Changing semiotic modes indicates the introduction of new elements in children's reasoning: the case of earthquakes

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ABSTRACT
Analyzing individual, semi-structured interviews of 41 preschoolers (age 4-6) in a pre-posttest research design, an attempt was made to investigate whether the change in the use of children's semiotic modes indicates the introduction of new elements to their thinking. For many children changing in semiotic modes indicates enhancement in their reasoning. Furthermore, in many cases the modalities regarding human body and drawing are more meaningful compared to children's speech.

KEYWORDS
Reasoning, semiotic modes, multimodal approach, physics teaching

RÉSUMÉ
Cette recherche se base sur des entretiens individuels, semi-structurés de 41 enfants' âgés de 4 à 6 ans. Un pré et post test ont été utilisés pour déterminer si le changement dans l'utilisation des modes sémiotiques des élèves indique l'introduction de nouveaux éléments dans leur raisonnement. Il a été montré que chez plusieurs enfants, les changements dans les voies d'expression soulignent aussi des changements dans leur raisonnement. En outre, dans plusieurs cas, l'expression corporelle et leurs dessins sont plus significatifs sur le plan conceptuel que lorsqu'ils passent par la formulation orale.

MOTS-CLÉS
Raisonnement, modes sémiotiques, approche multimodale, l'enseignement de la physique

THEORETICAL FRAMEWORK

Meaning making can be perceived as a multimodal process in which many semiotic modes are involved in. As far as the contribution of human body in children's reasoning is concerned Hadzigeorgiou, Anastasiou, Konsolas and Prevezanou (2009) claim that the human body not

only clarifies what is being uttered, but very often it totally serves in the construction of meaning. Givry and Tiberghien (2012) argue that the absence of gestures could be an obstacle to understanding speech. Respectively, research by Ping and Goldin-Meadow (2008) has shown that, when material objects are absent from the physical space, then the iconic gestures emerged by the students cooperate with the mental images of the objects. Furthermore, in other cases, gestures play the role of interface, jointing speech and material entities of the learning environment. For the material objects, Papert (1991, p. 4) considers them as "objects to think with", whilst Pozzer-Ardenghi and Roth (2005) studying the role of photographs in teaching science concepts, emphasize on teachers' and students' "placement" of deictic and iconic gestures as interpretative filters over them. Generally, the use of inscriptions such as drawings, tables, equations and photographs encourage learning (Tytler, Prain & Peterson, 2007; Abrahamson, 2009; Hubber, Tytler & Haslam, 2010). Especially for drawings a number of researchers realize their prominent role in signification of science concepts recognizing their communicative power (Einarsdottir, Dockett & Perry, 2009). Exploring students' thinking, researchers should pay attention to the explaining process and not solely to the morphological elements of the drawing. Actually the way in which students explain their own drawings constitutes a constructive process of thinking in action (Cox, 2005; Einarsdottir, Dickett & Perry, 2009). However, in several cases depiction per se, can give information on students' conceptions (Chang, 2012).

Regarding students' ideas about earthquakes children (age 6-12/ 1st-6th grade) have difficulty to focus on the spatial frame the phenomenon occurs and their alternative representations lie on the interior of the earth and on the entities which cause it (Ioannidou, 2001; Ross & Shuell, 1990; Kırıkkaya, Ģakın, Imali, & Bozkurt, 2011). Furthermore, children seem to have difficulties due to the scientific terms associated with the phenomenon, while there are many cases where they confuse the earthquakes with the volcanoes or adopt in their ideas indigenous cultural worldviews (Ross & Shuell, 1993; Tsai, 2001). All these aforementioned researches have studied students' oral responses rather than the rest of semiotic systems of making sense. However, Singer, Radinsky & Goldman (2008) investigated 6th grade students' reasoning on tectonic plates and their movement in terms of the gestures the students use, either individually or in the context of their working group. It was shown that the gestures emerged earlier in time than speech. Actually, since the gestures start appear together with the speech this combination enables a deeper understanding of the specific concepts. In the current paper an attempt is made to study how the interplay of speech, drawing and gestures serve in preschooler's reasoning about earthquakes.

The aim of this study is to investigate whether the new modalities used by children to explain aspects of the earthquakes generating phenomenon, add new aspects to their reasoning. The research question is formulated as follows: How does the change in students' multimodal structures indicate evolution in their reasoning?

METHODOLOGICAL FRAMEWORK

Research design

A pre- post-test research design was adopted. Similar tasks were realized a week before and a week after a properly designed teaching intervention. The teaching intervention between the two tests lasted 3 days and consisted of ten activities, relevant to the earthquakes phenomenon, its generating mechanism and means of protection we use. Data was collected through individual semi-structured interviews, in two pre-school classes (41 children/ 14 children age 4-5 and 27 children age 5-6) from the wider region of Patras, Greece. The interviews consisted of two tasks: a) questions about the mechanism that generates

earthquakes (speech context) and b) drawing and discussions that provided explanations on it (drawing context). Both tasks were videotaped. Children's speech was analyzed as well as the gestures they used in the speech context. The drawings were also analyzed, along with speech and gestures the children used in their attempt to explain them.

Coding

Coding concerned modalities of speech, body and drawing and took place in four phases: a) transcription of oral material in written text, b) video watching and indicating every gesture where it appears, c) codification of spatial modalities used by children in their drawings, and d) indicating the structures appearing as combination of the above. First, two researchers conducted the coding separately. Meetings between the two researchers were followed until a common agreement to be established (Givry & Roth, 2006).

Tables 1, 2 and 3 present the modalities that the children activated in every semiotic system to describe the cause of earthquake. These modalities refer to three general categories: movement, entity which is the cause of the phenomenon, and the area where the earthquake occurs. The dg_i and ig_i indicators refer to the deictic and iconic gestures respectively. In Table 3 the d_i data enclose the various parts of children's drawings which constitute points of interest.

TABLE 1

Modalities of speech (s_i)

Semiotic mode	***Referent***	***Modalities***
Speech (s)	movement	***s_1**: (they) move/shake/fall, **s_2**: (they) unite / get close/collide,**s_6**: (they) rub against one another, **s_7**: (they) immerse*
	causal entity	***s_0**: planets/space, **s_3**: stones/plates, **s_8**: from the core, **s_9**: creature of imagination - monster/Enceladus, **s_{10}**: seismologist/machinery, **s_{11}**: lava, magma*
	spatial framework	***s_4**: under the earth/under the sea, **s_{12}**:somewhere outside the earth*

TABLE 2

Modalities of body expression (dg_i, ig_i)

Semiotic mode	***Referent***	***Modalities***
Body expression (b)	movement	***ig_3**: repeated movement of marker/hand back and forth over the sketch (stones/earthquakes), **ig_6**: move a hand back and forth over the sketch, **ig_9**: vibrating motion with both hands, **ig_{10}**: representation with the index finger/hand/marker the collision of two planets on the sketch, **ig_{12}**: repetitive back and forth movement of one hand with closed palm, **ig_{13}**: repetitive movement of the two fingers coming together and apart over the sketch, **dg_2**: shows the arrows that has painted to demonstrate the movement of magma*
	causal entity	***ig_4**: fast movement representing two plates with spread out hands (fingers inward), **ig_{11}**: imaging of two virtual spherical objects ("plates")*
	movement and	***ig_1**: repetitive back and forth movement with closed or open palms, **ig_2**: collision movement with spread out or closed palms, **ig_5**:*

	causal entity	*moving one hand from right to left with stretched out palm,* ***ig₈****: rubbing movement with both palms spread out,* ***ig₁₄****: plates rubbing movement imaging with both hands spread out, one over the other,* ***ig₁₅****: plates rubbing movement imaging using both palms, spread out one over the other,* ***ig₁₈****: sinking movement of two plates with joined palms in 90° angle shape*
	spatial framework	

TABLE 3

Modalities of drawing (d_i)

Semiotic mode	***Referent***	***Modalities***
Drawing (d)	movement	***d₉****: it depicts movement with a continuous zigzag line,* ***d₂₀****: two arrows depicting right and left movement*
	causal entity	***d₁****: spherical plates,* ***d₃****: two horizontal lines (tectonic plates),* ***d₄****: many spherical stones beneath the soil,* ***d₁₁****: two united plates,* ***d₁₂****: collision of two planets,* ***d₁₃****: tectonic plates as horizontal line* ***d₁₇****: fictional creature/Enceladus beneath the Earth as the cause of the earthquake,* ***d₁₉****: magma being shaken "right-left" and shown with arrows*
	spatial framework	***d₂****: house positioned on stones,* ***d₈****: the soil and subsoil,* ***d₁₀****: it depicts the soil and the subsoil by adding more elements (tectonic plates, magma),* ***d₁₄****: the planet Earth/Earth bark,* ***d₁₅****: a house that has been damaged by the earthquake,* ***d₁₆****: the sea showing that the stones are inside or underneath it,* ***d₁₈****: the plates/rocks beneath planet Earth*

The interplay among oral, bodily and spatial modalities was also codified. Table 4 presents these structures used by the children in both tests.

TABLE 4

Children's syntactic/multimodal structures that appeared in pre and posttest

Speech context	*Drawing context*
s_i	d_i
$s_i(ig_i)$	$d_i(s_i)$
$[(s_i)ig_i, (s_i)ig_i]$	$d_i(s_i, ig_i)$
$[s_i, s_i(ig_i)]$	

The brackets [ ] signify a grammatical sentence which may include one or more clauses.

Single items such as ig_i or s_i (e.g., ig_9: vibrating motion with both hands, or s_3: plates) were the simplest structures that appeared. More complex syntactic structures were constructed by means of interplayed modalities activated in different semiotic systems. Thus, two different, in terms of semiotic system, modalities can co-operate creating for example the $d_i(s_i)$ element or the synergy of $d_i(ig_i,s_i)$. In the first case the child explains orally (s_i) his/her drawing (d_i), while in the second case another child constructs his/her drawing explanation in terms of oral

plus gestural signs. In Table 4 the multimodal structure [(s_i)ig_i, (s_i)ig_i] refers to a grammatical sentence consisting of two clauses. The part (s_i)ig_i which stands for each clause, is composed by an iconic gesture appearing together with the child's utterance.

Data analysis

1st level of analysis: change in modalities

Change in modalities is defined as any change that occurs in the post test compared to the pretest and has to do with the emergence of new signifiers in speech (s_i), body expression (ig_i, dg_i) and drawing elements (d_i). These developments can either have the form of a single component (e.g., $ig_{18:}$ sinking movement of two plates with joined palms in 90° angle shape) first appearing in the post test, or the form of a more complex structure (e.g., d_4 (s_1, s_4, ig_6)), within which old and new elements may appear together.

2nd level of analysis: change in reasoning

It was studied whether the change in modalities from the pre- to posttest denotes also change in children's reasoning. In this case was used the criterion of the most coherent reasoning. A more complete thinking was noted when, during posttest, the children introduced new entities and/or formed new links between these entities, compared to the pretest regarding the earthquake generating mechanism. For example, the subject B16 in the pretest uses the vague component **s_{10}** (seismologist/machinery) to signify the phenomenon of earthquakes. In the posttest he/she develops the more complex structure **[s_1, s_3, $s_2(ig_2)$]** signifying the referents [s_1: moving, s_3: plates, $s_2(ig_2)$: collide (collision movement with spread out palms)] respectively. These semiotic elements interweave a more complete reasoning since they introduce new entities and construct links among them.

RESULTS

None of the 14 younger children (age 4-5) managed to change his/her modalities from pre to posttest. However, fourteen elder children, age 5-6, out of 27 showed an evolution in modalities comparing to the pretest. Table 5 presents only the children who improved the range of the modalities they used, either in the speech context or/and in the drawing context. The symbols in bold indicate the new elements integrated for the first time in the posttest by the children in their effort to conceptualize the phenomenon of earthquakes. The rest of the modalities with the regular form in Table 5 had appeared for the first time in pretest and they still remain active in posttest.

TABLE 5

Change in the 14 children's modalities from pre to posttest

Change in modalities		
Subjects	***Speech context***	***Drawing context***
B2	**$s_3(ig_4)$**	**$d_3(ig_5, s_2)$**
B3		**$d_4(s_1, s_4, ig_6)$**
B7		**$d_{10}(s_1, s_3, s_6)$**
B8	s_1**(ig_{12})**	**$d_{11}(s_1, ig_{13})$**
B11		**$d_{13}(s_3, dg_2)$; d_{19}; d_{20}**
B13	**$(s_3, s_7)ig_{14}$; s_2; $(s_3, s_1)ig_{15}$**	**$d_3(s_2, ig_{15})$**
B16	**[s_1, s_3, $s_2(ig_2)$]**	**$d_{13}(s_3)$; $s_2(ig_3)$; text**
A1	**$(s_3, s_6)ig_1$**	

A2	s_3**(ig$_{11}$)**	d_7**(**s_3**,** s_2**, ig$_3$)**
A3	**s$_4$**	d_{11}**(**s_3**,** s_2**, ig$_2$)**
A4	**[s$_3$, s$_1$(ig$_1$), s$_4$]**	**(s$_3$, s$_1$, s$_4$)ig$_1$**
A7		d_{18}**(**s_3**,** s_1**, ig$_3$)**
A10	**(s$_3$, s$_1$)ig$_{18}$**	**d$_{11}$(s$_3$, s$_1$, ig$_{18}$, ig$_1$); (s$_3$, s$_{12}$)ig$_3$**
A21	**s$_4$**	

The brackets [ ] signify a grammatical sentence which may include one or more clauses.
The mark (;) signifies the use of more than one sentence.

Subsequently, it was studied whether the changes in the modalities presented in the Table 5 denote also changes in children's reasoning on scientific aspects of the phenomenon of earthquakes. It was shown that all these 14 children evolved their reasoning (see Table 6), since the new modalities they introduce convey new information about the spatial framework in which the phenomenon takes place, the entities which cause it and/or the movement of the tectonic plates.

TABLE 6

Change in students' reasoning in terms of the introduction of new modalities in posttest

Reasoning			
Subjects	***Speech***	***Body***	***Drawing***
B2	Reasoning (+) *Causal entity (s_3)*	Reasoning (+) *Causal entity (ig_4)* *Movement and causal entity (ig_5)*	Reasoning (+) *Causal entity (d_3)*
B3	Reasoning (+) *Movement (s_1)* *Spatial framework (s_4)*	Reasoning (+) *Movement (ig_6)*	Reasoning (+) *Causal entity (d_4)*
B7	Reasoning (+) *Causal entity (s_3)* *Movement (s_6)*		Reasoning (+) *Spatial framework (d_{10})*
B8		Reasoning (+) *Movement (ig_{12}, ig_{13})*	Reasoning (+) *Causal entity (d_{11})*
B11	Reasoning (+) *Causal entity (s_3)*	Reasoning (+) *Movement (dg_2)*	Reasoning (+) *Causal entity and Spatial framework (d_{13}, d_{19})*
B13	Reasoning (+) *Movement (s_1, s_2, s_7)* *Causal entity (s_3)*	Reasoning (+) *Movement and causal entity (ig_{14}, ig_{15})*	Reasoning (+) *Causal entity (d_3)*
B16	Reasoning (+) *Movement (s_1, s_2)* *Causal entity (s_3)*	Reasoning (+) *Movement and causal entity (ig_2)* *Causal entity (ig_3)*	Reasoning (+) *Causal entity (d_{13})*
A1	Reasoning (+) *Movement (s_6)*	Reasoning (+) *Movement and causal entity (ig_1)*	
A2		Reasoning (+) *Causal entity (ig_{11})* *Movement (ig_3)*	
A3	Reasoning (+)	Reasoning (+)	

	Spatial framework (s_4)	*Movement and causal entity (ig_2)*	
A4	Reasoning (+) *Causal entity (s_3)* *Movement (s_1)* *Spatial framework (s_4)*	Reasoning (+) *Movement and causal entity (ig_1)*	
A7		Reasoning (+) *Movement (ig_3)*	
A10	Reasoning (+) *Causal entity (s_3)* *Movement (s_1)* *Spatial framework (s_{12})*	Reasoning (+) *Movement and causal entity (ig_{18}, ig_1)* *Movement (ig_3)*	Reasoning (+) *Causal entity (d_{11})*
A21	Reasoning (+) *Spatial framework (s_4)*		

The symbol (+) indicates an improvement in child's reasoning.

The children improved their reasoning using one or more semiotic modes (see Example 1).

Example 1(Subject: B11)
In Example 1 the child adds in his/her reasoning new entities as well as links among them. More specifically, he/she integrates in the posttest the new modalities $d_{13}(s_3, dg_2)$ and d_{19} (see Table 5). Table 7 presents the oral modalities in the two tests of the speech context.

TABLE 7

Responses of subject B11 to the question "How do you think an earthquake occurs?"

Student's (B11) utterances in pre- and posttest of the speech context	
Pretest	***Posttest***
"I believe that the whole city <u>is shaking</u> *(s_1)* and sometimes when a very powerful earthquake occurs, some houses fall down" […] "Because <u>something</u> can happen <u>in space</u> *(s_0)*"	"I think, from the <u>tectonic plates</u> *(s_3)*"

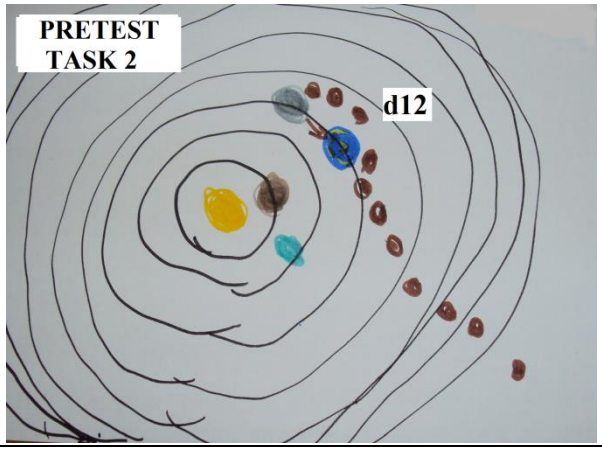
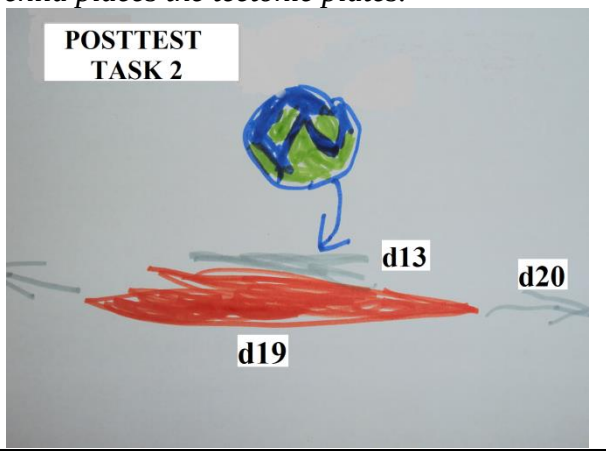
The child B11 goes from a generalized denotation of movement ('shaken') to defining the entities involved (i.e., 'tectonic plates') in the earthquake phenomenon. It should be noted that during the pretest the child does not link the movement to a mechanism. He/She simply presents the movement as a result of the earthquake ('the whole city is shaking') and not vice versa. On the contrary, at posttest he/she identifies the material entities that create the earthquake.

Additionally, in the pretest drawing context, he/she attributes the cause of earthquakes to the collision of the planets. In the posttest there is a change since the child includes in his/her reasoning entities such as 'magma', 'movement of the magma' and 'tectonic plates' (Figure 1).

More specifically, she draws the item ***d_{12}: collision of two planets*** and utters the motion verb ***s_2***: "collide (two planets)" noticed together with the gesture (***ig_{10}***) of "unifying" the two planets that appear in sketch. However, in posttest the child depicts the magma (***d_{19}***) while drawing two arrows at both sides (***d_{20}***), and over that she places the tectonic plates (***d_{13}***).

At the same time she utters "tectonic plates (***s*$_3$**)", while showing with a deictic gesture (***dg*$_2$**) the arrows that has painted and may indicate "movement". This multimodal structure represents the movement of magma and hence the swing of tectonic plates on it.

FIGURE 1

Pretest: *Illustration of the planetary system with a material object colliding with earth.*	***Posttest:*** *Depiction of the magma with arrows on the right and on the left that indicate the movement of it. Over magma the child places the tectonic plates.*
	
[student's utterance and gesticulation]: "the moon (*ig*$_{10}$*: representation with the hand the collision of two planets on the sketch)* collides *(s*$_2$*)* with the Earth"	[student's utterance and gesticulation]: "tectonic plates *(s*$_3$*)* (*dg*$_2$*: shows the arrows that has painted to demonstrate the movement of magma*) "

Student's (B11) drawings, utterances and gestures in pre- and posttest of the drawing context

In summary, the child advanced his/her modalities concerning speech and drawing as well as corporeal expression. With his utterance he/she introduces new entities (i.e., **s**$_3$: tectonic plates), while with the structure [***d*$_{13}$*(s*$_3$*, dg*$_2$*); d*$_{19}$*; d*$_{20}$] he/she places the tectonic plates over the magma and suggests their back and forth movement.

In general, 6/14 preschoolers use all three semiotic systems to reason in the posttest, 5/14 preschoolers use two, while 3/14 preschoolers use just one (see Table 6). Typical case of evolution in reasoning through all three semiotic systems is the student B11 in Example 1. It is worth noting that 12 out of 14 preschoolers used their bodies to add new elements while reasoning. These children in the pretest had not used at all their bodies in their effort to explain the phenomenon.

Especially for the corporeal modalities (ig_i/dg_i), as well as for the modalities of drawing (d_i), it was found that in several cases they convey more *powerful meanings* compared with those of speech (s_i). The term *powerful* assigns meanings that on one hand are not expressed with any other sign-vehicle, and on the other hand communicate more essential aspects to the earthquake phenomenon. In Example 1 of the drawing context (see Figure 1), the child's drawing at posttest is more rich in information than the utterance 'tectonic plates', as it identifies the form of the plates and places them over the magma. In another case, gestures enabled the child to communicate and describe the type of movement that occurs during an earthquake in a way that was not expressed with any other semiotic system (see Example 2).

Example 2 (Subject: A10)
Table 8 shows elements of speech uttered by the child in the two tests of speech context.

TABLE 8
Responses of the student A10 to the question "How do you think an earthquake occurs?"

Student's (A10) utterances in pre- and posttest of the speech context	
Pretest	***Posttest***
"When a giant monster (s_9) comes and walks …"	"(ig_9: *vibrating motion with both hands*) when the other falls (s_1) there" […] "the tectonic plates (s_3)… if one falls (s_1) and the other the same …(ig_{18}: *sinking movement of two plates with joined palms in 90^o angle shape*) will make more earthquake"

In pretest the student attributes the cause of the earthquake phenomenon to an imaginary creature, without being able to deliver more details. In posttest, he/she moves from a general suggestion of movement through speech (i.e., "when the other falls there") to a clarification of the elements involved (i.e., 'tectonic plates'). However, it is the child's gestures that are gradually deployed which add new elements in his/her reasoning. Actually, the child gesticulates suggesting the shape and the kind of movement of the uttered entities (i.e., **ig_9**: *vibration movement* and **ig_{18}**: *immersion movement*). These gestures describe in terms of child's palms the shape of the tectonic plates, but also their movement. On the contrary, the utterance 'tectonic plates' only mentions them as a lexical item without defining any physical properties such as flatness or immersion movement. Maybe it's the nature of the specific phenomenon that allows more powerful meanings to be transferred through body expression.

DISCUSSION

It seemed that the change in modalities used by children is interconnected with the evolution in their reasoning. In most cases, gestures and drawing visualize moving and spatial entities, while speech is insufficient of describing them. Concerning the earthquake phenomenon, coherent thinking cannot be achieved without the use of modalities of body expression and drawing. In science, gestures may play a particularly important role in constructing meaning regarding domains that direct experience is not accessible for young children (e.g., seasonal change, tectonic plates, etc.) (Singer, Radinsky & Goldman, 2008). Novack and Goldin-Meadow (2015) support that gestures add a spatial or iconic element in spoken language. Given the fact that gestures don't limit to linear rule-based standards, they have the capacity to express ideas that can be difficult to be expressed with words. Especially for the human body Goldin-Meadow & Alibali (2013) mention that gestures reflect what speakers know about, and that basically serves as a window onto their thoughts. The aforementioned researchers also realize that from this window, speakers very often reveal thoughts they do not even know they have. Gestures are not just a hand-waving but represent a means of evolution of the consisted meanings (Goldin-Meadow & Wagner, 2005). They enable thoughts which are not previously expressed to emerge. Gestures can also add new elements to students' reasoning modifying the context of a conversation. Givry & Roth (2006) argue

that bodily actions can set the conditions of the evolution in students' reasoning, while Wagner-Cook, Pitchell & Goldin-Meadow (2008) underscore the value of students' using of their body in representing concepts which crucially contributes in the construction of knowledge.

A multimodal perspective receives great interest especially for the young children since multiple representations have a direct impact on children's learning (Hadzigeorgiou et al., 2009; Waldrip, Prain & Carolan, 2010). More extensive research on the role of the semiotic modes in meaning making process will provide useful data for the curricula design, enrich the teaching practices with a semiotic view and re-organize the development of the educational materials in the context of multiple representations.

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