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From 3D to 2D: Drawing as documentation and reflection processes by young children

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Abstract
The purpose of this study is to gain a deep understanding of kindergarten children's drawings as a form of documentation of their work, of their ability to notice and depict substantial details, as well as their understanding of how objects in the world "work". In the study, we examined drawings created by kindergarten children for documenting artefacts they previously constructed. The drawing process demands the cognitive transition from the perception of the 3D object to its 2D drawing. Most theoretical and research work conducted over the years focused on children's free, intuitive and/or spontaneous drawing. As well, most studies focused on children drawings of given objects, even their copy of drawings of objects, or on free representation of ideas or feelings. In this study, we addressed two aspects that differ from the foci of previous work: (a) children drew an object they have constructed; and (b) the drawing has a functional purpose (i.e., documentation) as part of a design task. The study participants included 30 kindergarten children, aged 5-6. During freeform play, the children produced constructions using a building kit and documented these in drawings. A total of 39 constructions and corresponding drawings were analyzed. Data analysis was conducted to examine the characteristics of children's drawings, as well as the relationship between the features of the constructions and the corresponding drawings. The insights emerging from the study indicate that drawing can serve as a tool for documentation and reflection by kindergarten children and may support the development of technological thinking.

Keywords
Documentation, Reflection, Drawing, Sketching, Construction, Kindergarten Children, Technological Thinking

Introduction
The purpose of this study is to gain a deep understanding of kindergarten children's drawings as a form of documentation of their work, of their ability to notice and depict substantial details, as well as their understanding of how objects in the world "work".

The study is part of a long-term research program based on the constructionist "Design and Learning" (D&L) model, designed to advance kindergarten children's design and technological thinking (Mioduser, 2009; Mioduser, Kuperman & Levy, 2012). The learning program has been implemented in kindergartens for over a decade, coupled with a comprehensive curriculum, a teacher training module as well as a robotic programming environment. "Designing and sketching" is one of the six strands that comprise the curriculum (Dagan, Kuperman & Mioduser, 2012; Aladjem, Kuperman & Mioduser 2020).

A core goal of the learning program is to foster design thinking - an iterative process in which designers toggle back and forth between analysis and synthesis and operate in both the concrete and abstract worlds (Beckman & Barry, 2008). Design thinking involves procedural knowledge (know-how), conceptual knowledge (know-what) and declarative knowledge, as well as metacognitive processes and analysis, synthesis, and evaluation skills (Kimbell et al. 1991; McCormick, 2004; Mioduser & Dagan 2007; Stevenson, 2004; Kimbell & Stables, 2007; Stables, 2020)

The focus of the study reported here is a design and documentation activity in which children are first asked to construct an artefact using a building kit (LEGO and LEGO Duplo blocks), and then to document their constructions by generating a detailed sketch.

The research questions on which we report in this paper focus on: (a) the concrete properties of the drawings generated by the children for depicting the object they constructed by themselves; and (b) children's knowledge as reflected in the drawings concerning artifacts' static and dynamic features:

1. What types of constructions (and corresponding drawings) did the children produce?
2. How accurately do the drawings depict the structural and dynamic properties of the constructions?
3. What perspectives and projections did children use while documenting the constructed objects (e.g., drawing from the side, from above, mixed views)?
4. Is it possible to replicate the constructions from the drawings?

An all-embracing question: What do children (in our study) know when they "draw what they know"? (Elaboration on this fifth question will be presented in the discussion section).

The following review briefly surveys the background for the study concerning designing and drawing by kindergarten children.

Theoretical background

Construction kits in the kindergarten

Children construct knowledge through being involved in a wide range of experiences, e.g., participating in games, in social interactions, inquiring about phenomena in the environment, and behaving within it (Piaget & Inhelder, 1969). Active experience with objects, and their operation, is crucial for developing concrete and abstract thinking and facilitates the transition from direct manipulations to formal and abstract operations (Resnik, 2007).

Construction and assembly are an integral part of the kindergarten experience. Engaging in assembly activities is a meaningful part of the children's cognitive, social, and emotional development, encouraging curiosity and active participation in spatial problem-solving (Bagiati & Envangelou, 2016; Newburger & Vaughan, 2006; McGarvey et al., 2018; Parkinson, 2017; Wellhousen & Kieff, 2001). Studies among young children demonstrate that problem-solving tasks with building blocks contribute to spatial thinking (Bagiati & Envangelou, 2016). Problem-solving while constructing involves estimation and relativity - as children should estimate, e.g., the number, size or required function of pieces to be included in a structure and apply concepts of spatial relation and configuration (e.g., near/far, up/down).

Educational construction kits have been in use for about two centuries (Zuckerman, 2006) - since the systematic use of Frederik Froebel blocks' and 19th century alphabetic blocks up to the endless types of construction kits currently in use (see Provenzo & Brett, 1983, interesting historical account of blocks kits for children). Construction kits are considered to be effective learning tools that enhance cognitive, social, emotional and sensitivity skills. These kits afford construction options and pose constraints that may promote curiosity and foster the ability to design and solve spatial problems (Parkinson, 2017). The rapid development of spatial skills occurs between the ages of 5-8 and can be facilitated with activities such as building with construction kits, playing 3D computer games, copying, drawing and more (McGarvey et al., 2018). Furthermore, designing structures with building blocks requires creativity and the development of a sense of esthetics, motivating children to manipulate changes in size, appearance, and stability of the structure. Moreover, formal knowledge (e.g., physics laws - balance, gravity- or arithmetic procedures) may be learned through practice (Bagiati & Envangelou, 2016). Studies also show that children develop physical, social, creativity and problem-solving abilities during free blocks-construction play (Newburger & Vaughan, 2006).

Children's Drawing

Research focusing on children's drawings characteristics, as well as on the development of children's ability to represent aspects of their inner and outer world, is being conducted for over a century. However, two issues characterizing the vast body of knowledge generated are relevant for our study: (a) Seminal research work and comprehensive accounts of the development of children's drawing were conducted and published during the previous century, mostly until the 80's and 90's. Research since then has addressed highly interesting but specific aspects of drawing in varied contexts. (b) Research on children's drawing for technical or functional purposes, as part of design processes, is definitely scarce.

A detailed presentation of published work on the development of children's drawing is beyond the scope of this paper – for this we can refer to the comprehensive review of the history of theoretical and research work (the foundations) published by Strommen (1988), or to the background section in the recently published paper by Sawyer & Goldstein (2019). Undoubtedly, several important insights stemming from this long research endeavor are highly relevant to our study.

A substantial issue is the attempt to trace the developmental path of children's representational ability, and to identify stages in this development based on salient variables and characteristics in the drawings. The developmental process has been characterized in different ways, vis-à-vis the theoretical stance adopted.

Emphasis on the content of the drawings, and the intellectual and conceptual aspects involved in their production, view these as external representations of thought. In this theoretical approach, drawings do reflect children's mental images of aspects of the world or conceptual knowledge. Early stages in the development of children's drawing are synthesized in the claim: "children draw what they know rather than what they see". Advanced stages seem to rely increasingly on perceptual inputs affecting the gradual construction of complex representational schemas externalized in the drawings. The developmental path thus advances from "intellectual realism" (e.g., evident in the inclusion of "impossible views" in the drawings)

to "visual realism" (e.g., guided by perceptual data), as formulated in Luquet's pioneering work (1927).

An alternative developmental framework focuses on the specific components used in the drawings, and the skills and strategies implemented to produce these. Here the answer to the question "what develops" emphasizes the representational resources used by the children, (e.g., graphical units, recurring schemas), spatial strategies (e.g., perspective taking, spatial configuration) and production-skills (e.g., visuo-motor abilities). The development path is depicted in terms of the increasing mastery and refinement of abilities and strategies as well as the scope of the tool box used by the children in their drawings. (e.g., Ackermann, 1996; Karmiloff-Smith, 1990.

A third theoretical framework conceives drawings as a systemic product, integrating among different layers: cognitive/intellectual/conceptual (what is represented); resources/skills/strategies implemented (how the content is represented); socio-cultural parameters (context for the production of the representation). The last layer refers to aspects affecting (or comprising) the drawings such as culturally-accepted features (e.g., use of conventional schemas such as the square+triangle scheme for a house, or color, gestures and configuration conventions in religious art – Arnheim, 1997; Picard & Durand, 2005); externally defined functions (e.g., as in curricular tasks, or in imposed functions such as drawing for planning or manufacturing); or socially-convened constraints. This comprehensive-systemic view of developmental paths is rooted in a range of theoretical and research work over the years, including systems, cognitive development, art or socio-cultural theories.

In the study reported in this paper we rely on this vast body of knowledge while focusing on a specific genre of drawings: children's technical drawing.

Children's technical drawing

In contrast with the extensive research work conducted for many decades on children's free and expressive drawings, inquiry on children's drawings with functional (and technical) purposes has been scarce.

In design thinking, drawing is a key element for visualizing ideas, communicating them (to oneself and others), and exploring new ideas (Lawson, 2004; Hope 2008; Sung, Kelley and Han, 2019). Recognizing that children draw their mental image of an object, the image in their mind's eye (Ferguson, 1994), and not solely their visual perception of it, is pivotal to understand how they represent aspects of the world. Research on drawings produced for planning and construction, showed that most young children are able to draw a 2D design, but many of them had difficulty using their drawings/plans to produce actual constructions (Anning, 1997; Anning, 2008; Fleer, 2000; Hope, 2008; Hope 2017).

Representational technics and resources for depicting 3D objects in two dimensional drawings were developed in Renaissance times (e.g., linear perspective, cutaway and exploded views, or drawing apparatuses), serving artistic and technical representations as well (Ferguson, 1994). Since then, a wide range of technics and conventions (and currently software tools) has been developed for supporting technical and engineering work. Spatial intervention studies with engineering students emphasize the importance of generating different representations of 3D models created/to-be-created, e.g., a coded plan (2D representation on a grid or isometric

paper); orthographic drawings (top-front-side); or isometric sketches (perspective drawings). While young children can perform the first and the second type of drawings, they have difficulties with the third (McGarvey et al., 2018). These skills are developed as part of building with imposed constraints, and require flexibility of thinking allowing moving between 2D representations and 3D constructions. The creation of these representations demands multiple perspective-taking thought in different forms of drawing and are an essential aspect of spatial skills development (Ackermann, 1996; McGarvey et al., 2018).

Piaget and Inhelder's (1971) distinction between reproductive (R) and anticipatory (A) images is highly important for the discussion of children's technical drawing. 'R' refers to the capability to represent in images something already perceived (as in documenting an object). 'A' implies imagining a yet non-existing object (as in planning). Moreover, they deepen the analysis to refer to either 'R' or 'A' images depicting static (S), Kinetic (K) or transformation (T) states. Their findings show that while 'RS' images are produced at early stages in children's development (preoperational stage), anticipatory images in general and either reproductive or anticipatory images of 'K' and 'T' processes in particular are produced only by the age of 7-8 (operational stage). These observations are relevant for addressing children's technical drawing in design tasks, where they are asked to represent constructed artefacts (most often including mechanical-kinetic components) and even the transformations resulting from their functioning (e.g., movement, changing relative position of components) - as in our study.

In this study, we consider drawings as an expression of children's cognitive development and their ability to manipulate symbols, meaning the way they use signifiers to represent signified static and kinetic objects and their transformation states (Vygotsky, 1980; DeLoache, 2004).

Conceptual framework for the study

Grounded in relevant aspects of the body of knowledge briefly surveyed, our research questions and variables address children's drawing in a specific context: documenting an object following its construction.

Two important characteristics in our study contrast with the setting and variables of most of the surveyed previous research: Children's' involvement in constructing the represented object, and the functional aim of the drawing.

In most studies children are requested to draw existing objects, many times even to copy drawings of objects or manipulate cards with drawn components. In our study children are actively involved in constructing the object they are required to draw. Thus, critical issues immediately emerge, vis a vis the conclusions of previous research, e.g., how "drawing what they know" is affected by the fact that "what they know" is constructed while constructing the object (the 'constructionist way')? Will this imply also in this study an early and biased stage of representation less accurate than the "visual-realism" stage as traditionally claimed?

The second differing characteristic relates to the functional goal of the drawing. In most research work children are requested to represent aspects of reality or concepts. They either observe models or objects or the are asked to represent concepts or feelings. All these pertain to the genre of free or expressive drawings without any constrain related to a function to be fulfilled. In our study, as in any study related to design or engineering processes, the drawing activity play a functional role. We asked children to create drawings that document their

constructed objects, to depict as good as possible the objects structure, components, or any other important property. Moreover, we aimed to examine whether the drawing can guide the construction of the depicted object (i.e., a planning function).

Methodology

Research setting and participants

Participants in the study were 30 children aged 5-6 from average socio-economic-status (SES) homes attending compulsory kindergarten in the center of Israel. The activities conducted during the research were part of the curriculum entitled "Developing technological thinking in early childhood education" (Mioduser, Kuperman & Levi 2012).

Concerning ethical issues: the kindergarten was defined as "experimental" by the Ministry of Education and all necessary permits to conduct research were granted, including parents informed consent. Data collected did not include audio or video recordings and any personal identity information. Photographed constructions and drawings constitute the data base of the study.

In the specific activities, children created constructions using LEGO and LEGO Duplo bricks, as part of their playtime in the kindergarten. The children did not receive instructions or mediation from the staff before or during the construction process. After constructing their artifact, the children were asked to produce drawings of their creations, using a plain sheet of paper, pencils, crayons, and markers of their choice. They were free to draw according to their understanding. Thirty-nine constructions and corresponding drawings were produced. Additionally, children were encouraged to describe their constructions - the teacher documented their verbal explanations if they chose to do so. As a result, 21 of the 39 drawings collected were complemented by verbal descriptions. The constructions and sketches produced, documented and photographed, constituted the database of this study.

Data analysis

The analysis of the findings was conducted following qualitative methods, using a grounded (bottom-up) paradigm. The definition of the categories was grounded on: (a) the actual data collected – children drawings; and (b) previous work, in particular developmental research, as surveyed in the background section (e.g., in Piaget & Inhelder, 1971; Karmiloff-Smith, 1990; Ackermann, 1996).

The analysis included several phases:

1. Defining the potential classing criteria emerging from the drawings and photographic documentation of the constructions.
2. Analyzing the (photographed) constructions according to the defined categories (e.g., looking at aspects such as static or moving parts; or technological mechanisms).
3. Transcripts of descriptions (if available) were also analyzed to shed light on children's intentions and decisions while building.
4. Analyzing the drawings according to representational parameters defined (e.g., match with the physical construction; representation of parts; projections).

Criteria and categories of analysis

For the first research question, three categories for classing the constructions and drawings were defined. Examining the drawings, a clear-cut variable emerged: whether they included mechanical or movement related components and moreover, compounds that enable the artifact as a whole to move and navigate in space. Although conceptually these data-grounded categories correspond to the developmental paths depicted in the literature on children's representations, we do not refer to them as ordinal or hierarchical. The categories were:

1. **Static**. No dynamic mechanisms are present and there is no evidence in children's explanations of any intention to build something that can move or has movement.
2. **Semi-dynamic**. These contain technological mechanisms that generate some level of movement (levers, relays, axes, gears, etc.). In addition, the children described the construction as one that "does" something, with evidence of parts that enable movement (e.g., wheels, axes).
3. **Dynamic**. The entire construction has mobile compounds or can move or travel.

For the second research question each sketch was analyzed focusing on the following characteristics:

- General level of detail in the sketch.
- Degree of accuracy of scale and proportion between parts
- Degree of accuracy in portraying construction details including emphasis in prominent elements
- whether a human figure is included

For the third research question, we looked at the perspectives and projections included in the drawings, e.g., top, side or mixed projections.

For the fourth research question, we examined the extent to what the representation can serve as guide for reconstructing the depicted object.

Findings

The findings are presented in the following sections according to the research questions.

Q1: Mechanical/dynamic aspects in the constructions and corresponding drawings

Thirty-nine objects were constructed by the children and depicted in the drawings. Concerning static/dynamic we classed the constructed objects in three categories: *S* (structural) – mainly structures and static objects; *SD (semi-dynamic)* – including some mechanical and moving elements; *D* (dynamic) – including large mechanical compounds or even navigation capabilities for the whole artifact. A similar number of constructions (and drawings) of each type has been produced by the participants, about a third in each category (Table 1).

An example of a static object appears in Figure 5. The child built a tall tower – a fairly complex structure including the repeated use of one modular piece and symmetric design. All these are clearly visible in the drawing documenting the tower.

An example of a semi-dynamic construction appears in Figure 4. Attached to the static structure is a crane-like mechanism aimed to lift objects. The drawing of it is quite schematic, however emphasizing the core structural component of the dynamic compound, i.e., the gears. Children's verbal descriptions often unveiled aspects of their perceptions not included in the drawings. For the construction in Figure 4, the child explained: "I turn the stick then the gear turns as well ... the red piece does not move ... the 'fastener' grasps". Moreover, there is reference to purpose or functional aspects: "to catch fish ... to save someone from drowning ... I made a crane".

An example of a fully dynamic construction us shown in Figures 2, 3 and 7. In these artefacts all compounds (structural and dynamic) contribute to fulfill its defining function: to move and navigate in space. Correspondingly, the salient representational unit in the drawings are the wheels and axes, forcing their inclusion even in projections in which these would be out of sight.

Children are used to construct using many kinds of building kits at home and in the kindergarten. Thus, we can assume that they brought previous building schemas and knowledge into the task in our study. When faced with the free-construction (not directed) task, we can also assume that the inputs triggering the construction of semi-dynamic and dynamic objects were not only previous schemas but also the mechanical pieces at hand in the kits, e.g., wheels, axes, gears, hooks. These may have acted as cue for the inclusion of mechanical compounds in the objects and even for creating the whole construction (as in the cars).

Q2: Degree of accuracy in representing structural aspects

In this section we examine the extent to which the drawing accurately represents the construction. This includes an analysis of the level of detail, of proportionality, and whether all important details of the construction are represented including mechanisms and additional pieces (e.g., human figures).

Level of detail of the drawing

The degree of detail in the drawings ranges from highly-detailed (showing even the bumps on the LEGO bricks or details on the wheels), to these that only show the contour of the construction. Of the 11 sketches of static constructions, seven were contour-only and four were detailed (Figure 1). For nine of the 15 semi-dynamic constructions, the drawing show only outlines, sometimes a few bricks are represented. Other details such as holes in the blocks were scarcely drawn. In the more detailed drawings, particular prominence is given to mechanisms (Figure 4). Axles, hooks with ropes and gears do appear, even if the sketch is minimalistic. Most sketches of the dynamic constructions (9 out of 13) consisted of outlines. Four of them had more detail. Like for the semi-dynamic constructions - in these the moving parts are always shown, even if not in detail (Figure 7).

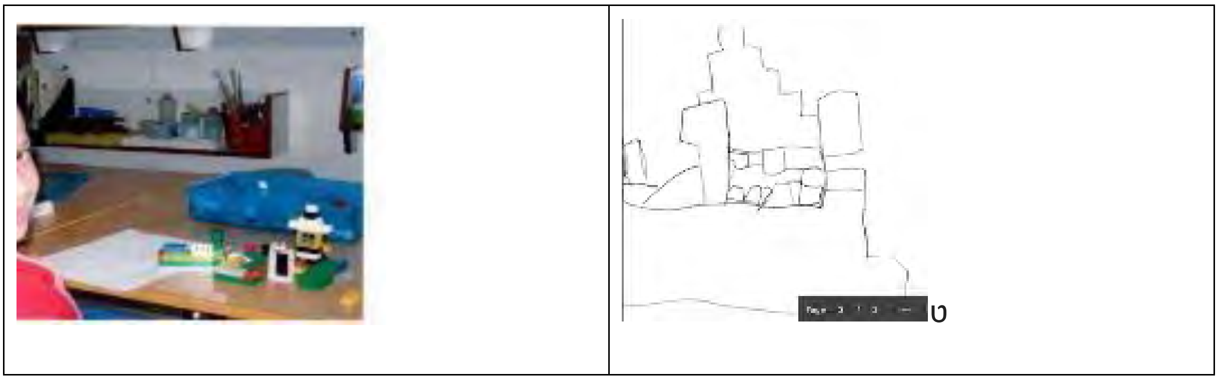

Figure 1: Sketch of a static construction – contour-only

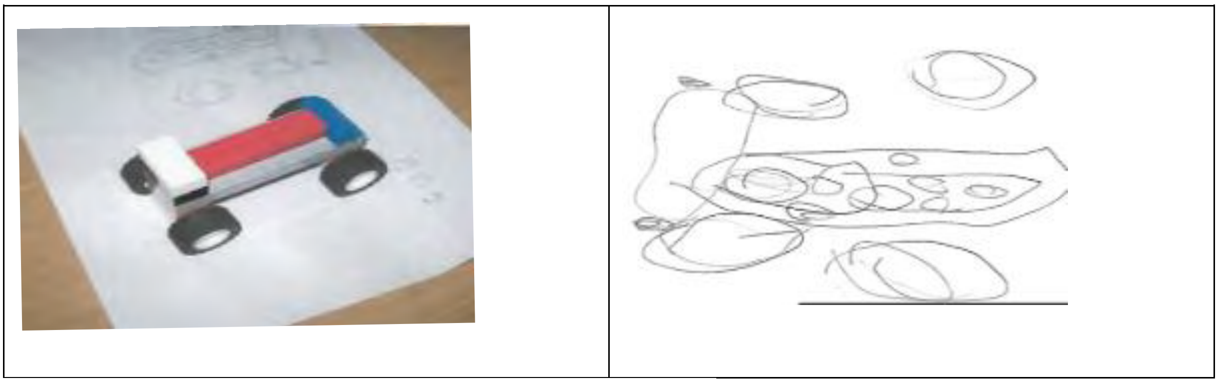

Figure 2: Sketch of a dynamic construction with details

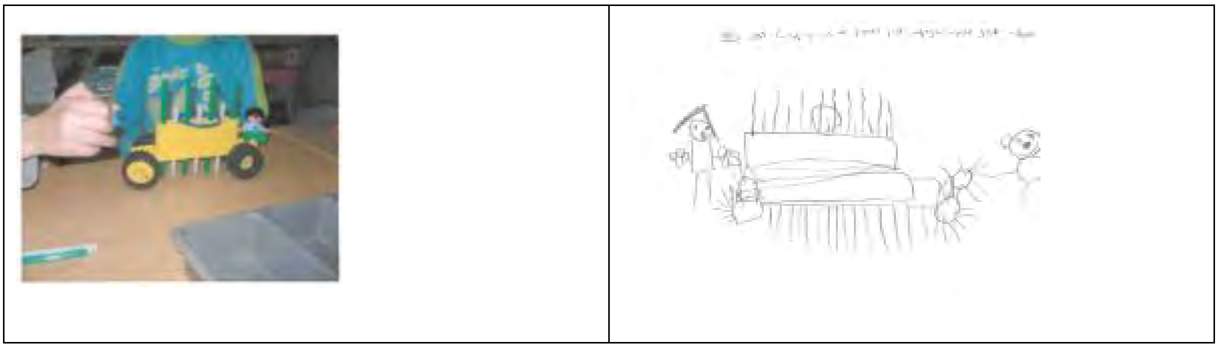

Figure 3: Side view of a car with four wheels

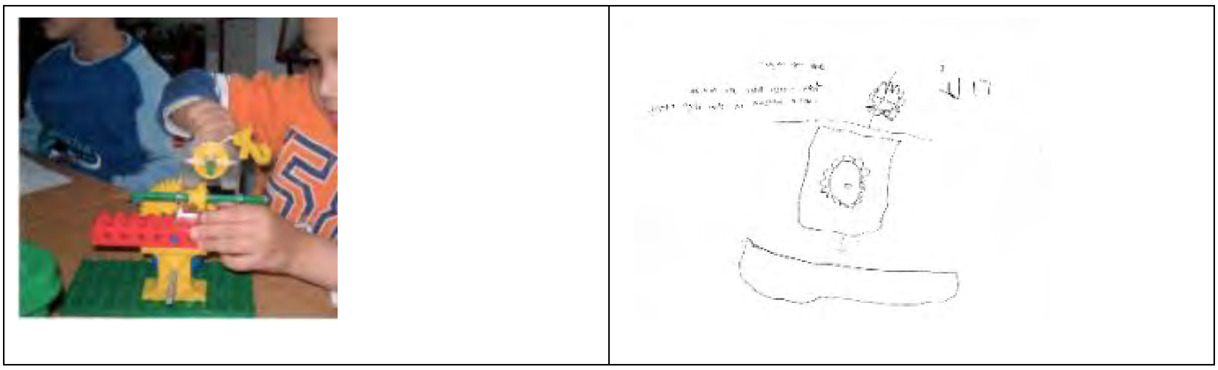

Figure 4: Sketch including a technological mechanism

Degree of accuracy of scale and proportion

Ten of the 11 static sketches showed accurate proportions between the different parts as well as between their size on paper and their actual size (Figures 1, 5). In all 15 of the semi-dynamic sketches the proportions matched the physical construction. In the sketches of dynamic artefacts, however, although the proportions between the parts were appropriate, if a human-figure was included, its representation was not proportional – either too small or too big.

Degree of accuracy in representing construction details

The extent to which details were included in the sketches was very varied, ranging from having only contours with no details at all, to very detailed drawings showing the gears teeth and bumps in the LEGO bricks.

All 15 semi-dynamic sketches portrayed the technological mechanisms, even when other elements were not fully detailed. In the dynamic sketches, the wheels always appeared as full circles, i.e., from a side view, even in the top-view sketches. Sometimes all four wheels were sketched, even though only two are visible from the side (see Figures 2, 3, 7).

Concerning the inclusion of human figures in the sketches - in the 11 static sketches only one has a figure both in the physical construction and in the sketch. In the semi-dynamic category, eight of the 15 physical constructions had a human figure and in seven of these the figure also appeared in the sketch. A human figure appeared in six of the dynamic constructions and their respective sketches. Moreover, one of these sketches included an additional figure (a passenger next to the driver) that does not appear in the actual construction.

Q3: Perspectives and projections in the representations

When drawing a 3D object, designers/engineers usually do so from a number of perspectives in order to accurately represent the object in its entirety, from all sides (Ferguson, 1994). In a single sketch one must choose an angle that better reflects the construction. Analysis of the sketches (see Table 1) shows that 18 of them show a side view and eight show a top view. The remaining 13 sketches comprise mixed views, i.e., looking at the construction from several angles or a combination of a side view and a top view. The sketches with mixed views always contained mechanisms, (i.e., they belonged to the dynamic and semi-dynamic categories but not to the static category).

By construction categories, we saw that in sketches of static constructions, 6 were drawn from a side view and 5 from a top view. In the semi-dynamic constructions' sketches, 7 out of 15 were drawn from a side view and 8 with mixed views. In the dynamic-construction sketches 5 were drawn from a side view, 3 from a top view, and 5 with mixed views.

Furthermore, the sketches of tall constructions were almost always drawn from a side view, whereas when the construction is flat the tendency was to show a top view.

The sketch of the tower (Figure 5) emphasizes its height and clearly represent its structural sections (a topic also mentioned in the child's verbal description). From above, this aspect of the construction would not be visible.

In sketches of constructions that are spread out and flat, the components and important parts can be seen only from above, as they are shown in the drawings. In Figure 6 (depicting a dynamic construction) though mainly a top view, all wheels were drawn from the side view.

Table 1: Constructions and drawings by category and view

Category / View	Side view	Top view	Mixed view	Total
Static	6	5	-	11
Semi-dynamic	7	-	8	15
Dynamic	5	3	5	13
Total	18	8	13	39

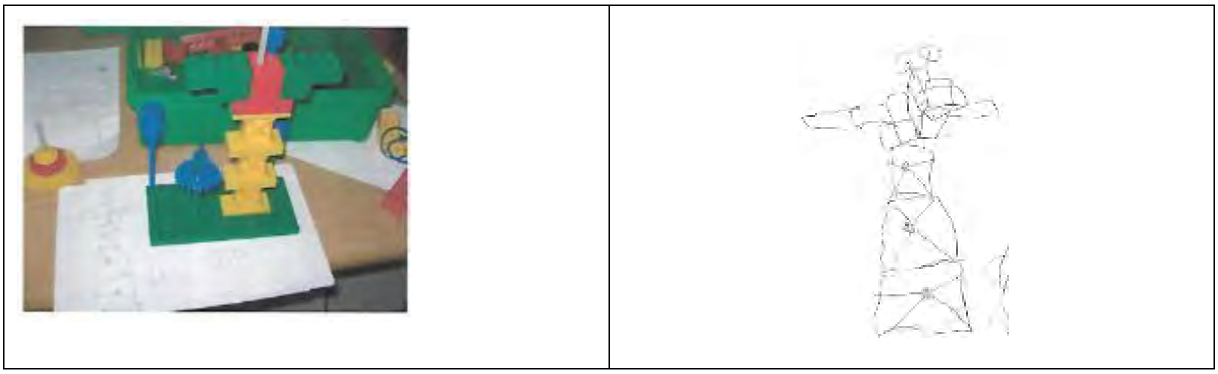

Figure 5: Side-view depiction of a static construction

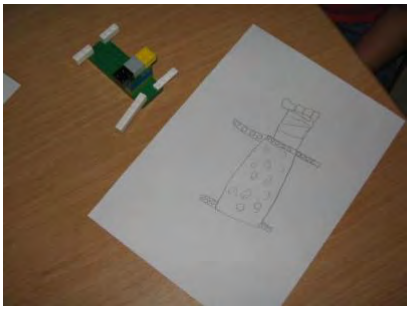

Figure 6: A Top-view sketch

Figure 7: Mixed-view sketch

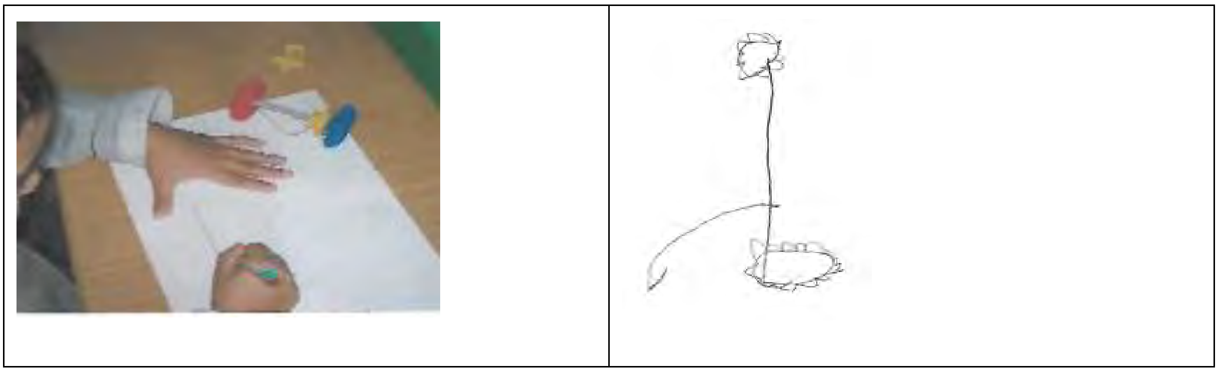

Figure 8: A simple construction that can be recreated from the sketch

Q4: The possibility to replicate the construction from the drawings

Analysis of the possibility to recreate the construction from the sketches showed that although some of are fairly accurate, even containing detailed information, it is hard to replicate the constructions from the representations of the objects. Evidently, the more components in the construction, the lower the possibility to reconstruct it. In fact, only three out of the 39 could be reconstructed solely based on the sketches (e.g., Figure 8).

Summary of key findings

With the purpose to bridge between the data level of the study (detailed above) and the discussion and implications level, we present in the following a mid-level (undetailed) summary of the data collected:

- Children's previous experience with building kits (e.g., building schemas and knowledge), as well as the presence of mechanical pieces in the kits (e.g., wheels, axes), affected their performance in the task and the constructions created.
- Drawings of S and SD constructions: mechanisms and compounds do appear and moving parts are always shown, even if not in full detail.
- Drawings of D constructions: Wheels and axes were the salient representational unit and were included even in projections in which these would be out of sight.
- Most drawings in all categories depicted the artefacts by their contour.
- Proportions: Most sketches showed accurate proportions between the different parts as well as between their size on paper and their actual size. The only exception were non-proportional representations of human figures.
- Accuracy and detail of the representations: a wide range of levels was observed, from contour-only and undetailed to highly detailed drawings.
- Projections: Sketches of tall constructions were usually drawn from a side view, whereas in flat constructions is the tendency was to show these from the top view. Sketches mixing viewpoints always contained mechanisms.
- Replication: For most sketches, we found hard to replicate the constructions from the drawings.

Discussion

Building and assembly activities have become a vital part of the kindergarten curriculum, due to their importance to the child's growth and development (Parkinson, 2017). In our study, participants were asked to document their free constructions in a 2D drawing - an activity

which requires a cognitive shift from three dimensional to two-dimensional thinking (McGarvey et al., 2018). Our findings suggest that drawing as means for documentation, which is not typically part of the kindergarten curricular repertoire, has implications for supporting the development of technological and engineering thinking as well as representational skills and strategies for functional (not only expressive) purposes.

As part of the activity, the children freely created 3D constructions and then represented them in 2D form. The process involved "translating" the mental image of an object (about to be built) into a 3D construction, then depicting the constructed object in a 2D sketch (Anning, 2008; McGarvey et al., 2018). In this type of "engineering" sketch, no decorative or secondary elements unrelated to core properties of the construction are included (Lane, 2018). The creation of the 2D depiction requires paying attention to structural and mechanical aspects and conducting iterations between the representation and the actual construction. It typically begins by focusing on the most important components, and then move on to the less important ones. In fact, children are abstractly representing their 3D constructions, using a novel and functional language for drawing - a representational mode that is not part of the regular kindergarten curriculum or experience. In the following, we discuss a range of strategies used by the children to cope with the challenge of representing a 3D object in a 2D sketch.

- *Choosing a view*. Representing a 3D model in a 2D drawing requires a choice of a view (e.g., top, side). We found that a side view was chosen mainly for tall constructions, whereas a top view was used for flat ones. Sketches with mixed views (side and top) were found mainly for dynamic constructions, e.g., these containing wheels, where the wheels were drawn as a full round circle, even when the rest of the vehicle was represented from a top view. Luquet (1927), noted that combining perspectives results from the conflict between wanting to show the wheels from the top and showing them in full. This can be viewed as an example of a problem-solving strategy, where the solution involves changing the vantage point and combining perspectives.
  The ability to imagine what an object would look like from different points of view is considered a core component of the multi-skill construct of human spatial ability (Eilam & Alon, 2019). Ackermann (1996, Pp. 5) pointed out that the perspective-taking ability involves "*objectifying one's own view of the object and anticipating that moving to another station point results in specific changes in its presentation. In other words, perspective-taking involves both differentiation and coordination of viewpoints*" while understanding that these relate to the same object. "*Viewpoints are lenses, and lenses transform reality in specific ways*" (Ackermann, 1996). Given the functional purpose of the drawing, children in our study chose "lenses" guided by their understanding of what core features of the objects should be drawn to represent it at its best (e.g., structural height, mechanical compounds). In addition, they used "combined lenses" if features pertaining to different vantage points were considered essential for representing efficiently the object (e.g., four wheels in a vehicle).
- *Representing proportions*. The accurate representation of proportions in both number and size, requires an understanding of relativity and scale (McGarvey et al., 2018). Luquet (1927), posited that young children are not capable of such understanding and that drawing each detail is independent, without conception of different items' relative sizes and distances from each other. In our study, most drawings show appropriate proportions when depicting parts of the construction (the only exception is the human

figure), indicating that children have at least a basic understanding of correct proportions.

- *Representing mechanisms and internal components*. The challenge faced by the children was how to depict the mechanism and its movement in a static 2D representation. We found that all the drawings of semi-dynamic constructions have representations of the dynamic mechanisms, and that the drawings of the full dynamic constructions included the elements enabling the whole artefact movement (e.g., wheels and tires). Since planning and constructing mechanisms and movement compounds require engineering-related thinking, their representation in the drawings might indicate children's awareness of the thinking/problem-solving processes that led the construction. For producing a sound representation, children's' drawing solutions included often-times what can be seen as "violations" of (correct) realistic drawing, e.g., inclusion of 'insides' or mixing views. Actually, these are resources that allow a better communication of the constructions features within the constraints of 2D drawing. Children are less worried about the correctness of the drawing than about its documentative/communicative function.
- *The social/functional layer* (the perceived reason d'etre of the artefact). It seems obvious that the object constructed has robust linkage with the child's inner world and life experience. Artefacts fulfill functions and these, as well as their representations, include components that reflect this linkage. A clear example in children's products was the incorporation of human figures (included in the construction kits) – apparently a non-necessary element as opposed to key structural or mechanical components. Where a human figure was included in the construction, it always was represented in the drawing as well. Actually, the human figure constitutes a connection between the child's experience and the construction. The figures play explicit social/functional roles: they are drivers, passengers (sit aside the drivers), or operators of the mechanical device. By incorporating this social/emotional layer to the constructions and drawings, these became objects for symbolic play and expression of children perceptions and thoughts about world situations. Un their verbal descriptions explicit allusion to functions fulfilled complemented the representation, e.g., "I've built a truck that collects bottles, classifies them and takes them back to the factory" ... "this is a 'grasping truck' – it grasps garbage cans and collects the garbage with the hook".

What do children know when they 'draw what they know'?

Almost a century ago, Luquet (1927) noted in his pioneering work, that young children solve the problem of representing 3D reality in 2D drawings through 'intellectual realism', meaning that children "draw what they know, rather than what they see". Only around the age of eight they reach the stage of 'visual realism' in which they can draw reality as is (relying on perceptual data). In the current study, we found that in contrast with Luquet's assumptions, kindergarten children (aged 5) do in fact show capabilities that correspond with the later "visual realism" stage. As well, in terms of Piaget & Inhelder (1971) theory of mental imagery development, we found that children were able to represent reproductive (R) static and kinetic (S, K) features of the artefacts at an earlier age level than the one in their stages' depiction. We suggest that these findings stem from the fact that in the activity in our research, children constructed their own 3D objects and then drew them - thus we assume that their mental image of the 3D object was loaded with a large amount of visual information gained during the construction phase.

Based on these observations, we would like to formulate a different interpretation of the claim: "they draw what they know". What do children know? Undoubtedly, as stated in most theories surveyed, children's mental images are the result of factors such as, e.g., developmental affordances and constraints; life experience (gained through the very immersion in an artefacts-saturated environment); internalization of social constructs (such as canonical or prototypical visual schemas); formal schemas acquired through schooling. However, taking a constructivist/constructionist perspective, in addition to the above factors "what they know" is conceived as a knowledge construction process in which the learner plays the crucial role of active constructor of her/his knowledge – emphasis on "active". What children know, instead of being molded solely by developmental forces, by schooling or the mere (passive) immersion in a nurturing environment, is the result of an active and interactive construction process.

Concerning our questions about the visual knowledge and schemas used by children to produce their drawings, we suggest that these are constructed in iterative process while dealing with the challenge of constructing the real object. In the process, a large amount of real-world knowledge is constructed. Thus, drawing "what they know" is no longer an inferior developmental stage on the way to the "higher" visual realism stage. In constructing the inner repertoire of knowledge and schemas while constructing real objects in the world, "drawing what they know" now becomes a very sophisticated and complex representational activity. Children know a lot, and they know what they know due to their intimate acquaintance with the represented structures and mechanisms (their own constructions), and to their active role as constructors of both their inner (in their mind) knowledge and the outer (in the world) object.

Concerning technical or engineering-like drawing, the above working hypothesis allow us to look differently at the representational resources and strategies used by the children. Unlike dree-form or creative expression tasks, the drawings in our study have to fulfill a functional goal: to document and communicate, to convey knowledge about the physical artefact previously constructed. As such, they ought to be informative about the essential features of the constructions. For example, the use of canonical or prototypical schemes is no longer relevant for describing the necessary features and details (structural, mechanical) of a working artefact. Hence, the importance of the resources used to represent these features, e.g., selection of appropriate views, of foci, of ways to unveil key features (even if these are hidden or not visible from the chosen view). In engineering drawings, these resources are praised as essential for advancing the design, planning, and actual construction of artefacts. For example, exploded views, showing numerous levels of "insides", or multiple projections of an artefact in the same drawing space, are consider legitimate resources in engineering processes (Ferguson, 1994). From this perspective, children's "violations" of supposedly perceptually correct rules, might be considered as their representational solution for producing a sound description of the construction.

Concluding remarks

A vast body of knowledge about young children's drawing has been produced for more than a century of research (e.g., Luquet, 1927; Piaget & Inhelder, 1971; Arnheim, 1997; Wilats, 2005). This impressive body of knowledge embraces many essential aspects, such as developmental paths, characterization of visuo-motor processes, detailed account of the drawings' features or of skills and strategies involved in drawing. However, most theoretical and research work

focused on children's free, intuitive and/or spontaneous drawing. And most data collection focused on children drawings of given objects, even their copy of drawings of objects, or on free representation of ideas or feelings.

In this study, we addressed two aspects that differ from the foci of previous work: (a) children draw what they have constructed; and (b) the drawing has a functional purpose (i.e., documentation) as part of a design task. We examined drawings within the context of a pedagogical approach that expands the experience of assembly and construction play in kindergarten and includes drawing for documentation and reflection purposes.

We are aware that this is only a preliminary study. Further studies are needed to broaden our understanding of this complex topic and to shed light into how this engineering-related drawing process contribute to the development of children's representational abilities in design tasks.

Further studies should focus on additional functional purposes within design processes, e.g., sketching for exploring ideas or elaborating on these with peers, drawing for planning a design, or for prescribing the actual construction of an object.

Additional research should also focus on children's drawing in more structured design tasks, were explicit requirements and constraints are part of the process.

Last but not least, an important venue of research should focus on the effect of functional drawing on the development of cognitive processes and skills linked to academic readiness for formal schooling.

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