. An example of combined arrow groups.*

Arrows that represent temporal order between the entities were classified into Sequence group (left). Arrows that represent change in the form of the entity were classified into Transform group (middle). Arrows that represent close-up and detailed view of the particular part of the entity were classified into Zoom group (right).

Hence, each group was compared to each other to determine their common functional role. If a common role was found, they were combined into a broader group. This process was repeated several times until distinct groups were obtained. At the end of this analysis, three main arrow classes were obtained which were named “deictic”, “relational”, and “iconic”. In this study, the arrows which did not fit into any class were classified as “other” (1.8% of all arrows). In the third pass, the groups were divided into subgroups based on their minor differences which will be explained further in this chapter. After the classification process, arrows were evaluated according to whether or not they had a common syntactic structure.

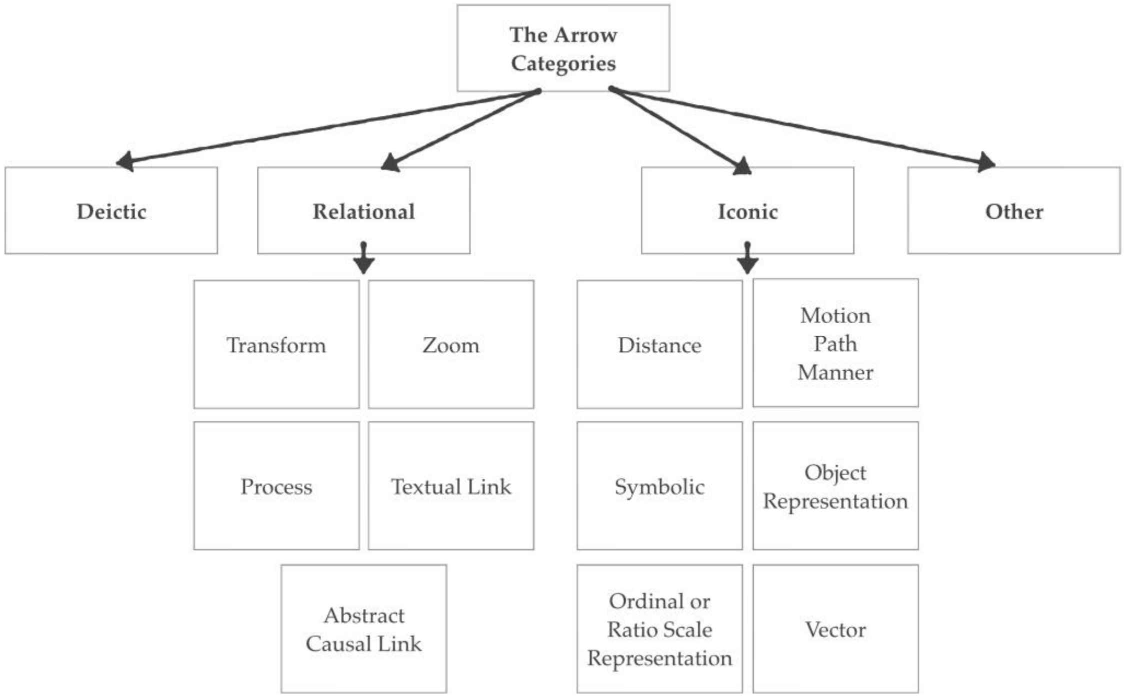


*Figure 3.2. Classification of arrows based on their semantic role.*
Groups and subgroups of arrow which were obtained at the end of classification.

### 3.3. The Classification of Arrows

This section presents the classification of the arrows based on semantic and syntactic analysis. Arrows were classified into three classes based on their semantic role: “deictic”, “relational”, and “iconic” (see **Table 3.2**). There are cases in which deictic arrows and some subclasses of relational arrows play similar semantic roles in context. As a working assumption, in this study, deictic arrows and relational arrows are considered distinct classes.

Table 3.2

*The count of arrow tokens according their types*

| Type | Count | Percent |
|---|---|---|
| Iconic | 605 | 59.61% |
| Relational | 378 | 37.24% |
| Deictic | 14 | 1.38% |
| Total | 997 | 98.23% |

The term semantic role is used to indicate context-dependent function of the arrows. The semantic analysis focuses on the information which was conveyed by the arrows. The syntactic analysis focuses on node-link representation of the arrow classes which is only applicable for deictic and relational arrows. Iconic arrows represent picturable aspects of the content by using the space and visual properties of the arrow. Therefore, they were not formulated by a node-link diagram due to being in a visuospatial format. Node-link diagrams represent the systematic relations between constituents of an arrow diagram at a basic level without considering the information which is conveyed by the diagram.

In diagrammatic comprehension studies, it is typical for diagrams to be analyzed subject to their syntactic/semantic characteristics. For instance, Kosslyn (1989) conducted a similar syntactic-role and semantic-role analysis to understand charts and graphs. Kosslyn defined basic-level constituents and their interrelations. In Kosslyn's framework, the syntactic analysis describes the inner and outer organization of the constituents without considering what they represent. The semantic analysis focuses on the meaning of the display which varies based on the configuration of the constituents. Finally, the pragmatic level focuses on the meaning of the display which is different than direct semantic interpretations of symbols. In this study, we performed semantic and syntactic analyses of the arrows, as we describe in detail in the following sections.

### 3.3.1. Iconic Arrows

Iconic arrows were the most frequently used arrow type in the collected samples. A total of 605 iconic arrow samples was collected which composed 59.6% of the total arrow samples. Iconic arrows represent picturable aspects of the content. Each part of the arrow may play a role in the interpretation of the arrow-containing diagram. The angle of the arrow head may represent resistance as Frutiger (1989) mentioned, the length of the arrow may indicate the distance between two entities, or the shape of the arrow body may represent the trajectory of the motion. The semantic and syntactic properties of deictic arrows are presented below.

*3.3.1.1. Semantic Role*

Arrows that depict visuospatial aspects (e.g., motion, distance, axes) of the content by using space and geometric properties of the arrow are classified as iconic arrows. Iconic arrows may highlight information about working principles of a system which are invisible in the absence of the arrow (e.g., the motion of the pump in the heat engine).

*3.3.1.2. Syntactic Representation*

Iconic arrows are not formulated with node-link diagrams because a similar syntactic pattern was not investigated for them.

*3.3.1.3. Subclasses of Iconic Arrows*

An iconic arrow may vary according to visuospatial aspects of the content. In this study iconic arrows were classified into subclasses based on the observed semantic role of the collected data. The iconic arrows were divided into six subclasses which are named "motion", "distance", "object representation", "ordinal or ratio scale representation", "symbolic" and "vector."

*3.3.1.3.1. Motion*

Motion arrows represent a function of a mechanism (e.g., to convey twisting forces effect in a mechanism), behavior of physical concepts which cannot be observed with the naked eye (e.g., electric field, ray), or dynamic behavior (e.g., force, pressure, velocity).

Path and manner of motion can also be represented by manipulating the body slot (shape) of arrow (see **Figure 3.3.**).

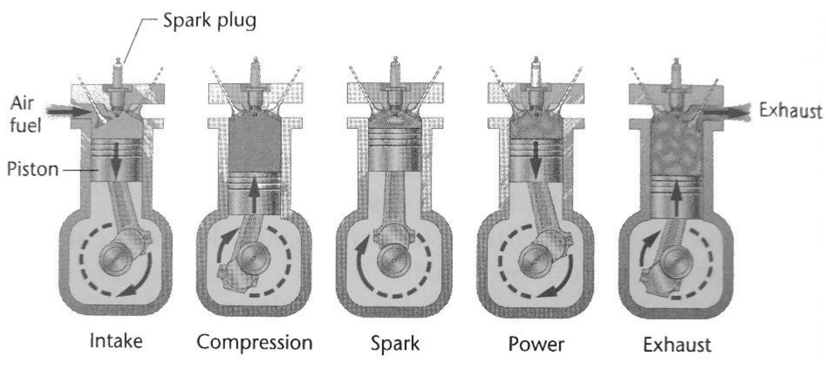


*Figure 3.3. A motion arrow sample.*

The diagram represents working mechanism of heat engine. Reprinted from *Physics: Principles and Problems* (p. 290), by Paul W. Zitzewitz et al., 2009, Glencoe/McGraw-Hill.Physics: Principles And Problems Teacher Wraparound Edition.

*3.3.1.3.2. Distance*

Arrows in the distance group refer to a distance between two entities. The referral area is considered to be the area between the start point and end point of the arrow. Arrow – Distance relation is mostly determined using demonstrated with an additional attribute. For instance, an arrow can be used with a symbol such as *d* or *r* or the limits of arrow can be highlighted by a dashed line (see **Figure 3.4.**).

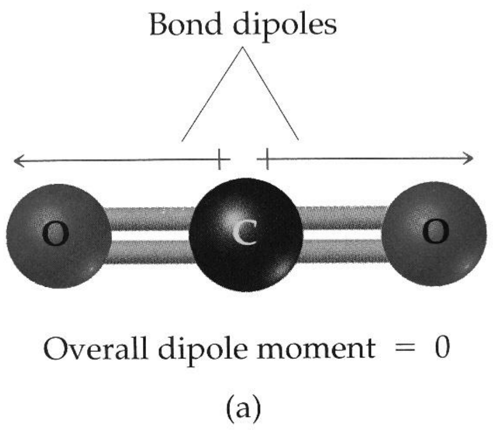


*Figure 3.4 A distance arrow sample.*

Arrows represent equal distance between elements in a bipolar molecule figure. Reprinted from *Chemistry: The Central Science* (p. 358) by T. L. Brown, 2009, Pearson Education.

*3.3.1.3.3. Object Representations*

An arrow is an analogical demonstration of an object. All referral areas of the arrow represent one part of the represented object. For instance, length is related to the length of the represented object or start point refers to the beginning of the represented object. This kind of arrow is mostly used in the field of physics (see **Figure 3.5.**).

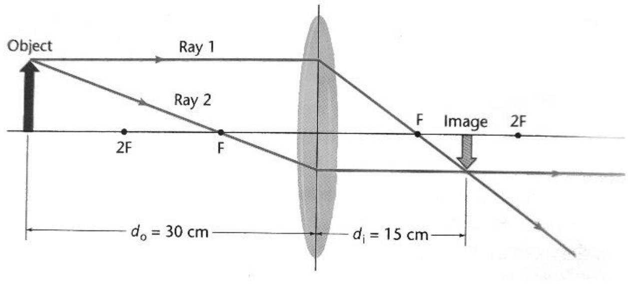


*Figure 3.5. An object representation arrow sample*

The reflections in convex lens are illustrated with two arrows to represent object and image. Reprinted from *Physics: Principles and Problems* (p. 430), by Paul W. Zitzewitz et al., 2009, Glencoe/McGraw-Hill.Physics: Principles And Problems Teacher Wraparound Edition.

*3.3.1.3.4. Ordinal or Ratio Scale Representation*

Arrows in an axis or number line are classified in this group (see **Figure 3.6.)**.

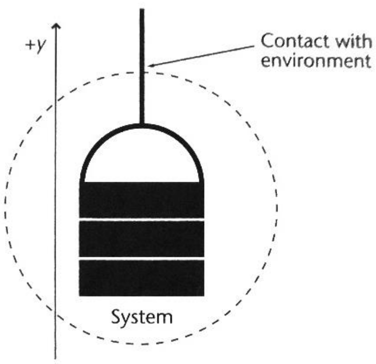


*Figure 3.6. An ordinal or ratio scale representation sample*

The arrow indicates vertical axis. Reprinted from *Physics: Principles and Problems* (p. 129), by Paul W. Zitzewitz et al., 2009, Glencoe/McGraw-Hill.Physics: Principles And Problems Teacher Wraparound Edition.

*3.3.1.3.5. Symbolic*

Symbolic arrows are symbolic representations, for instance an arrow in a photon symbol (see **Figure 3.7.**).

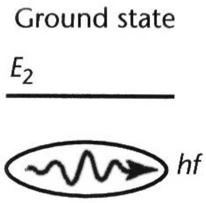


*Figure 3.7. A symbolic arrow sample*

The symbolic representation of photon with energy. Reprinted from *Physics: Principles and Problems* (p. 660), by Paul W. Zitzewitz et al., 2009, Glencoe/McGraw-Hill.Physics: Principles And Problems Teacher Wraparound Edition.

*3.3.1.3.6. Vector*

Vectors (e.g., force, velocity) which are demonstrated with an arrow are classified in this group (see **Figure 3.8.**).

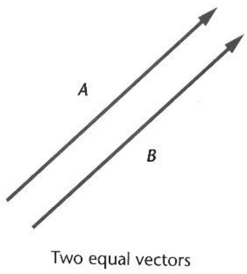


*Figure 3.8. A vector arrow sample*

The arrow represents two equal vectors. Reprinted from *Physics: Principles and Problems* (p. 64), by Paul W. Zitzewitz et al., 2009, Glencoe/McGraw-Hill.Physics: Principles And Problems Teacher Wraparound Edition.

The subclasses of iconic arrows may vary depending on the visuospatial aspects of the content. The main focus of this study is not the classification of the arrow types. This study proposed a brief overview of iconic arrow classification based on the analysis of the collected samples. The following sections will focus on three main arrow classes, namely deictic, relational and iconic.

### 3.3.2. Relational Arrows

Relational arrows were the second most frequently used arrow type in the collected samples compared to iconic and deictic arrows. A total of 378 deictic arrow samples were collected from nine resources composing 37.2% of the total arrow samples. The semantic and syntactic properties of relational arrows are presented below.

#### *3.3.2.1. Semantic Role*

Relational arrows represent the asymmetric relation between two entities such as closure, similarity, and consist of/part of relations. Hence the direction of an arrow plays a role in the interpretation of the arrow-containing diagram.

#### *3.3.2.2. Syntactic Representation*

Relational arrows show the relational connection between two entities and therefore require two nodes in node-link representation. All relational arrow-containing diagrams can be represented by a single node-link diagram (see **Figure 3.9.)**. The function of a relational arrow can be written near the arrow to indicate what kind of relation exists between the entities, and the <operation> tag shows this option.

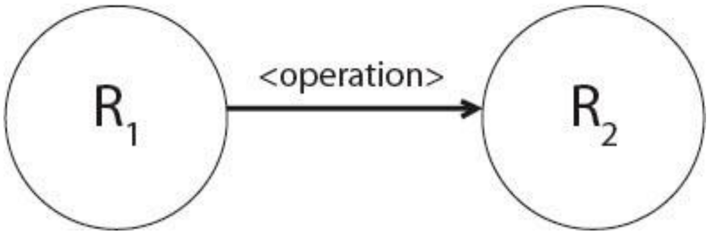


*Figure 3.9. A syntactic representation of a relational arrow*

$R_1$ and $R_2$ represent the entities and the arrow represents the kind of relationship between them.

#### *3.3.2.3. Subclasses of Relational Arrows*

A relational arrow may vary according to its semantic role in context. The followings are subclasses of relational arrows which are separated from each other based on their specific operations. In this study, the relational arrows which convey different aspects of the relationship between entities were divided into five subclasses: “textual link”, “abstract causal link”, “transform”, “zoom” and “process.”

*3.3.2.3.1. Textual Link*

Textual link arrows attach text to an entity by labeling (see **Figure 3.10.)**.

The schematic description A real sample

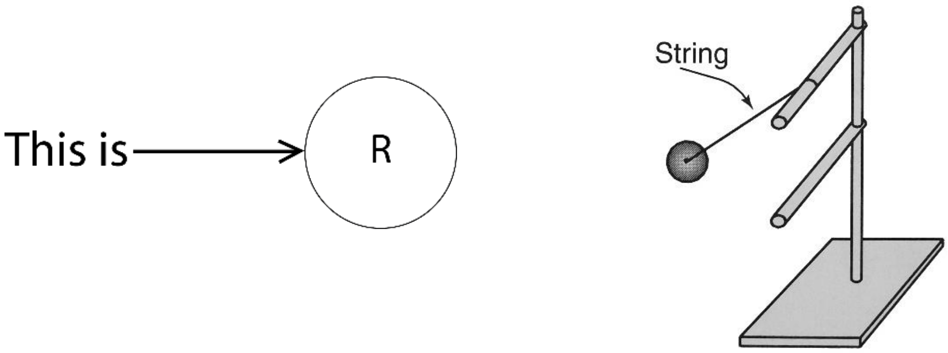


*Figure 3.10. A representation of a textual link*

R represents the entity which is linked with its name by the arrow (left). A textual link illustration (right). Reprinted from *Physics: Principles and Problems* (p. 260), by Paul W. Zitzewitz et al., 2009, Glencoe/McGraw-Hill.Physics: Principles And Problems Teacher Wraparound Edition.

3.3.2.3.2. *Abstract Causal Link*

There is an abstract causal relation between the entities (see **Figure 3.11.**).

The schematic description A real sample


*Figure 3.11. A representation of abstract causal link*

R and N represent the entities and arrow represents an abstract causal link between them (left). The diagram indicates direct effect of level of magnesium on quality of sleep and indirect effect on muscle tone (right). Reprinted from Non-Bayesian Inference: Causal Structure Trumps Correlation (p. 1186), by B. Bes, S. Sloman, C. G. Lucas and E. Raufaste, 2012, *Cognitive Science*, 36(7).

*3.3.2.3.3. Transform*

Transform arrows show the change in sequence which can be temporal, causal or another type (see **Figure 3.12.**).

The schematic description A real sample

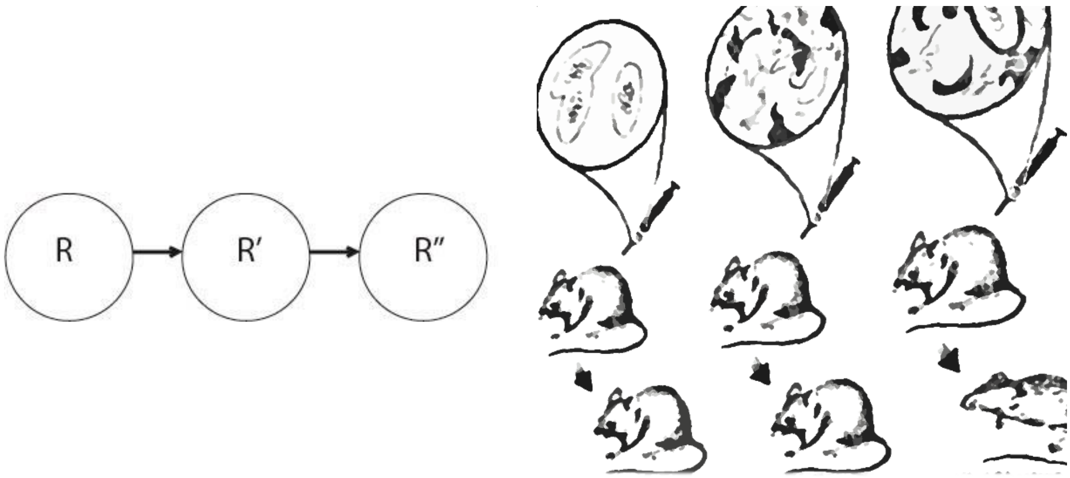


*Figure 3.12. A representation of transform*

R, R' and R'' represent entities which one of them transformed form of the other and arrows represents sequential transformation between them (left). Transform arrows show change in sequence which can be temporal, causal or any other (right). Reprinted from *Texas Biology: Stephen Nowicki* (p. 191), by Holt McDougal, 2014, Houghton Mifflin Harcourt.

*3.3.2.3.4. Zoom*

Zoom arrows represent a close-up and detailed view of a particular part of the entity (see **Figure 3.13.**).

The schematic description                A real sample

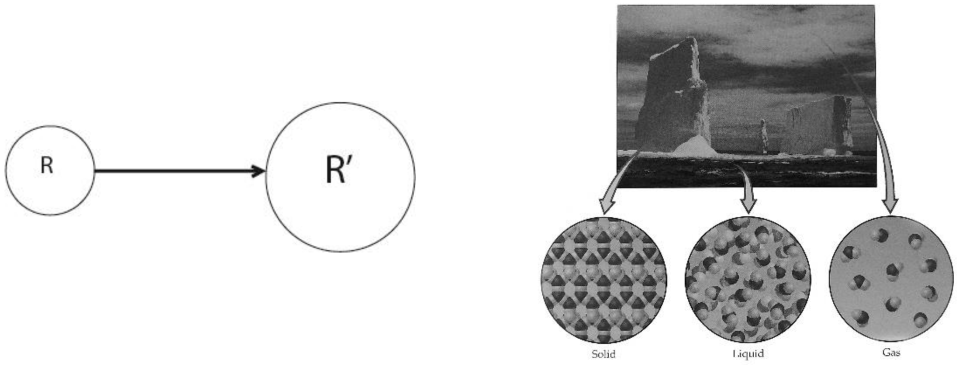


*Figure 3.13. A representation of zoom*

R and R' represents entities which R' is the close up and detailed view of R (left). Transform arrows close-up and detailed view of the particular part (right). Reprinted from *Chemistry: The Central Science* (p. 5), by T. L. Brown, 2009, Pearson Education.

*3.3.2.3.5. Process*

Process arrows are used in texty diagrams such as UML, flowchart are in the process class (see **Figure 3.14.**).

The schematic description                A real sample

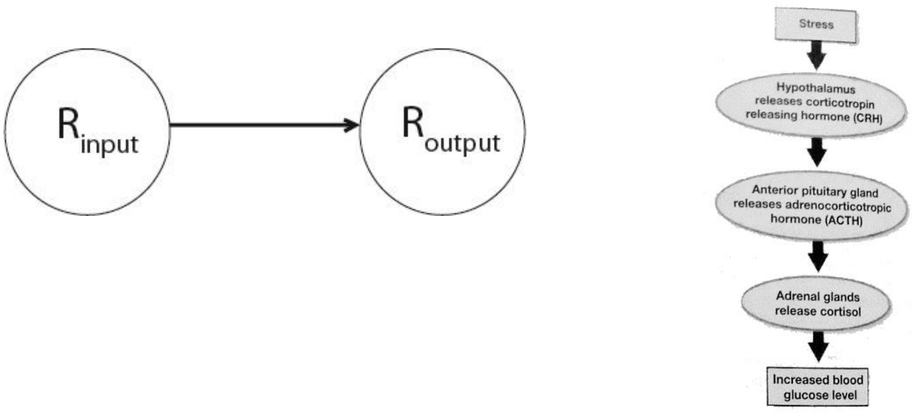


*Figure 3.14. A representation of process*

Rinput and Routput represent boxes in diagrams such as UML, flowchart (left). Arrows represent processes in texty diagrams (right). Reprinted from *Texas Biology: Stephen Nowicki* (p. 982), by Holt McDougal, 2014, Houghton Mifflin Harcourt.

The subclasses of relational arrows may vary depending on their semantic differences and there may be cases in which the alternative relational arrow classification does not match the classification in this study. Determining subclasses of the relational arrows is not the purpose of this study. This classification should be considered a snapshot-view of the other different subclasses of the relational arrows. The following part presents iconic arrows.

### 3.3.3. Deictic Arrows

Deictic arrows were less frequently used in the collected samples compared to iconic and deictic arrows. Although their rare use in written materials, deictic arrows play an important role in communication.  A total of 14 deictic arrow samples were collected from nine resources which was 1.3% of the total arrow samples. The semantic and syntactic properties of deictic arrows are presented below.

*3.3.3.1. Semantic Role*

Deictic arrows point the entity by directing viewer's attention towards the direction of the arrow. Hence, the direction is the crucial property for a deictic arrow.

*3.3.3.2. Syntactic Representation*

The variations of deictic arrow representations are shown in **Figure 3.15**. A single entity, which either is pointed out by use of an arrow or refers to the direction where an arrow points, is used with the deictic arrow.

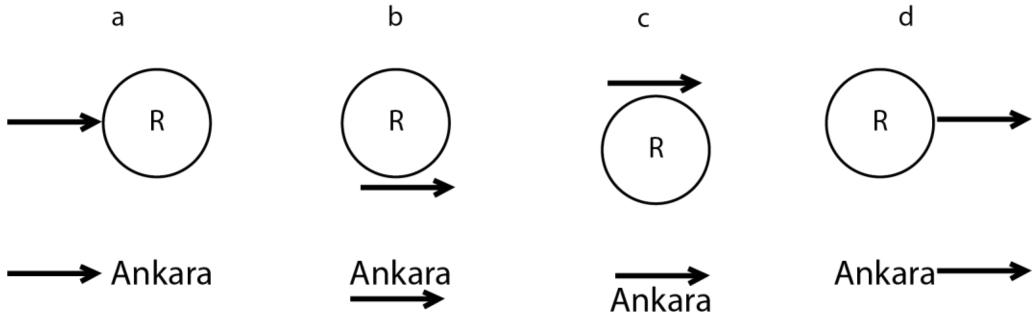


*Figure 3.15. Syntactic representations of deictic arrow*
R represents the entity which is indicated or refers to the direction where arrow points.

Despite their widespread use in depictive illustrations, there are limited studies on the classification of arrows. The studies of Kurata & Egenhofer (2005b, 2008) are one of those. They presented similar semantic and syntactic analyses of arrow classification to develop a method which provides an automated interpretation of arrow-containing diagrams. To investigate a systematic interpretation of the arrow-containing diagram they classified arrows based on the following criteria:

- required entity count
- whether the arrow modify the entity itself or represent connection between the individual entities.

In the analysis presented in this section, arrows were first classified based on their semantic similarities and then the arrows in the same class were evaluated according to whether or not they had a similar syntactic structure. On the other hand, Kurata and Egenhofer (2005b, 2008) classified arrows based on the required entity count of the arrow-containing diagram first, and then analyzed semantic roles of the arrows. As a result, arrows which have a similar semantic role may be in different classes. For instance, arrows that represent motion were classified as being in the property or action class based on whether single or multiple entities were required respectively. Arrows in the property class represent motion of the entity itself, whereas arrows in the action class represent the motion of the entity towards the other entity. Moreover, Kurata and Egenhofer (2005b, 2008) divided arrows which were called relational in the analysis of this section into two classes according to whether the arrow represents a modification or labeling between the entities. Finally, deictic arrows and some subclasses of arrows (e.g., object representation, ordinal-scale) were missing in the classification of Karuta and Egenhofer (2005b, 2008).

In conclusion, arrows are frequently used elements in written materials. Because the previous research reveals no consensus on classification of arrows, this analysis aimed to determine ontology in order to examine how arrows are used in various instructional materials. As a result of this analysis arrows were classified into three main classes: deictic, relational and iconic. Deictic and relational arrows were formulated by node-link diagrams; however, such a similar syntactic pattern was not investigated for iconic arrows due to the iconic arrows' content-dependent structure. Not only syntactic pattern but also the parts of the arrow that convey information were different among the arrow classes. The direction of an arrow is a common basis for all arrow classes whereas the length and shape of an arrow body merely played a role in the interpretation of iconic arrows.

The following section represents the empirical study based on the arrow classification proposed in this chapter and the gesture classification proposed by McNeill (1992).

# CHAPTER 4

# 4. EXPERIMENTAL STUDY: METHOD, DATA COLLECTION AND ANALYSIS

## 4.1. Participants

Twenty-four content specialists, who had expertise content knowledge in math or science and were experienced in designing instructional products, (15 female, nine male) volunteered to participate in the study. They were aged between 25 and 38 (*M* = 30 and SD=3.7). The language of the experiment was Turkish and the participants were native Turkish speakers.

Thirteen participants were experts in Math and 11 participants were experts in Science.

Twenty-one participants were employees of SEBIT, which is a company producing e-learning products, one participant was an employee of Ahmet Yesevi University Turkey E-learning Office, one participant was an employee of the General Directorate of Highways, and finally one participant was a research assistant at Ankara Gazi University.

All participants were experienced in e-learning, their experience ranging from one year to six years and averaged 3.6 years.

Except for one of the participants all were experienced in teaching between 1 and 18 and averaged 7 years, twenty-two participants reported that they had experience in e-learning product design/production, twenty-two participants reported that had experience in one-to-one teaching, thirteen participants reported that they worked as an exam class teacher, and six participants reported that they worked as a school teacher.

Fourteen participants (58.3%) reported that they did not use tablet as a teaching tool but they are familiar with it, seven participants (29.2%) reported having no idea about tablet, and finally three participants (12.5%) reported that they used tablet as a teaching tool (see **Figure 4.1.)**.

All participants were right-handed.

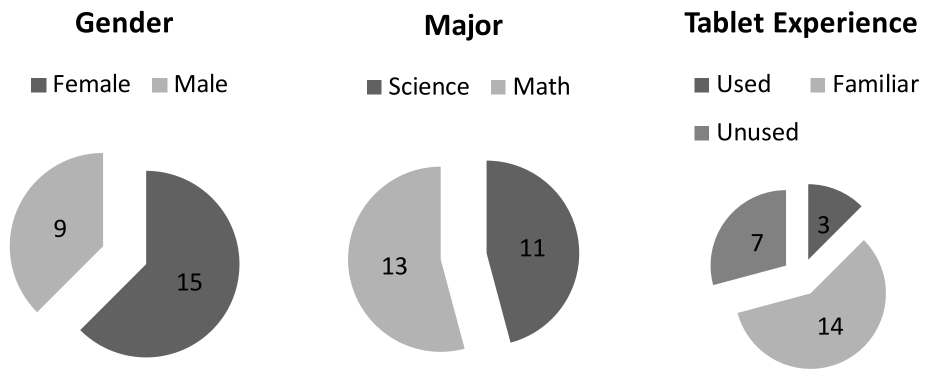


*Figure 4.1. Demographics*
Distribution of participants according to gender, major and tablet experience

#### 4.2. Software and Equipment

The experiment consisted of three sessions; board, paper, and tablet. Whiteboard was used in the board session. White A4 paper was used in the paper session. Finally SMART Podium ID422w interactive pen display was used in the tablet session (see **Figure 4.3.**).

In the tablet session, Microsoft PowerPoint 2007 or Windows 7 version of Notepad was used to provide white background for drawings. Also a headset microphone was used to capture audio of the participants and Camtasia Studio was used for screen recordings.

Writing/drawings with different colors were available in all sessions.

All sessions were recorded by a digital camera, Fujifilm X-S1. Also a tripod was used to hold camera steady.

#### 4.3. Instructional Topics

The participants were asked to choose a topic based on their preference. **Table 4.1**. shows the topics selected by the participants.

Table 4.1

*Selected topics by participants*

| Participant | Topic | Major |
|---|---|---|
| 1 | Equation of a line | Mathematics |
| 2 | Circles | Mathematics |
| 3 | Cylinder | Mathematics |
| 4 | Endocytosis | Science |
| 5 | Electric field | Science |
| 6 | Analytic geometry | Mathematics |
| 7 | Determine the density of a mixture of liquids | Science |
| 8 | Equivalent fractions | Mathematics |
| 9 | Charles's Law | Science |
| 10 | Circulatory system | Science |
| 11 | Area of a rectangle | Mathematics |
| 12 | Relationships of Percents | Mathematics |
| 13 | Triangle classification | Mathematics |
| 14 | What is speed? | Science |
| 15 | The changing states of solids, liquids, and gases | Science |
| 16 | Factors affecting resistance | Science |
| 17 | Basic set operations | Mathematics |
| 18 | Food chain | Science |
| 19 | Boyle-Mariotte Law | Science |
| 20 | Trigonometric values of different angles | Mathematics |
| 21 | Limits | Mathematics |
| 22 | Basic set operations | Mathematics |
| 23 | Divisibility rules For 2, 3 ,5 ,6, 9 and 10 | Mathematics |
| 24 | Law of conservation of mass | Science |

## 4.4. Procedure

The experiment was conducted in a within subject format. The experiment consisted of three sessions; board, paper, and tablet. Six groups were created by changing the order of these sessions in each group. This order was randomized across participants to counterbalance variance. The participants were randomly assigned to each group (see **Figure 4.2.**).

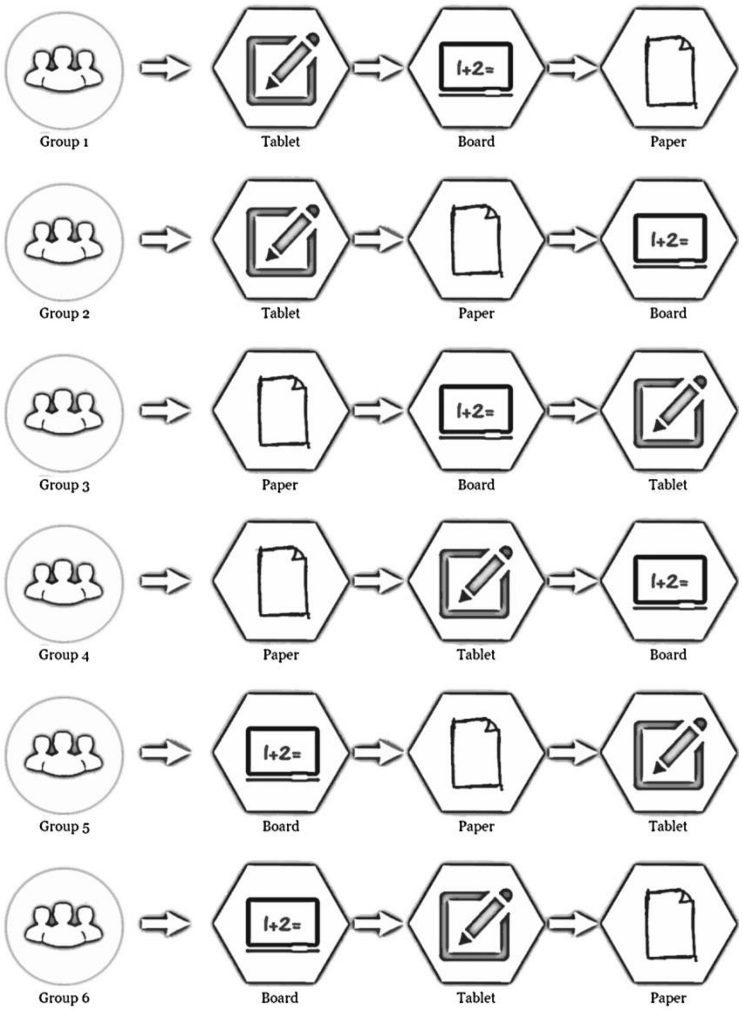


*Figure 4.2. The Design of The Experiment Groups.*

Six groups were created by changing the order of these sessions in each group. This order was randomized across participants to counterbalance variance. Three participants were randomly assigned to each group

Instructions were given to all participants before starting the experiment. None of the participants were aware of the aim of the study. They were told that it was investigated how different technologies affect learning. The participants were asked to select a topic and teach it as if there was a listener and to repeat it as same as possible in three sessions, namely board, paper and tablet. Participants were manipulated to select a topic which could be supported by images such as shapes, diagrams. All the participants provided verbal informed consent for video recording during the sessions. It was told that these tutorials were played by students later. Time was constrained to between 5 and 10 minutes for each session.

How to use the tablet was introduced to participants and training provided for about thirty seconds before starting to the tablet session. Output of the tablet recording was showed briefly to novice tablet users.

For all sessions, the recordings started when the participant stated that she/he was ready to start. It was permitted to start over when participants did not feel confident in their instruction. Some technical problems also caused to repeat or start over the session. The cases that caused interruption or restarting were explained below.

- Although quiet places were preferred to conduct the experiment, the recording of one participant was restarted due to interruption (1% of the all sessions).
- The recordings were stopped when a participant asked for a restart (12.5% of the all sessions). Participants were asked for restarting due to such cases as changing selected topic (2.8% of the sessions), rearranging the order of explanation (2.8% of the all sessions), and correcting misspoken explanation (6.9% of the sessions).
- When the recording quality of the camera was low due to focus problem, the recording was interrupted by the experimenter and the session was started again (4.2% of all sessions).
- The recording was started over when the duration of the session was shorter than 5 min (1% of the all sessions with the duration 4 min).
- The session was interrupted and started over when a participant had technical problems in using the tablet (46% of the tablet sessions). Participants were frequently faced with difficulties in using tablet pen. There were two buttons on two sides of the pen which located near the holding area. One of these buttons served the purpose of cleaning the screen. The location of the button caused participants to press the button accidentally. In those cases, the recordings were restarted.

When a session recording was restarted, the previous recordings were not included in further analysis.

All experiments were conducted in SEBIT meeting rooms and studios. The board session took place in the meeting room. The paper session took place in either the meeting room or the recording studio based on their state of fullness.  Finally, the tablet session took place in the recording studio. Particularly lunch break was preferred to prevent interruptions and obtain quiet place.

### 4.5. Experiment Design

The experiment was conducted according to a within-subject design with three conditions including the within-subject variables *teaching environment* (board, paper, and tablet). The number of produced communicative elements (gesture and arrows) was measured as a dependent variable. A sample from each session was shown in **Figure 4.3.**

The Board Session The Paper Session The Tablet Session


*Figure 4.3. The Sessions of The Experiment*
Explanation of equivalent fractions in the board (left), paper (middle) and tablet (right) session.

### 4.6. Data Collection and Annotation

The data in the study were collected by using two tools; surveymonkey.com was used for demographic data and ELAN was used for gesture and arrow annotations.

#### 4.6.1. surveymonkey.com

Demographic data was collected by surveymonkey.com (https://tr.surveymonkey.com/).

Surveymonkey is an online service that allows users to create their own web based surveys, get the responses. Demographic data were collected by surveymonkey.com after the experiment was completed.

#### 4.6.2. ELAN

Gesture and arrow annotations were created by using ELAN (version 4.6.2) on the MPI tools website (http://tla.mpi.nl/tools/tla-tools/elan/).

ELAN was developed at the Max Planck Institute for Psycholinguistics in Nijmegen, The Netherlands. It is a time-aligned annotation tool that allows users to study on both video and audio files. ELAN is used for various types of annotation but mainly for language, gesture and sign language annotation. “Tier” is one of the key elements in annotation structure and it works like a container which is used to put the same kind of annotations together. In timeline view, each tier is layered as shown in **Figure 4.4**. It is possible to add numerous tiers and also arrange them in parent-child relation (Lausberg & Sloetjes, 2009).


*Figure 4.4. An screenshot from ELAN*

The participant produced deictic gesture with her left hand. The gesture was annotated on Gesture tier.[1]

## 4.7. Data Analysis

By the end of the experiment, 24 participants were recorded in three sessions and a total of 72 experiment protocols were obtained. Two categories of data were defined for annotation as *gesture* and *sketch*. Tier structure of ELAN was organized accordingly in order to include these annotations. Briefly; arrows were annotated on the *sketch* tier and gestures on the *gesture* tier (see **Figure 4.4.**).

The gesture annotation guide, which was proposed by Duncan (2005), was employed for annotating data.

All video recordings of each participant were inspected for creating lists of instructed subtopics in each session. In this way, three lists were acquired; a sample list is shown in **Table 4.2**. Afterwards, these lists were compared to each other. If there

[1] All the participants presented in the pictures granted permission to publish their photos.

was a difference between the lists, the subtopic that caused the difference was detected and the related section of the video was not included in data annotation. In other words, only the subtopics mentioned in all three sessions were annotated. 2.2% of the recordings were eliminated in this way. (The total duration of the experiment was 8 hr 15 min, the eliminated part was 10 min 13 s).

Table 4.2

*Subtopic Lists of Participant 6*

Topic : Analytic Geometry

| Board | Paper | Tablet |
|---|---|---|
| 1. What is the coordinate plane? | 1. What is the coordinate plane? | 1. What is the coordinate plane? |
| 2. Points on a number line | 2. Points on a number line | 2. Points on a number line |
| 3. Points on the coordinate plane | 3. Points on the coordinate plane | 3. Points on the coordinate plane |
| 4. An Example of points on the coordinate plane | 4. An Example of points on the coordinate plane | 4. An Example of points on the coordinate plane |
| 5. The terms abscissa and ordinate | 5. An example of applying the Pythagorean Theorem to find the point on the axis | 5. The terms abscissa and ordinate |
| 6. Quadrants of coordinate plane | 6. The terms abscissa and ordinate | 6. An example of applying the Pythagorean Theorem to find the point on the axis |
| 7. An example of applying the Pythagorean Theorem to find the point on the axis | 7. Distance between two points | 7. Distance between two points |
| 8. Distance between two points | 8. An example of points on the coordinate plane | 8. An example of points on the coordinate plane |
| 9. An example of distance between two points | | |

*Note* Excluded subtopic was underlined in the board session

### 4.7.1. Annotation of Gestures

In gesture annotation, only the gestures that were accompanied by speech were annotated. Therefore, gestures without speech were not included in the analysis.

Detecting strokes was very critical to the identification of gestures for annotation. When annotating gestures it was taken into account that gestures are usually organized around the stroke which is the phase with *meaning* and *effort* (Kendon, 1980). Each video was inspected in slow-motion speed besides its normal speed to detect this stroke phase and to annotate the gesture appropriately.

The following annotation conventions based on Furuyama practices (as mentioned McNeill, 2007) were applied to indicate which hand was used to produce a gesture: “BH” was used for “both hand” and “LH” for “left hand”. Finally, “RH” was used to indicate the “right hand” (see **Figure 4.5.)**.

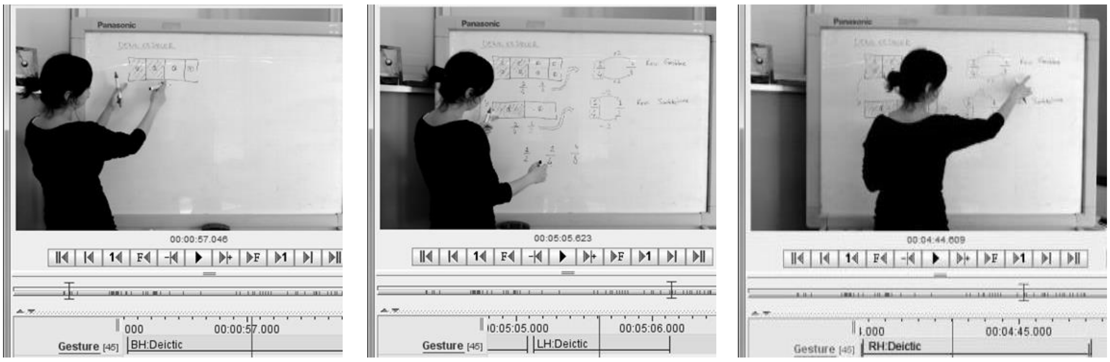


*Figure 4.5. Deictic Gesture Annotation*

Illustrates annotation convention for both hand (left), left hand (middle) and right hand (right).

Type of gestures was determined based on the following descriptions;

The interpretation of gestures was based on their being imagistic or non-imagistic. Those which were imagistic were classified as iconic, but those which were non-imagistic were classified as either deictic or beat gestures (McNeill, 1992), as explained below.

<u>Deictic Gesture</u>: Deictic gestures are pointing movements that indicate objects, drawings, people etc. (McNeill, 1992).

- The words referring to objects such as “this”, “here”, “there” were often accompanied by deictic gestures.
- Gestures that pointed a particular part or all parts of a drawing were assumed to be deictic gestures as shown in **Figure 4.6.**

(00:00:43.350 ms) (00:00:43.650 ms) (00:00:43.700 ms)

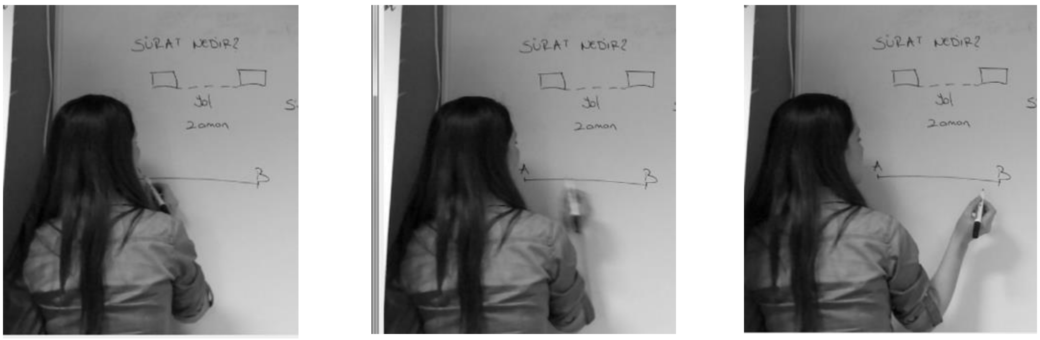

*Figure 4.6. A sample of deictic gesture*

Participant produced deictic gesture to point the distance between A and B points by moving her hand from A to B.

- Gestures pointing a group of text, drawings or formulas were assumed to be deictic gestures. It created an impression on the audience that the speaker was indicating things inside a particular area the boundary of which was marked by the speaker's hand movements (see **Figure 4.7.**).

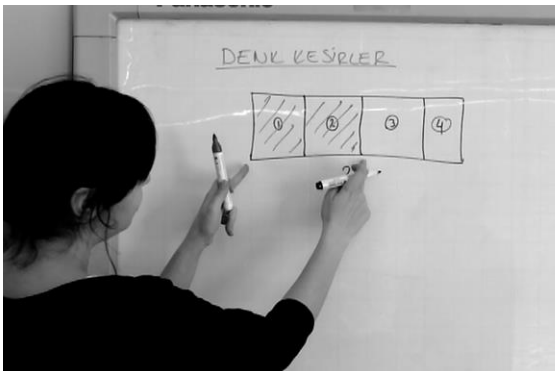


*Figure 4.7. A sample of deictic gesture points an area*
The speaker was indicating the items inside a particular area the boundary of which was marked by the speaker's hand movements.

- Deictic gestures were typically performed with the extended finger or hand in the board session whereas they were mostly produced by the pen in paper and tablet sessions (see **Figure 4.8.)**.

The board session The paper session The tablet session

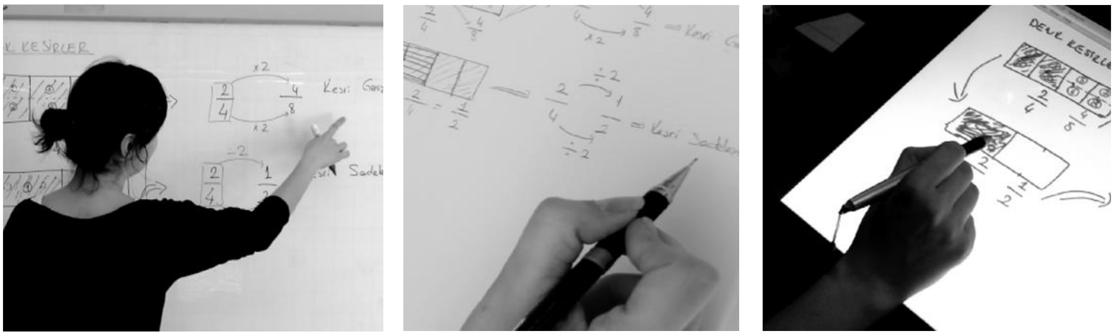

*Figure 4.8. Deictic gesture production in different ways.*
Participants used their body to produce deictic gesture in the board session whereas they were provided with pen in paper and tablet sessions.

<u>Iconic Gesture</u>: Gestures that presented picturable aspects of semantic content were assumed to be iconic gestures (McNeill, 2005). Based on McNeill's (1992) typology view, iconic gestures and metaphoric gestures were identified according to whether they represented concrete or abstract concepts. It should be noted that in the current

study, iconic and metaphoric gestures were considered together and classified as iconic gesture. Various aspects of gesture such as form, direction, motion trajectory of hand played a certain role in the depiction of semantic content (Alibali & Nathan, 2011). Below are assumptions for the iconic gestures:

- Gestures that represented action or concept of a drawing or an object were assumed to be iconic gestures. As shown in **Figure 4.9.**, the speaker's hand moved around a particle to represent electric field.

(00:02:40.313 ms) (00:02:40.612 ms) (00:02:41.155 ms)

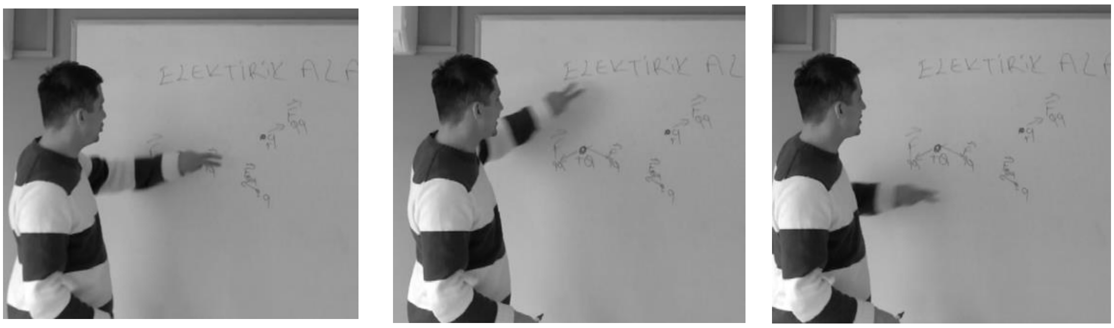

*Figure 4.9. A sample of iconic gesture represents electric field*
Participant moved his hand around a particle to represent electric field.

- Gestures that represented direction were accepted as iconic gestures. For instance, in one part of the experiment the participant moved his hand forward while showing an upward palm to represent an outward direction (see **Figure 4.10**).

(00:04:16.933 ms) (00:04:17.231 ms) (00:04:17.554 ms)

*Figure 4.10. A sample of iconic gesture represents direction*
The participant moved his hand forward while showing an upward palm to represent an outward direction

Beat Gesture: Beats were speech-related rhythmic hand movements. They were divided into two forms; discrete and continuous.

Beat gestures in discrete form seemed to appear when a syllable, word or clause was stressed and disappeared right after the utterance.

Beat gestures in continuous form were produced throughout speech (word, clause, and sentence). They often seemed to occur in a series of a particular hand movement. Circular continuous movement of hand could be an example for a beat gesture in continuous form (see **Figure 4.11.**).

It should be noted that the interaction between specific types of arrows and beat gestures was not analyzed in this study.

| **An Iconic Gesture** | **A Deictic Gesture** | **A Beat Gesture** |
| --- | --- | --- |
| illustrating "pull and push " action | pointing to the particle on the table | which is a speech-related rhythmic movement |

*Figure 4.11. Examples of iconic, deictic and beat gesture*
Illustrating an iconic, deictic and beat gesture.

The number of gestures was defined based on the following assumptions;

Typically, the onset and the offset of movement were easy to annotate for iconic and deictic gestures. In McNeill's terms, iconic and deictic gestures consisted of three phases, namely preparation, stroke, retraction (McNeill, 1992). Each unit consisting of these phases was accepted as a single gesture. Each iconic, deictic, and beat gesture in discrete form was considered as a single gesture (Exceptions were listed below). Moreover, a beat gesture in continuous form was also accepted as a single gesture. However, the segmentation of beat gestures in continuous form was relatively difficult because there were times when a continuous beat gesture was followed by another continuous beat gesture that was quite similar to the previous one. In such cases distinguishing between the two was challenging. The choice of the annotator was cross-checked by means of an inter-rater reliability analysis, as explained later in the following section.

Each gesture unit mentioned above was accepted as a single gesture. There were some exceptions to this case which were listed below;

- Iterated gestures within the related utterance were classified as a single gesture. For instance: the speaker's utterance referred to the diagram while his or her hand continued pointing the diagram.

- Gestures reproduced due to pronunciation corrections in speech: If there existed a pronunciation mistake, speakers tended to correct his or her mistake immediately, which caused the gesture to appear again following the corrected utterance. Repeating gestures -due to mispronunciation of a word- were also classified as a single gesture.
- The number of gestures was calculated based on the number of objects referred to by utterances, where applicable. For instance, the speaker was talking about fractions on a rectangle which consisted of four equal pieces. In one part, he said “these four pieces here”. While he was uttering “four pieces” in his explanation, he was pointing each piece separately with his finger. This was accepted as a single gesture. On the other hand, when a speaker uttered referring words separately such as “one, two, three, four pieces”, and again pointed to each other piece, these gestures were counted separately (see **Figure 4.12.)**.

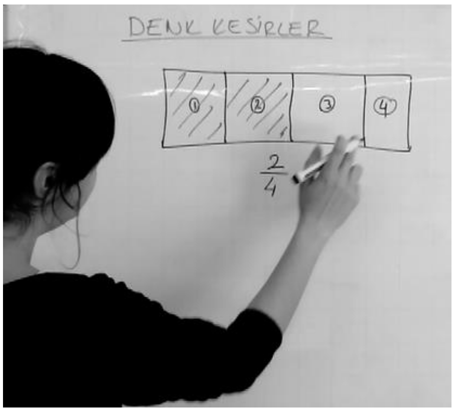


*Figure 4.12. A sample of deictic gesture*

The part of the experiment that the participants explained fractions on the rectangle drawing. She pointed the pieces of rectangle with both uttering “these four pieces here...” and “one, two, three, four pieces”. Although similar gestures were accompanied by the utterances, the number of gestures was calculated one-by-one.

The hand movements in the following cases were not included in the analysis;

- Speakers moved their hand around, mostly without speech, when they were confused about what to say next. These hand movements were not accepted as a gesture.
- Hand movements such as scratching, putting hands in a pocket were not included in data annotation.
- Counting gestures were not included in data as shown in the **Figure 4.13.;** counting of drawings or fingers.

*Figure 4.13. Two different counting gestures*

### 4.7.2. Annotation of Arrows

Arrows that were produced in the board, paper and tablet sessions were annotated in the second part of the analysis. Accompanying speech condition was not considered in the arrow annotation, unlike gesture annotation.

| **An Iconic Arrow** | **A Deictic Arrow** | **A Relational Arrow** |
|---|---|---|
| illustrating pressure | pointing to the table | showing relation between two values |

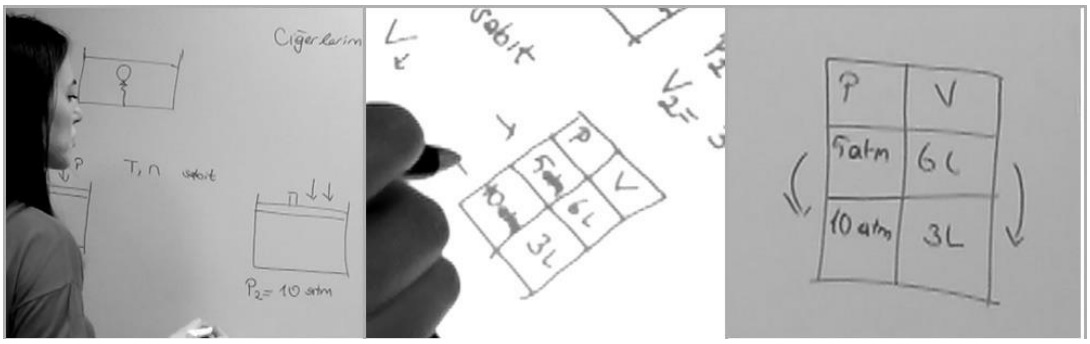


*Figure 4.14. Examples of iconic, deictic and relational arrow*

The arrows were classified into three classes, as explained below; examples are shown in **Figure 4.14.** Each arrow was assigned to one of these classes. This classification is the working assumption of this study. Alternative arrow classifications may be found in different studies.

<u>*Iconic Arrow:*</u> Arrows that represented motion (e.g., movements of particles in a cap), force (e.g., the pressure on the piston), physical representations (e.g., electric field), and processes (e.g., increase, decrease) were assumed to be iconic arrow.

*Deictic Arrow:* Arrows that were used to direct attention to the specific area were assumed to be deictic arrow.

*Relational Arrow:* Arrows that worked as a conjunction, in other words, connected two representations were assumed to be relational arrow. Relational arrows conveyed meanings such that closure, similarity, relation, temporal sequence between representations and being part of whole or vice versa.

In addition, each arrow token was assumed to belong to one of these classes.

The number of arrows was determined based on the following assumptions;

- There were cases which multiple arrows were accepted as a single arrow (see **Figure 4.15.**). These exceptions were listed below;
    - Arrows that were consisted of the electric field (0.9% of total arrows and 5.3% of iconic arrows)
    - Arrows that represented motion of the particles in a cap (2.0% of total arrows and 11.6% of iconic arrows)
    - Arrows that represented the increase in the pressure (0.2% of total arrows and 1.0% of iconic arrows)
    - Arrows that represented motion of the piston (0.4% of total arrows and 2.1% of iconic arrows)

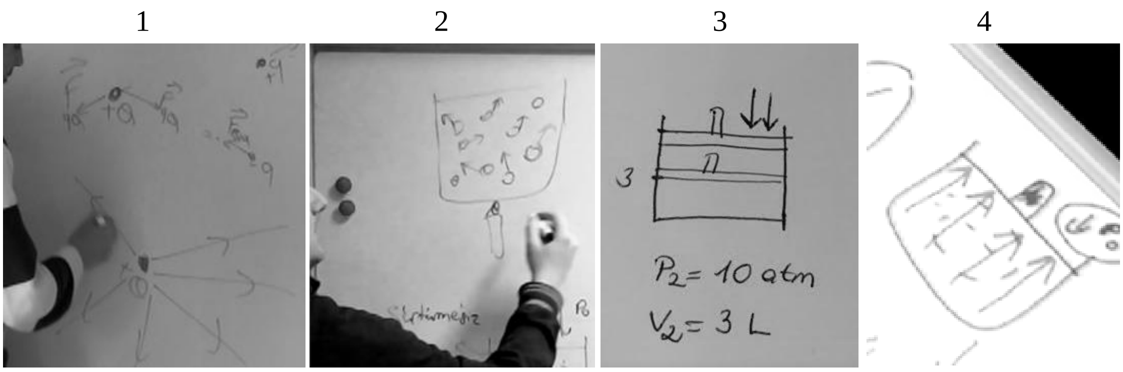


*Figure 4.15. Illustrations require more than one arrow*

Electric field illustration consisted of various arrows (1). Motions of particles in a cap required arrow for each particle (2). The increase in pressure was represented with two arrows (3). The motion of the piston was represented with four arrows (4).

As shown in **Figure 4.16.** the arrows in the following cases were not included in the analysis;

- Arrows at the start points and end points of axis lines, such as the horizontal and vertical axes of a coordinate system
- Arrows located above a letter to represent vector were ignored.

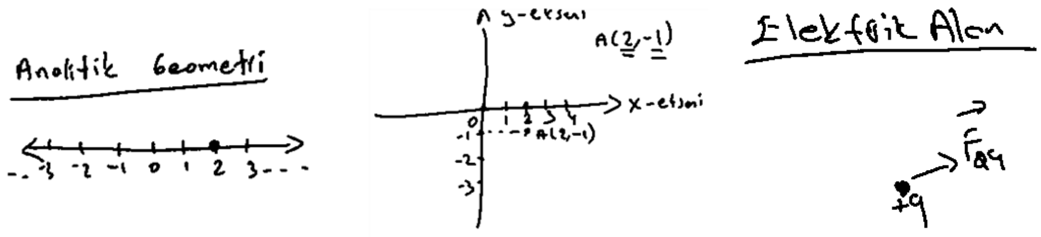


*Figure 4.16. Arrows not included in data analysis*

Arrows in number line (left). Arrows in coordinate system (middle). Arrow above a letter (right).

### 4.8. Inter-Rater Reliability Analysis

All the gesture and arrow annotations were performed by the author of thesis. Randomly-selected 25% of the all gestures (880 of 3523) and 20% of the all arrows were annotated independently by a second coder, for reliability analysis. Both coders were native Turkish speakers and they annotated the participants' gestures and arrows by listening and watching their recordings. The comprehension of the participants' sayings also played role in the annotation. Cohen's kappa was used to calculate inter-rater reliability between coders. The inter-rater agreements of initial annotations were calculated as .75 for gesture annotation and 1.0 for arrow annotation. The value above .61 indicates substantial inter-rater agreement and the value between .81 and .99 indicates almost perfect agreement based on Landis and Koch (1977). Upon discussion the coders re-annotated the gesture data and the agreement was calculated as .96.

# CHAPTER 5

# 5. EXPERIMENTAL STUDY: RESULTS

The analyses reported above investigated types of gestures and arrows. Gesture and arrow classifications were completed prior to the analyses and were not altered based on the results. Further studies may propose new classifications based on the results of this study.

This chapter presents the results of the analyses in two parts. The first part focuses on the answers of the hypothesis: how different multimedia teaching settings influence communicative element production, namely gesture and arrow productions, and whether a trade-off exists between gesture and arrow productions. The second part investigates the effect of teaching settings on the gesture types proposed in the literature and arrow types based on the analysis described in the previous section.

## 5.1. Part-1: Major Findings

### 5.1.1. Descriptive Statistics

This section presents the descriptive statistics for gesture and arrow production. A comparison of the three sessions indicated that participants produced more gestures in the board session compared to the paper and tablet sessions whereas the sessions had a reversed effect on arrow production. The results are presented in **Table 5.1** below.

Table 5.1

*The Means (Standard Deviations) for Gesture Overall, Arrow Overall and Teaching Duration for All Participants*

| | Board Session | Paper Session | Tablet Session |
|---|---|---|---|
| Gesture Production | 55.58 (27.70) | 49.04 (26.71) | 42.25 (17.43) |
| Arrow Production | 7.38 (7.13) | 7.50 (6.61) | 7.92 (6.88) |
| Teaching Duration (per session *min*.) | 6.5 (2.22) | 6.0 (2.11) | 6.8 (2.29) |

Note Zero values were included in the analysis. The numbers in parentheses indicate Standard Deviation.

### 5.1.2. Teaching Duration

A one-way within-subjects ANOVA was conducted to evaluate whether there exists a significant difference in the duration of the teaching sessions. The results of the ANOVA test revealed no significant difference in the teaching durations among the three sessions, Wilk's $\lambda = .82$, $F (2, 22) = 2.4$, $p = .11$, multivariate $\eta^2 = .18$.

This result indicates that teaching duration was not affected by the sessions. Therefore, it was not included in the further analyses.

### 5.1.3. Gesture Overall

The term *gesture overall* was used to describe the total number of gestures produced by the participants in each session. A one-way within-subjects ANOVA was conducted to compare the total number of gestures among the three experimental conditions. The results of the ANOVA test revealed a significant difference in the total number of gestures among the three sessions, Wilk's $\lambda = .63$, $F (2, 22) = 6.44$, $p < .05$, multivariate $\eta^2 = .37$.

Three paired-samples *t* tests were conducted to compare the total number of gestures among the sessions, controlling for familywise error rate using Holm's sequential Bonferroni approach. Gesture overall was significantly higher in the board session compared to the tablet session ($M = 13.33$, SD = 17.87), $t (23) = 3.66$, $p < .05$. However, there was no significant difference in the paper session ($M = 49.04$, SD = 26.71) compared to the tablet session ($M = 6.79$, SD = 19.86), $t (23) = 1.67$, $p = .11$, and in the board session compared to the paper session ($M = 6.54$, SD = 18.30), $t$ (23) =, 1.75 $p = .09$.

Participants produced more gestures in the board session compared to the paper and tablet sessions. Although there was a difference in means among the sessions, this difference was only significant between the board and tablet sessions; therefore, the significant trend was due to changes between these two sessions.

### 5.1.4. Arrow Overall

The term *arrow overall* was used to indicate the total number of arrows produced by the participants in each session.

A one-way within-subjects ANOVA was conducted to compare the total number of arrows among the three experimental conditions. The results for the ANOVA revealed no significant teaching environment effect on the total number of arrows, Wilk's $\lambda = .94$, $F(2, 22) = .64$, $p = .54$.

The main goal of the analysis of arrow overall was to investigate whether the teaching environments had a significant effect on arrow production. However, the results indicate that there was no significant difference among the sessions in arrow production.

Next, the interaction between gesture production and arrow production was analyzed.

### 5.1.5. Gesture x Arrow Production Analysis

A two-way within-subjects analysis of variance was conducted to evaluate the effect of teaching environment on the total number of communicative elements. The dependent variable was the number of communicative elements. The within-subjects factors were the teaching environments with three levels (board, paper, and tablet) and communicative element type with two levels (*all* gestures, *all* arrows). The Teaching Environment main effect and Communicative Element × Teaching Environment interaction effect were tested using multivariate criterion of Wilk's lambda ($\lambda$). The Teaching Environment main effect was significant, $\lambda = .62$, $F(2, 22) = 6.85$, $p < .05$, as well as the Communicative Element × Teaching Environment interaction effect, $\lambda = .64$, $F(2, 22) = 5.97$, $p < .05$.

Three paired-samples *t* tests were conducted to follow up on the significant interaction. We controlled familywise error rate across these tests by using Holm's sequential Bonferroni approach. The differences between gesture and arrow productions significantly changed between the board and tablet sessions ($M = 13.87$, SD = 19.25), $t(23) = 3.53$, $p < .05$. However, there was no significant change between the paper and tablet sessions ($M = 7.21$, SD = 20.58), $t(23) = 1.71$, $p = .10$, as well as the board and paper sessions ($M = 6.67$, SD = 19.84), $t(23) = 1.65$, $p = .11$. Although the difference between gesture and arrow productions was higher in the board session, this difference decreased in the paper and tablet sessions.

Three paired-samples *t* tests were conducted to examine whether differences exist in communicative element production among the sessions, controlling for familywise error rate using Holm's sequential Bonferroni approach. The number of communicative elements was significantly higher in the board session compared to the tablet session ($M = 6.39$, SD = 8.37), $t(23) = 3.74$, $p < .05$. However, there was no significant difference in the paper session compared to the tablet session ($M = 3.19$, SD = 9.88), $t(23) = 1.58$, $p = .13$, and in the board session compared to the paper session ($M = 3.21$, SD = 8.79), $t(23) = 1.79$, $p = .09$.

In summary, these results suggest that the participants produced significantly more communicative elements, namely gestures and arrows, in the board session compared to the tablet session. Finally, the results indicate that there was a significant interaction between gesture and arrow productions. The participants produced slightly more arrows when they produced fewer gestures, and vice versa. These results may offer some evidence in support of the hypothesis that there is a trade-off between gesture and arrow productions.

The analysis reported above investigated whether gesture and arrow productions were affected by the teaching environment and whether there was an interaction between gesture and arrow productions. The results indicated that gesture production was different in the board session compared to the tablet session whereas gesture production in the paper session did not vary from the board session or the tablet session. Unlike gesture production, arrow production was not affected by the environment. Finally, the results of the analyses indicated that there was an interaction between gesture and arrow productions; gesture production was dramatically decreased from the board session to the tablet session, whereas the arrow production slightly increased. The following part investigates the effect of the teaching environments on gesture types which were proposed in the literature (McNeill, 1992) and arrow types based on the analysis in the previous section.

### 5.1.6. Summary of the Major Findings

The first main finding was that there was an interaction between gesture and arrow productions. This interaction is particularly explicit between the board and the tablet sessions.

The results revealed that gesture production was higher in the board session while it decreased in the paper and tablet sessions. The difference in gesture production was significant between the board and tablet sessions. Gesture production in the paper session did not significantly differ from either the board or the tablet sessions. Finally, although there was a change in arrow production among the sessions, this was not significant.

## 5.2. Part-2: Further Findings for Subtypes of Gestures and Arrows

In this section, the results for gestures and arrows are presented according to their specific subtypes.

### 5.2.1. Gesture Types

This part of the chapter presents the analyses examining the effect of the teaching environment on gesture types proposed in the literature. The descriptive statistics for the types of gestures are presented. The table shows that deictic gestures were more frequently produced in the sessions compared to both iconic and beat gestures. On the other hand, participants rarely produced iconic gestures in the sessions. The results are presented in **Table 5.2.** and **Figure 5.1.** below.

Table 5.2.

*The Means (Standard Deviations) for Subtypes of Gestures*

| | Board Session | Paper Session | Tablet Session |
|---|---|---|---|
| Beat Gestures | 20.79 (20.16) | 17.00 (14.55) | 14.38 (10.03) |
| Deictic Gestures | 31.25 (13.59) | 29.92 (16.22) | 26.75 (11.63) |
| Iconic Gestures | 3.54 (3.71) | 2.13 (2.19) | 1.13 (1.23) |

*Note* Zero values were included in the analysis. The numbers in parentheses indicate Standard Deviation.

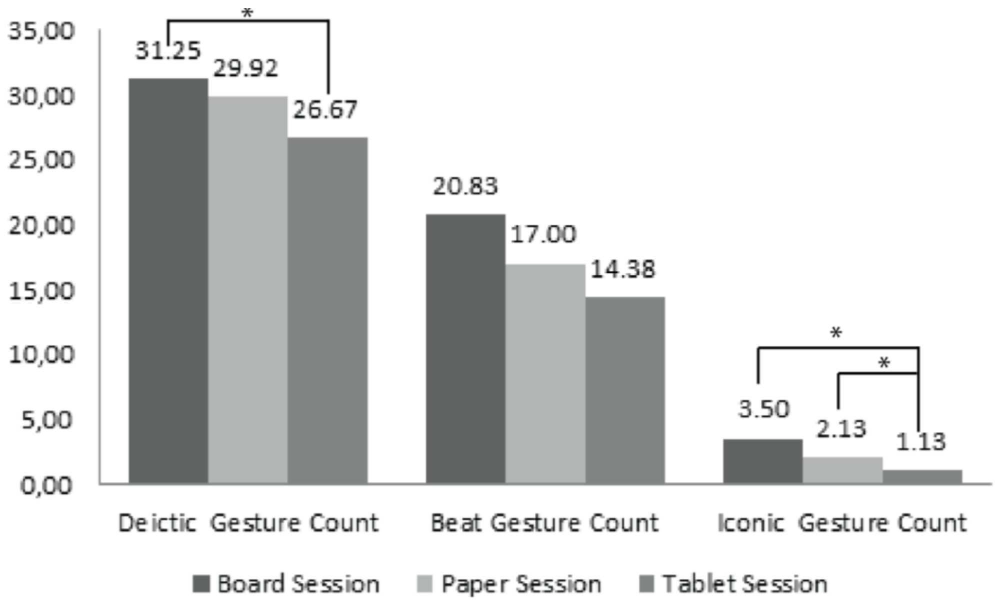


*Figure 5.1. The difference in mean was significant between the board and the tablet session for deictic gesture.*

It was also significant for board and paper sessions compared to the tablet session. (*) indicates significant difference between the sessions.

### *5.2.1.1. Deictic Gesture*

Deictic gestures have a larger proportion in gesture production. A one-way within-subjects ANOVA was conducted to investigate whether there was a difference in deictic gesture production among the sessions. The results for the ANOVA revealed a significant difference in deictic gesture production among the sessions, Wilk's $\lambda$ = .77, $F(2, 22) = 3.31$, $p$ = <.05.

Three paired-samples $t$ tests were conducted to compare the number of deictic gestures among the sessions, controlling for familywise error rate using Holm's sequential Bonferroni approach. The number of deictic gestures was significantly higher in the board session compared to the tablet session ($M$ = 4.50, SD = 8.38), $t$ (23) = 2.63, $p < .05$. However, there was no significant difference in the paper session compared to the tablet session ($M$ = 3.17, SD = 13.50), $t$ (23) = 1.15, $p = .26$, and in the board session compared to the paper session ($M$ = 1.33, SD = 12.52), $t$ (23) = 0.52, $p = .61$.

In summary these results were parallel to the findings of gesture overall analysis. Participants produced more deictic gestures in the board session compared to the paper and tablet sessions. Although there was a change in means among the sessions, the difference was only significant between the board and tablet sessions; therefore, the significant trend was due to changes between these two sessions. These results suggest that speakers produce more deictic gestures in standing position compared to sitting position. Moreover, these results may suggest that using tablet leads speakers to produce fewer deictic gestures.

#### *5.2.1.2. Iconic Gesture*

A one-way within-subjects ANOVA was conducted to compare the total number of iconic gestures among the three experimental conditions. The results for the ANOVA revealed a significant difference in iconic gesture production among the sessions, Wilk's $\lambda$ = 66, F (2, 22) = 5.66, $p < .05$.

Three paired-samples $t$ tests were conducted to compare the number of iconic gestures among the sessions, controlling for familywise error rate using Holm's sequential Bonferroni approach. Iconic gesture production was significantly higher in the board session compared to the tablet session ($M$ = 2.42, SD = 3.45), $t$ (23) = 3.43, $p < .05$, and to the paper session ($M$ = 1.42, SD = 2.90), $t$ (23) = 2.39, $p < .05$, as well as in the paper session compared to the tablet session ($M$ = 1.00, SD = 2.34), $t$ (23) = 2.09, $p < .05$.

To sum up, the significant difference was found among the sessions and as found in deictic gesture results, there was a downward trend in iconic gesture production in the board session, paper session and tablet session respectively.

#### *5.2.1.3. Beat Gesture*

A one-way within-subjects ANOVA was conducted to compare the total number of beat gestures among the three experimental conditions. The results for the ANOVA revealed no significant difference in beat gesture production among the sessions, Wilk's $\lambda$ = .85, F (2, 22) = 2.01, $p = .16$.

These results indicate that although there was a change in beat gesture production among the sessions, none of these differences were statistically significant.

#### *5.2.1.4. Summary of Gesture Types Results*

The main goals of the analyses were to investigate whether the teaching environments had significant effect on specific subtypes of gestures which were proposed in the literature (McNeill, 1992). The results showed that all environments did have influence on iconic gesture production whereas deictic gesture production was only influenced by the board and tablet conditions. Finally, the environments did not have influence on beat gesture production.

### 5.2.2. Arrow Types

This part presents the analyses to investigate the effect of the teaching environments on arrow types based on the analysis of the previous section. The descriptive statics for arrow subtypes are presented (see **Table 5.3**). The table shows that relational arrows were more frequently produced in the sessions compared to both iconic and deictic arrows. On the other hand, participants rarely produced deictic arrows among the sessions. The results are presented in **Table 5.3** below.

Table 5.3

*The Means (Standard Deviations) for Subtypes of Arrows*

| | Board Session | Paper Session | Tablet Session |
|---|---|---|---|
| Relational Arrows | 7.00 (7.50) | 6.92 (7.37) | 6.33 (6.90) |
| Iconic Arrows | 0.96 (2.61) | 1.67 (3.77) | 1.33 (2.91) |
| Deictic Arrows | 0.21 (0.59) | 0.13 (0.45) | 0.25 (0.61) |

*Note* Zero values were included in the analysis. The numbers in parentheses indicate Standard Deviation.

#### *5.2.2.1. Iconic Arrow*

A one-way within-subjects ANOVA was conducted to evaluate the effects of the teaching environments on iconic arrow production. The ANOVA indicated no significant differences in iconic arrow production among the sessions, Wilk's $\lambda$ = .80, F (2, 22) = 2.73, $p$ = .09.

This result indicates that although there was a change among the sessions, none of these differences was statistically significant.

#### *5.2.2.2. Relational Arrow*

A one-way within-subjects ANOVA was conducted to evaluate the effects of the teaching environment on relational arrow production. The ANOVA indicated no significant differences in relational arrow production among the sessions, Wilk's $\lambda$ = .96, F (2, 22) = .45, $p$ = .64.

The result indicated that although there was a slight change in means among the sessions, this change was not significant.

#### *5.2.2.3. Deictic Arrow*

A one-way within-subjects ANOVA was conducted to evaluate the effects of the teaching environment on deictic arrow production. The ANOVA indicated no significant differences in deictic arrow production among the sessions, Wilk's $\lambda$ = .95, F (2, 22) = 6.3, $p$ = .54.

Similar to the previous arrow production findings, there was no significant change in deictic arrow production among the sessions.

*5.2.2.4. Summary of Arrow Types Results*

The results indicate that there was no significant difference in iconic, relational or deictic arrow productions. Teaching environment did not have influence on arrow production when each arrow type was evaluated individually. These findings are much like the findings of arrow overall analysis.

A one-sample chi-square test was conducted to assess whether the proportion of arrow types differ in the experiment from the proportion of arrow types which were collected from the written materials. The results of the test were significant, $\chi^2$ (2, $N$ = 595) = 500.44, $p < .01$. The proportion of iconic arrows in the experiment (P = .16) was much lower than the proportion of written materials (P = .60), while the proportion of relational arrows in the experiment (P = .82) was much greater than the proportion in the written materials (P = .37). Finally, the proportion of deictic arrows in the experiment (P = .02) was slightly more than the proportion in the written materials (P = .01). Overall, these results suggest that the iconic and deictic arrows in written materials differ from the arrows in the experiment.

These results revealed that the distribution of arrow subtypes which were produced by the participants differed from the distribution in the written materials. Deictic arrows were less common in both analyses. Although iconic arrows were the most frequently used arrow type in the written materials based on the analysis in Chapter 3, the participants frequently produced relational arrows in instructional communication rather than iconic arrows. These results demonstrate the differences between the live instructional communication settings and well-prepared communicative materials and their effect on arrow production.

### 5.2.3. Gesture Types x Arrow Types

The following analyses investigated whether there is an interaction between specific types of gestures and arrows.

*5.2.3.1. Communicative Gesture (Iconic plus Deictic Gestures) x Arrow Overall*

Because beat gestures are expressive rather than communicative, they do not share any communicative similarities with arrows. In order to test whether an interaction exists between gestures and arrows, the previous analysis (gesture overall and arrow overall) was replicated by subtracting beat gestures from gesture overall.

A two-way within-subjects analysis of variance was conducted to evaluate the effect of teaching environment on the number of communicative elements. In this analysis, communicative gestures and arrow overall were considered to be communicative elements. The dependent variable was the number of communicative elements namely, communicative gestures and arrow overall. The within-subjects factors were the teaching environments with three levels (board, paper, and tablet) and communicative element type with two levels (communicative gestures, arrow overall). The Teaching Environment main effect and Communicative Element × Teaching Environment interaction effect were tested using multivariate criterion of Wilk's lambda (λ). The Teaching Environment main effect was significant, $\lambda = .61$, F (2, 22) = 6.94, $p < .05$, as well as the Communicative Element × Teaching Environment interaction effect, $\lambda = .70$, F (2, 22) = 4.74, $p < .05$.

Three paired-samples *t* tests were conducted to follow up on the significant interaction. We controlled familywise error rate across these tests by using Holm's sequential Bonferroni approach. The differences between communicative gestures and arrow overall means were significantly different between the board and tablet sessions ($M$ = 7.46, SD = 11.60), $t$ (23) = 3.15, $p < .05$. However, there was no significant change between the paper and tablet sessions ($M$ = 4.58, SD = 15.01), $t$ (23) = 1.50, $p = .15$, as well as the board and paper sessions ($M$ = 2.87, SD = 13.97), $t$ (23) = 1.01, $p = .32$. Although the differences between communicative gestures and arrow overall were greater in the board session, they were slightly decreased in the paper and tablet sessions, respectively.

Three paired-samples *t* tests were conducted to examine whether differences in communicative element production among the sessions, controlling for familywise error rate using Holm's sequential Bonferroni approach. The number of communicative elements was significantly higher in the board session compared to the tablet session ($M$ = 3.19, SD = 4.10), $t$ (23) = 3.81, $p < .05$. However, there was no significant change between the paper and tablet sessions ($M$ = 1.87, SD = 7.40), $t$ (23) = 1.24, $p = .23$, as well as the board and paper sessions ($M$ = 1.31, SD = 7.13), $t$ (23) = 0.90, $p = .38$.

These results indicate that the main effects and the interaction effect were not affected when beat gestures were subtracted from all gestures. In other words, these results supported the findings of gesture overall and arrow overall analysis. Recall that the change in the difference between communicative gesture and arrow overall productions were significantly different among the sessions. It should be noted that this significant change was based on the difference between the board and tablet sessions. Finally, it was noted that the participants produced slightly more arrows when they produced fewer communicative gestures. These results may suggest some evidence supporting the hypothesis that there would be a trade-off between arrow and gesture production.

To test whether there is a direct relation between the specific type of gestures and arrows, the iconic gestures and arrows were compared.

*5.2.3.2. Iconic Gesture x Iconic Arrow*

An ANOVA test was conducted to evaluate the effect of teaching environment and communicative elements on produced iconic gesture and iconic arrow count.

A two-way within-subjects analysis of variance was conducted to evaluate the effect of teaching environment on the total number of communicative elements. The dependent variable was the total number of communicative elements, namely iconic gestures and iconic arrows. The within-subjects factors were the teaching environments with three levels (board, paper, and tablet) and communicative element type with two levels (iconic gesture, iconic arrow). The Teaching Environment main effect and Communicative Element × Teaching Environment interaction effect were tested using multivariate criterion of Wilk's lambda (λ). The Teaching Environment main effect was significant, $\lambda = .72$, $F(2, 22) = 4.22$, $p < .05$, as well as the Communicative Element × Teaching Environment interaction effect, $\lambda = .59$, $F(2, 22) = 7.48$, $p < .05$.

Three paired-samples *t* tests were conducted to follow up the significant interaction. We controlled familywise error rate across these tests by using Holm's sequential Bonferroni approach. The results revealed that iconic gesture and iconic arrow productions were significantly different between the board and tablet sessions ($M$ = 2.79, SD = 3.46), $t$ (23) = 3.95, $p < .05$, as well as between the board and paper sessions ($M$ = 2.12, SD = 3.67), $t$ (23) = 2.83, $p < .05$. However, there was no significant change between the paper and tablet sessions ($M$ = 0.67, SD = 2.87), $t$ (23) = 1.50, $p$ = .15. Although the difference in mean iconic gesture and iconic arrow production was higher in the board session, it decreased in the paper session, and reversed itself in the tablet session.

Finally, three paired-samples *t* tests were computed to assess differences in communicative element production between the teaching environments, controlling for familywise error rate using Holm's sequential Bonferroni approach. The number of communicative elements was significantly higher in the board session compared to the tablet session, ($M$ = 1.02, SD = 1.81), $t$ (23) = 2.76, $p < .05$, as well as in the paper session compared to the tablet session ($M$ = .67, SD = 1.34), $t$ (23) = 2.44, $p <$ .05. However, there was no significant difference in the board session compared to the paper session ($M$ = .35, SD = 1.56), $t$ (23) = 1.11, $p$ = .28.

In summary, participants produced significantly more communicative elements in the board session compared to the tablet session, as well as in the paper session compared to tablet session. Participants produced fewer iconic arrows when they produced more iconic gestures, and vice versa. Finally, these results showed that although the differences in mean iconic gesture and iconic arrow productions were higher in the board session, the difference decreased in the paper and board sessions.

The analysis reported above investigated whether specific types of gestures and arrows were affected by the teaching environments and whether there was an interaction between them. The results indicated that deictic gesture production was different in the board session compared to the tablet session whereas iconic gesture production was different among the sessions. On the other hand, the environments did not have influence on either beat gestures or any subtypes of arrows. Furthermore, the findings showed that there was an interaction between communicative gesture and arrow overall productions, iconic gesture and iconic arrow productions. In particular, the analysis of the relationship between iconic gesture and iconic arrow production may suggest strong evidence for the existence of a trade-off between gestures and arrows. To repeat, the difference in mean iconic gesture and iconic arrow production was higher in the board session, it decreased in the paper session, and reversed itself in the tablet session. Altogether, the results of Part-2 suggest that, as found in Part-1, there might be a trade-off between gesture and arrow productions.

#### 5.2.4. Summary of the Major Findings

The analysis in Part-2 showed that, as found in Part-1, there was an interaction between gesture and arrow production which was investigated with respect to interaction between communicative gesture and arrow overall productions, and iconic gesture and iconic arrow productions.

Moreover, the results revealed that there was a significant change among the sessions in regard to iconic gesture production. Although there was a change in deictic gesture production, this difference was only significant between the board and tablet sessions. Furthermore, the environment did not have an influence on the participants' beat gesture production.

Finally, the change in arrow production was not significant among the sessions with respect to iconic, deictic and relational arrows.

**5.3. Summary of the Results**

The purpose of the analysis in Part-1 was to investigate the interaction between gestures and arrows as well as the influence of the environment on gesture and arrow productions without considering their subtypes. The analysis in Part-2 investigated this issue according to specific subtypes of gestures which were proposed in the literature (McNeill, 1992) and arrows based on the analysis of the previous section.

The analysis revealed that the environment had an influence on the participants' gesture production. The participants produced more gestures in the board session compared to the tablet session. The results showed that all environments did have an influence on iconic gesture production, whereas deictic gesture production was only influenced by the board and tablet conditions. Finally, the environments did not have any influence on beat gesture production.

Teaching environment did not have an influence on arrow production when each arrow type was evaluated either individually or together.

The findings of Part-1 revealed that there was an interaction between gestures and arrows. Participants produced slightly more arrows when they produced fewer gestures. The findings of Part -2 were parallel to the findings of Part-1 with respect to gesture-arrow interaction for communicative gestures and arrows, and iconic gestures and iconic arrows. The participants produced slightly more arrows when they produced fewer communicative gestures, namely deictic and iconic gestures. This interaction between iconic gesture and iconic arrow production was also investigated. Overall, these results suggest some evidence for the hypothesis that there is a trade-off between gesture and arrow production. Further studies should investigate the interaction between specific gesture and arrow types in more detail.

# CHAPTER 6

## 6. DISCUSSION AND CONCLUSSION

Arrows and gestures are both visual representations but of different modalities. The arrow symbol is one of the ubiquitous elements of visual communication. It is used for a variety of meanings, such as for causal or temporal relations, motion or forces, directions, or labels. Arrows convey meaning through their geometric and gestalt properties. Gestures are an integrated part of speech. People typically produce gestures while talking, either for expressive or communicative purposes. Gestures can represent a wide range of meanings as arrows do and these meanings may overlap with those of arrows. Gestures and arrows can convey the same information by using similar diagrammatic features. As a result, they share similar conceptualization aspects. This thesis examined whether there is a trade-off between gesture and arrow production through communication settings. Because they convey the same information and share similar conceptualization aspects, gesture production may affect arrow production and vice versa. Moreover, there is a consensus on the gesture classification in the literature. Similar classification was investigated for arrows and examined that whether there exists an interaction between specific subtypes of arrows and gestures.

A variety of arrow samples were collected from various resources and they were classified based on their specific semantic role in content. A similar trend existed in the arrow classification. Arrows were classified into three classes: iconic, relational and deictic. Iconic arrows depict visual aspects of the content, relational arrows represent the relation between the entities and finally, deictic arrows point to an entity which the direction of the arrow indicates. The relation between gestures and arrows were investigated both without considering their subtypes and according to their subtypes.

The participants, who were all experienced educators, were asked to teach a topic of their choice as if they were teaching to a learner audience. They taught the same topic in the same way in three instructional environments: (i) at the board, (ii) with pen-and-paper, and (iii) by a tablet. The participants stood during the board session and sit down in the paper and tablet sessions. All sessions were videotaped and gestures and arrows were annotated. The gestures were classified into three groups: beat, deictic, and iconic (McNeill, 1992). Beat gestures are merely speech-related rhythmic movements. Deictic gestures are pointing movements that indicate concrete or virtual entities referred to by speech. Iconic gestures represent picturable aspects of speech. In a similar manner, the arrows were classified into three groups: deictic, relational, and iconic.  Deictic arrows point to the entity by directing the viewer's attention in the direction of the arrow. Relational arrows represent the relation between two entities. Finally, iconic arrows depict visuospatial aspects of the content by using space and the geometric properties of the arrow.

In the first part of the analysis, the gestures and arrows were evaluated without considering their subclasses. In the second part of the analysis, the gestures and arrows were evaluated according to their specific subtypes.

The first part of the analysis revealed that the participants more frequently produced gestures in the board session compared to the paper and tablet sessions. In particular, the participants produced fewer gestures in the tablet session compared to the board session. In the standing position, the speakers may include their body in a conversation more freely compared to the sitting positions. The sitting positions may restrict the hands of a speaker from engaging in conversation. Moreover, the possibility of a having technical problem may lead the speakers to feel uncomfortable; accordingly, this caused the speakers to limit their hand movements in the tablet session. This may be the reason of the difference in gesture production between the board and tablet sessions.

The analysis between gesture and arrow production revealed that there exists an interaction between them; this interaction is particularly explicit in the board and tablet sessions. The speakers produced slightly fewer arrows and dramatically more gestures in the board session and compared to the board session.  The sitting position or technological aspects of the tablet session may lead a speaker to produce fewer gestures; accordingly, the speakers produced slightly more arrows in the tablet session. This finding may suggest some evidence supporting the hypothesis that there would be a trade-off between arrow and gesture production.

In the second part of the analysis gestures and arrows were investigated with respect to classification in the literature and analysis proposed in Chapter 3.

According to gesture types, the participants were most frequently produced deictic gestures among the sessions. The participants frequently required to refer their utterance by pointing the drawings or writings on the board, paper or tablet. In other words, deictic gestures helped the participants to construct a bridge between their sayings and writings or drawings (see **Figure 6.1.**). The frequent use of deictic gestures may suggest that instructional communication may lead the participants to point the drawings or writings which were referred to in their speech. In parallel to the analysis of the overall results for gestures, deictic gesture production differed among the sessions. The change was particularly notable between the board and tablet sessions. A possible reason for this is that the distance between the environment and the participant was less in the sitting position. Hence, the participants may prefer different representations (e.g., underlining, indicating with different colors, or redrawing) to point to the entity instead of merely extending their hand. On the other hand, the reason may depend on technological aspects of the tablet settings. Gestures are readily available representations; hence, they are frequently produced by a speaker. However, there may be cases which other representations offer more advantages over deictic gestures.

*Figure 6.1. A sample of deictic gesture*

There was a noteworthy difference in iconic gesture production among the sessions. A possible reason is that in the standing position the participants spoke relatively independently of the drawings on the board because of the distance; hence, they may produce gestures to depict the meaning (see **Figure 6.2.**). On the other hand, in the sitting positions, the drawings were in front of the speakers; hence, the participants may prefer to visualize the meaning on the paper or tablet by drawing. Moreover, there was fewer iconic gesture production compared to the other gesture types. A possible reason is that the environment consisted of a drawing tool; hence, the speakers preferred to visualize their thoughts in a concrete way by drawing instead of a virtual one. Another possible reason may depend on picturable aspects of the content. Like iconic arrows, iconic gesture production may also be affected by a lack of picturable aspects of the content.

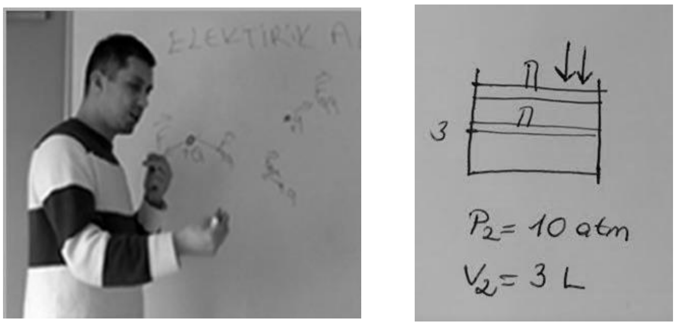


*Figure 6.2. A sample of iconic gesture (left) and iconic arrow (right)*

Speakers produced a similar number of beat gestures among the sessions (see **Figure 6.3.**). This can be expected because beat gestures do not carry semantic aspects; speakers produce beat gestures to express themselves.

*Figure 6.3. A sample of beat gesture*

The analysis revealed that there exists an interaction between gesture and arrow production. The gestures dramatically decreased in the tablet session compared to the board session while the arrows slightly increased. The gesture trend was not changed when beat gestures were subtracted from all gestures. These results may offer some evidence in support of the hypothesis that there is a trade-off between gesture and arrow productions. Moreover, both iconic gestures and iconic arrows represent picturable aspects of the content (see **Figure 6.2.**). Previous studies suggest that the dynamic aspect of the content represented by gestures can also be represented by arrows in the same manner (Acartürk & Alaçam, 2012; Tversky et al., 2012). The results of the analysis interaction between iconic gestures and iconic arrows supported the results of the previous studies. There exists a downward trend in iconic gesture production from the board session to the tablet and paper sessions, respectively and its reverse for iconic arrow production. The analysis of the relationship between iconic gesture and iconic arrow production may suggest evidence for the existence of a trade-off between gestures and arrows.

Moreover, there might be other communicative aspects that overlapped with the meanings of representations of gestures and arrows. These findings suggest that speakers frequently prefer gestures to externalize their thoughts. However, concrete representations have advantages over virtual ones through their contribution to problem-solving strategies, making inferences, and reducing cognitive load. Hence, speakers may prefer drawing when it is available.

Although iconic arrows were the most frequently used arrow type in the written materials, participants frequently produced relational arrows rather than iconic arrows. These results showed the difference between the live communication settings and well-prepared written forms with respect to arrow production. In the written materials relational arrows were used to indicate high-level relations (e.g., abstract causal link, temporal change, process) between the entities. However, the participants may produce relational arrows spontaneously as they produce gestures. Because each participant had a pen during the session, this may provide the participants to produce relational arrows to indicate any connection between the entities rather than uttering and gesturing. For instance the participants produced arrows as a cursor to indicate the connection between previous writings and current one when they moved the writings in a wider area. Moreover, the use of iconic arrows depends on picturable visuospatial aspects of the content. The contents which were selected by the participants may involve a lack of picturable aspects hence this may cause the participants produce fewer iconic arrows. Further studies should investigate the relation between live and prepared communication settings in more details.

### 6.1. Limitations

Technological aspects limited the efficiency of the instructions. There were some cases where the tablet session started over; hence, this caused the speaker to hurry up and finish the session quickly. Moreover, gesture annotation is difficult by itself. In the paper and tablet sessions, the area in which the speakers' hands moved was narrow; hence, identifying the gestures of each speaker was challenging, particularly for these sessions. Further, there were individual differences, which are beyond the scope of this thesis. Finally, instructors may arrange their speed and enrich communication with more visual representation if they were speaking to real listeners.

### 6.2. Future Work

Deictic gestures and deictic arrows share similar semantic roles, since both representations indicate an entity. However, deictic gestures differ from deictic arrows in terms of the represented geometric forms. A deictic arrow points to an entity by indicating a certain point related to the entity. On the other hand, deictic gestures may indicate the entity by using other geometric forms, besides pointing ones. For instance, a speaker may use the following forms to indicate a rectangle illustration: indicating a certain point of the rectangle, tracing a line between the corners, or redrawing the rectangle by tracing its edges. Hence, for some cases the representations of deictic gestures cannot be represented by deictic arrows. Moreover, there may be cases in which relational arrows and deictic gestures convey the same information. For instance, a relational arrow can connect two entities and a deictic gesture would represent the same meaning by indicating them. Hence, further studies should revise the classification of deictic and relational arrows.

In this study, the instructors taught a topic of their choice without considering its domain (e.g., science or math) or level (e.g., middle school or high school). Further studies should investigate this interaction with the specific domain and abstractness level. Science lessons are rich in respect of iconic representations; there are subjects such as pressure, motion, velocity, and electric field, which can be visualized with iconic arrows. In comparison, the mathematical domain consists of relational aspects; for example, there can be different representations of the same equation. The form of representations varies based on the abstractness level. Hence, further studies should investigate the topic of specific domains and abstractness level. Particularly iconic gesture and arrow productions depend on the picturable aspects of the content. Future studies should include social science to increase coverage hence more variety in gesture and arrow production can be observed.

Finally, further studies should investigate the visual representation aspects of the live and prepared communication settings with respect to arrow types.

Finally, further studies should investigate the visual representation aspects of the live and prepared communication settings with respect to arrow types.

# 7. REFERENCES


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# APPENDIX A: DEMOGRAPHIC DATA SURVEY

Demographic data was collected by questionnaire of Surveymonkey.com