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Understanding transfer from a dynamic system approach: Two studies of children using problem-solving tasks

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Abstract: Transfer is not static but a dynamic process of learning. In this article, the concept of transfer and the implications of its study are reconsidered from the theoretical basis of the complex dynamic system approach. We describe "transfer" as an emergent process that implies not a copy of knowledge applied to a new situation, but a new configuration of knowledge to solve new situations. Therefore, we discussed the concept of transfer based on the following dynamic principles: soft-assembly, multi causality, variability, self-organization, and iteration. To reconsider the concept of transfer, we provide empirical evidence, illustrating these principles by discussing two studies of transfer carried out with preschoolers. The participants were 34 children of 4 years old (M = 4,6), and 8 children of 4 to 6 years old (M = 5,2). Using repeated measure designs (3 weeks and 6 months, respectively), participants worked on sets of problem-solving situations in the domain of physics (i.e. Archimedes' principle and Air pressure). By using time-series graphs we identified the relevant elements of the tasks used by the children during the problem-solving process to analyze how this process

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PUBLIC INTEREST STATEMENT

The demands of modern society require people to be able of transferring knowledge to solve new situations within and between different domains of knowledge. From a complex dynamic system approach, this article rethinks the concept of transfer, leaving behind the idea of a mechanical result of applying previously acquired knowledge into a new situation. By presenting evidence of two empirical studies with children (4- and 8-year-olds), transfer is analyzed in the contexts of problem-solving tasks in the domain of psychics (i.e. Archimedes' principle and Air pressure). The findings suggest transfer as a dynamic self-organized process, instead of a static result of learning. Transfer emerges as a constant update of knowledge, based on context, and children's task comprehension. Transfer emerges as a dynamic and variable process, which depends on constant updating of knowledge, based on the context, and children's task comprehension.

changes over time. Results show transfer as a self-organized and context-related process in which the information is not static but in constant transformation.

Subjects: Cognitive Psychology; Educational Psychology; Theories of Learning

Keywords: dynamic systems approach; preschoolers; scientific reasoning; transfer of learning; problem-solving

1. Introduction

In modern society, a goal of educators is to provide experiences that allow students to think deeply about concepts and to develop skills, more than repeating information. The focus is on guiding students to apply learning in meaningful ways through different domains (Acedo & Hughes, 2014), considering that one of the essential aims of education for the 21st century is to foster the learners' abilities to transfer knowledge and skills to new situations (Pellegrino & Hilton, 2012). Therefore, the challenge for teachers is to generate the proper conditions for children to be able to successfully generalize their learning and skills to new scenarios and problems (Bransford, Brown & Cocking, 1999; Brown et al., 1989; Donovan & Bransford, 2005). This ability to learn from a particular experience and apply the knowledge gained to a different context has been called transfer (Singley & Anderson, 1989). The study of transfer is particularly interesting in children at preschool and primary school because they are in a critical period of the learning and development. At these ages, children construct basic knowledge in different domains to respond to educational and real-life demands. They are acquiring an understanding of new concepts and notions related with their physical and social context (Zimmerman, 2007; Rogoff, 1990, respectively).

Before introducing our dynamic approach to transfer, in this section, we will present the contribution to the study on transfer from the approaches of analogical reasoning, situated cognition, and constructivism. Finally, we will present the main limitations of the reviewed approaches, and finally, the introduction of an alternative dynamic approach to overcome these limitations.

In general, the literature on children's ability to transfer is dominated by the *Analogical reasoning approach*. According to this approach, analogical reasoning occurs when learners solve a new problem based on what they already know about a related problem (Gentner, 1983; Holyoak, 2012). This process requires at least two situations that share common properties to be considered analogous. Thus, initially, there is one analog, called the base or the source, and a second analog that is called the target. This analogical learning involves four different sub-processes: (1) Access to the base domain, in which the target serves as a retrieval clue to the source; (2) Mapping, where the learner establishes the correspondence between the base and the target; (3) Inferences, where the learner makes inferences about the target; and (4) Extracting commonalities, in which the learner extracts the common elements between base and target, generating new knowledge in the form of an abstract scheme, relational generalizations, of these extracted commonalities (Gentner, 1983; Holyoak, 2012). Then, for these approaches, the essential features of transfer rely strongly on the assumption of internal representations of problem-solving situations, on active comparison of the properties of those situations, and on the active perception of similarities.

In contrast to the previous theories, the situated and constructivist approaches constitute a change in the view of learning and transfer, including a more dynamic perspective of transfer. From a *Situated approach*, the transfer is explained in terms of actions and affordances. From this perspective, during initial learning, the learner is responsive to the affordances (action opportunities provided by the situation) of the learning situation. An affordance is defined as a property of the environment, which is directly perceived by an organism, in terms of a specific action opportunity, given the organism's possibilities for action. Thus, if the potential transfer situation presents similar affordances and, the person recognizes them, the person would apply the same, or adapted schema there (Greeno et al., 1993).

The *Constructivist approach* suggests that a form to promote transfer of learning, is by fostering learning with understanding more than memorization, an abstraction of knowledge, attention to critical elements during the learning situation and use of previous learning experiences (Bransford, et al., 1999; Bransford et al., 2006). From this approach, we infer that a key aspect to promote transfer is related to the generation of flexibility in the use of knowledge. As a result, the information to be transferred might be contextualized in a problem-solving situation instead of being introduced in an abstract way to the learner. In addition, it is possible to foster transfer by using the same knowledge in different settings and giving the learners an active role during the process (Renkl et al., 2010). This interpretation of knowledge is aligned to a dynamic view of knowledge in which their implementation consists of a soft-assembly process (see Thelen & Smith, 2007).

Irrespective of the theoretical stance taken, studies about children's ability to transfer present the following relevant findings: first, the studies have shown that children successfully solve problems of transfer when they are able to base their performance on structural similarities with previous knowledge. Second, preschool children have more difficulty to transfer knowledge in new situations than six to 7-year-old children (e.g., Kim & Choi, 2003; Tunteler & Resing, 2002, 2007a, 2007b). Third, preschool children need scaffolding support to think analogically and transfer knowledge in an effective way (Chen, 2003). Fourth, children from 3 to 7 years of age rely more on surface similarities between learning and transfer situations to transfer (Tunteler & Resing, 2002, 2007a). Finally, studies focused on training on working memory and its impact on near and far transfer, show significant effects on children´s near transfer, and no significant effects on far transfer (Sala et al., 2019).

However, we claim that the theoretical approaches presented above, have three underlying limitations, due to the conceptualization used. One consists of conceiving the use of knowledge as a static entity, in which transfer is seen as a carry-over process from the learning context to the new situation (Structure-Mapping Theory of Gentner, 1983, 1989). From this perspective, transfer assumes a reduced and limited perspective of learning, which does not consider the possible transformation of learning but instead relies on a "static" entity-based representation—(it means a kind of replica or transcript)—of knowledge that is applied in a new context (Carraher & Schliemann, 2002; Larsen-Freeman, 2013). The implication of this static view of transfer is that learning is understood as a finished process, in which the outcome of knowledge is available to be used in new situations. For instance, as an illustration of this view, we can mention Thorndike and Woodworth (1901), with the Theory of identical elements; the Structure-Mapping Theory of Gentner (1983, 1989)); and the Constraint-Satisfaction Theory of Holyoak and Thagard (1989).

The first limitation (static entity view of knowledge) is clearly demonstrated in the common methodological approach of many studies on transfer in children, which is based on the paradigm set by Gick and Holyoak (1980) in their seminal work about transfer. The design consists of a learning phase and a subsequent transfer phase, where children demonstrate their ability or not to use the information previously presented during the training phase (Chen, 2003; Kim & Choi, 2003). For example, Chen (2003) with 5-year-olds, used tasks on analogical problem-solving, which consisted of presenting a set of drawings to the children during the training phase, where the procedure and tool to solve the problem were displayed. Then, during the testing phase, children were required to apply the information presented in the drawings in a new task that involved actions to solve a physical problem. As a result, this procedure guarantees that learning occurs during the training phase, necessary for applying the acquired knowledge in a transfer phase.

A second limitation of the concept of transfer in the existing theories lies in its being conceived of as a separate process of learning instead of a fundamental feature of it. This implies that in a learning process the knowledge is built—or acquired—in the form of an entity that remains without being modified until later, to be used for future purposes. For that reason, to ensure learning, the training phase usually includes several attempts. In contrast, the transfer phase consists of a single measurement, since it is expected that the resulting knowledge of the previous phase can be transferred immediately and permanently to new situations (Klauer et al., 2002; Roth-van der Werf et al., 2002; Tunteler & Resing, 2002, 2007b, 2010). For instance, Tunteler and Resing (2002) presented a procedure used during the learning phase in a story, and then children had to apply it to a new problem. The results showed that four-year-old children solved the problems analogically when they were exposed to six sessions of practice, and not when they were exposed to only two sessions. This procedure assumed that the subjects have acquired the new ability to recognize that a new situation is similar to a situation given in a learning phase, including the ability to apply their knowledge/strategy acquired in the learning phase.

The last limitation is related to the evaluation of transfer, in which the performance of the learner is categorized in terms of the presence or absence of the transferred knowledge. In the reviewed studies, transfer has been successful if the participants are able to achieve the goal of the new situation (Chen, 2003; Kim & Choi, 2003). For example, in the study of Chen (2003), from the learning to the transfer phase, there was a change regarding the modality of the problems, from observing pictures in a story during the training phase, to executing actions to solve a problem during the transfer phase. A score of zero was assigned if children failed to solve the problem, and a score of one was assigned if the children's actions were like the solution depicted in the pictures (e.g., "removed a bear from a tube by attaching two sticks" (p. 422).

The disadvantage of this kind of design is that the performance of the participants on the tasks is evaluated in terms of success or failure. This approach of analyzing transfer as a final state does not allow to unveil the complete process and emergence[1] of transfer in real-time (i.e. the consideration of the task's restrictions, the evaluation of the performance in relation to the goal, and moment-to-moment adjustments of the actions).

Some researchers have pointed out these limitations of the conceptualization of transfer, and suggest that it is not a static process, but a fundamental part of the learning process itself. In this regard, Carraher and Schliemann (2002), consider that Piaget's notions of assimilation and accommodation imply a conception of learning as "crafted from a wealth of previous learning experiences" (p. 5), which seems to be a more suitable than a product- or result-(failure versus success) oriented view on learning. Additionally, Larsen-Freeman (2013) and Nokes (2009), argue that transfer cannot be considered as a mechanical procedure of exportation of knowledge, but as a continuous process in which knowledge is transformed. In summary, these authors argue that the limitations in the studies on transfer demand to re-think the conceptualization of transfer in the framework of learning and its changing and transformational nature. Therefore, if we consider learning as a dynamic process, it also demands a dynamic approach to explain how it happens. In the following section, we will describe transfer from this approach.

1.1. Transfer as a dynamic process

The study of learning—as a fundamental element of development—has been approached from different conceptual frames and the theory of complex dynamic systems is one of the most contemporary ones. This approach claims that developmental (macro-level) and cognitive changes (micro-level) can be considered as the result of a continuous *soft-assembly process* between the individual and the context (see Kloos & van Orden, 2009). It means that cognitive functioning emerges as a situated state (see further) of the dynamics between the individual and the properties and contingencies of the context. In this regard, Stephen and Dixon (2008) conceive of the problem-solving process as an open system in which self-organization emerges as a result of the exchange between the individual and the problem task (individual-environment). For these authors "self-organization" is the means by which a system shifts into a new configuration (p. 79) or into an emergent property of this particular dynamics.

In addition, soft-assembly suggests that human behavior is critically situated, "linked to the immediate constraints of the task context" and at the same time provides a "coordination across multiple scales of time and space" (Kloos & van Orden, 2009, p. 259). Then, learning adjusts over time, depending on the contexts and situations that actively participate in the learning, such as the reciprocity between the individual and the situation's demands (i.e. physical, psychological, and social). For instance, the sequence of moves of a chess player emerges according to the positions of the chess pieces on the board, the rules of the game and the level of expertise of the player and his or her contender. In terms of the timescale, the movements occur in the form of a short-term coordination, changing at a rate of seconds and minutes, while the long-term timescale refers to the future games of chess and their development of strategies over time. Therefore, human behavior is seen as a complex process of ongoing reciprocal coupling between perception and action in a context that actively contributes—through the person's specific perceptions and specific actions—to the emergence of an activity pattern in real time, and to the emergence of a developmental process on the long-term timescale. Also, there is a reciprocal coupling between the long-term and short-term timescale just as there is a reciprocal coupling between perception and action in the events on the short-term timescale.

The theory of complex dynamic systems has been applied to the study of long-term developmental processes. However, it has also been used to explain short-term changes, changes in micro-development such as learning processes (see Guevara, et al., 2016; van der Steen, et al., 2019; van Geert, 2019). In both cases, the understanding of development and learning could be based on the notion of a system which is governed by the following principles: multicausality, variability, self-organization, iterative process, and nested time scales, among others. *Multicausality* denotes the fact that there is not a unique focal and unidirectional process; instead, it has multiple possible elements that are reciprocally causally linked as a causal network. As an example, we can consider excellent levels of performance in sports. Author et al. (2016) explain excellent performance as a multicausal and dynamic network that emerges as a result of the reciprocal interaction of the individual with a great number of—often highly variable—factors such as genetic and epigenetic factors, motivation to improve his or her performance, high-quality practice, and coach support.

Strongly related to multicausality, *variability* denotes a property that can take two forms. One concerns the fluctuation in single developmental paths (within-individual variability). The second one concerns the differences between individuals (inter-individual variability), which could be termed as "multiplicity of developmental paths" or "multiplicity of developmental pathways." Variability is the rule rather than the exception, it is an intrinsic property of human development. For this reason, it has been identified as the main characteristic of human nature (Coyle et al., 1997, van Dijk & van Geert, 2014; Guevara, 2015; Vallacher, et al., 2015). S*elf-organization* is a property in which the interactions between the components of the system spontaneously lead to an increase in the system order as a "whole." Self-organization can occur at different and interrelated *time scales*, for instance, from seconds, minutes, hours, and years (van Geert, 1994, van Geert & Steenbeek, 2005). It implies the emergence of multiple attractor states or self-maintaining states to which the system evolves given the rules or principles that govern its dynamics at a particular moment in its current activity, or at a particular moment in its developmental history. Evidence of this property is the emergence of one or multiple attractor states. For instance, in a dyad of children solving a marble track or a balance scale, we can observe different types of interaction (i.e. No work, Imitate the work their partner, work passively, or work collaboratively) and related patterns of dyadic interactions (i.e. Distributed Dyadic Interaction or Unequal Dyadic Interaction) as a result of the dynamic relation of the children, the task, and the general context. (See Guevara et al., 2017; van Dijk & van Geert et al., 2014). Therefore, the fluctuation in the children's interaction is the result of a dynamic intertwining of continuously changing endogenous and exogenous variables such as the current experienced complexity of the task, the level of engagement of each child with its partner and the task, etc.

These dynamic principles can be applied to the study of transfer, as far as we conceive of transfer as a cognitive process that emerges in real time, in the relationship between the learner and the task context. *Iterative process* indicates how the system evolves over time because of repeating processes, in which each state of a system is a function of the preceding state. For instance, in a classroom context, an iterative process can be seen in the cycle of teacher-students' interactions, or child–child interactions, in which each response of the teacher/child is the result of a previous interaction (See Geveke, 2017). This reciprocal causality that is repeated over time is at the same time the result of the self-organization process of the system.

If we adopt a complex dynamic approach to study transfer, it is necessary to reconsider the classic concept of transfer. From the complex dynamic systems approach, we conceptualize transfer as a real-time *process* resulting from the emergence and *self-organization* of previous and new knowledge. From this point of view, transfer takes place as the adjustment of knowledge to the demands and constraints of a new situation. Stephen and Dixon (2008), characterized the flexibility of human behavior in the context of problem-solving, as the "adaptation of our behavior so as to anticipate and control outcomes, spontaneously generating novel solutions to problems" (p. 73). In this respect, it is important to notice that the knowledge is not a state that remains latent until a new situation appears. Instead, knowledge is in constant transformation. For instance, once the learner faces the challenge of a new situation, a *soft-assembly* process takes place in the real-time interactions with the context. The constraints of the task, as well as the cognitive skills and knowledge of the learner, influence each other in an iterative process. As the new situation presents new features, the learner might establish criteria about the relevant aspects of the task and about the respective actions to solve it. This is possible, mostly due to the online self-organization and self-assembly process, which is not the result of a pre-deliberation of criteria, after which the "right" action is selected and carried out.

For instance, in this respect, van Dijk examined patients who had to learn to use prosthetic limbs after surgical operations, and he wanted to know to what extent exercises in the form of video games transferred to the use of the prosthetic limbs in realistic contexts. In a study about action systems, Van Dijk (2016) examined how motor skills used in a video game task (myo games based on gestures recognition) will transfer to a prosthesis use (i.e. grasping task). The author shows that transfer on a new task can be affected by the subject understanding the task goal. If the goal is not clear to the subject, the performance could be more exploratory and focused on overcoming physical constraints. In contrast, if the subject understands the goal, and identifies the task-relevant information, the performance is focused on the functional calibration to attain a goal, resulting in a more global and dynamic relation with the task. In this case, transfer is more likely to emerge; Van Dijk (2016) calls this "functional calibration." In words of van Dijk (2016, p. 45), "task-relevant distinctions emerge on the basis of anatomical constraints (…) This implies that when the goal of the task is still unclear and the learning process is dominated by exploration for, rather than calibration to, information, the task might be partly distinguished by the anatomical components used." Finally, it should be noted that through exploring and calibrating, action systems develop that fit to specifics of the task.

From our perspective, the problem of prosthesis use provides an illustration of a soft-assembly process in which the performance is adjusted in relation to the interaction of the individual with the comprehension of, and relations with the task components. Therefore, in the process of motor learning, the calibration—(as soft-assembly process)—to the perceptual information is "functional" and independent from the "anatomical components" due to transfer taking place in terms of using the availability of task-relevant information.

Regarding the issue of *variability*, it can be shown that during learning, the performance takes place in the different attempts to solve a problem and is nested within different time-scales (e.g., brain activity happening in milliseconds, concrete activities carried out with materials and/or peers over the course of minutes, learning process emerging in minutes, hours, or days and developmental processes evolving over months and years). The variations in individual performance to solve a problem can change at slow or fast pace over time, depending on the comprehension of the task elements and the relation between prior experience or knowledge and the new target situation. For instance, let's think of people's performance with different levels of expertise trying to solve problems in different situations, to communicate in a second language, to score a goal in soccer, to follow steps dancing with a group, or solving a crossword puzzle. In these cases, in every attempt to solve the situation, the learner obtains and continually updates information about the elements of the task (if relevant or not), their constraints (if violated or not) and tasks demands (identification of sub-goals and their sequence) as well as about the learner's performance (if the goal was achieved or not). During these information loops, the learner adjusts his or her performance and updates the combination of elements that he/she considers relevant to the solution, for which the history of previous attempts is crucial. As a result of this, the sequence of attempts on the task can reveal iterative actions (*iterative process*) and different outcomes in performance (*multicausality*), or similar outcomes obtained through different means (*variability*). In summary, we shall define transfer in dynamic systems terms as a process of ongoing functional calibration to the demands of tasks and sequences of tasks, which is self-organizing and emerging during iterative interactions between task properties, past and current experiences, peer collaboration, adult instruction, and so forth.

1.2. Description of the current study

In order to understand transfer from a complex dynamic systems approach, the study of transfer should differ from the way it has been studied given the classical theories, in the following two aspects: (1) Conceptually, transfer should be conceived as a contextually related process instead of a static state of knowledge or fixed content that can be isolated from the learning process, and that is mechanically transferred from one situation to another. Therefore, transfer occurs not only because of similarities (analogies) between tasks (perceptually), but also, and primarily, as a structural and dynamic relationship between task elements that are adjusted on the spot. In addition, we suggest transfer as a property of the learning process that might be characterized by its variable nature and its temporal structure (see Guevara, et al. 2017). (2) Methodologically, the procedure to study and analyze transfer requires a follow-up of the history of the learner's performance. Therefore, a repeated measure instead of a single-measure design is required to track the adjustment of knowledge to new situations during the transfer process across a sequence of problem-solving occasions. Also, more open tasks are required to observe children's actions and, in this way, to uncover the flexibility and adaptivity of their thinking process. Moreover, problem-solving involves a process of inquiry in which the learners enact hypotheses in their ongoing activity and/or explicitly formulate hypotheses about the possible ways to solve the problem. Through individual actions, (carried out physically or mentally, in the problem context, they could test their hypotheses and reach their context-specific goal.

In this study, the main purpose is to suggest a dynamic approach that recognizes the complexity of learning and how it takes place in real contexts. For this purpose, we present an illustration consisting of two empirical studies with preschoolers. The two studies presented in this paper examine the following research question: *How does transfer emerge in preschool children during aproblem-solving about physics?* Specifically, study 1 examines transfer in 4-year-old children, by using a problem task about Archimedes' principle. Study 2 examines transfer in dyads of children of 4 to 6 years by using a problem task about Air pressure.

2. Method

The two studies presented in this paper examine how transfer emerges in children between 4 and 10 years old solving problems about physics (i.e. a set of tasks about *Archimedes' principle*, and a set of tasks about *Air pressure mechanisms*). Using repeated measure designs, each study examines transfer as follows:

Study 1,[3] about Archimedes' principle, examines transfer in a group of 34 four-year-old children using a multimedia format. Children were exposed to several problem-solving sessions, which contained a familiarization task, an animated cartoons task with three attempts, and a photograph task with two attempts. In this task set, children needed to help the characters to solve a problem that implies the understanding of Archimedes' principle.

Study 2,[4] about the notion of Air Pressure, explores transfer in a multiple case study of four dyads of 5-year-old children using hands-on tasks about air pressure. This set of tasks examines whether the transfer of scientific reasoning spontaneously emerges in a repeated design. In order to examine if transfer takes place in a more natural context as it supposed to happen in real life, in this study, the conventional "learning phase" of training learners to solve the task, was omitted.

2.1. Study 1—Archimedes' principle

2.1.1. Participants

In the original study (Rojas-Ospina, 2013) the participants were 34 children. From this sample size, the data from 17 participants, from the active problem-solving condition, were used for the analysis performed in this study, as can be seen in the results section of this manuscript (Figure 3, page 27). The participants of this study were 17 four-year-old Spanish-speaking children from Colombia (8 boys and 9 girls, M_{age} = 4,5 years). The children were recruited from private schools and daycare centers located in a middle-sized city in Colombia. Children at these schools and daycare centers have access to computers on a weekly basis during the school year. Children's participation was subject to parental as well as child consent forms.

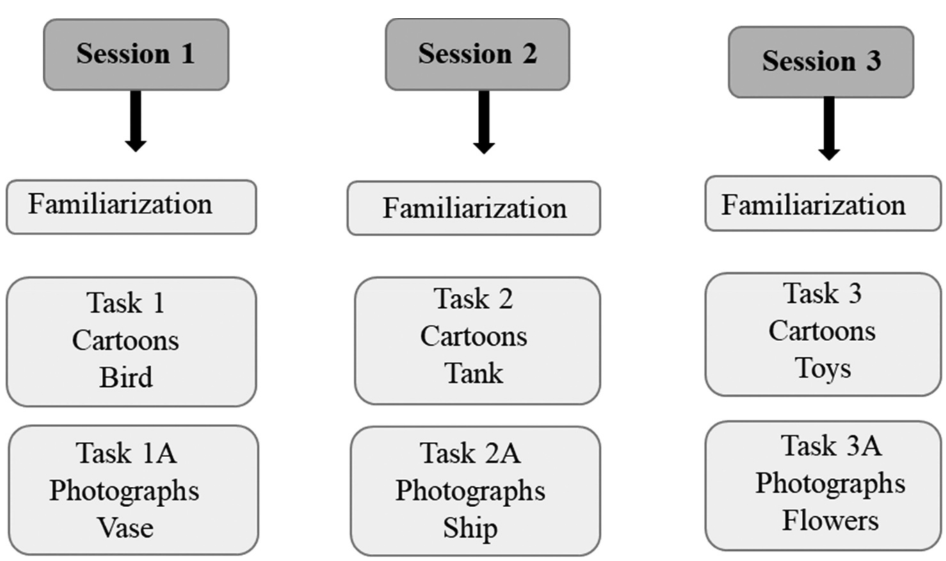
2.1.2. Design

A repeated measures design consisted of six task version were presented in a period of 3 weeks with three sessions, that were spaced 1 week apart. In each session, children were asked to solve two tasks and were exposed to one attempt during familiarization, which was a simple activity to ensure that children understood the instructions. Then, three attempts using animated cartoons, in which they can obtain more interaction with the activity. Finally, two attempts using photographs, in which the level of interaction with the task was more restricted than the previous phase. Each session involved to solve different problems that required the Archimedes' principle (See Figure 1 and Appendix 1).

2.1.3. Materials

With the name *Archimedes Start*, a set of six tasks using a multimedia format were created for the study; three tasks used animated cartoons and the other three tasks used photographs of real-life people. Based on the work by Tunteler and Resing (2002, 2007a, 2007b), the story chosen was one that

Figure 1. Schematic design of study 1.



addressed some attributes related to the Archimedes' principle. In addition, new tasks were designed using Archimedes'principle in order to achieve consistency among tasks through the entire process.

Animated cartoons tasks consisted of three stories presented as a problem-solving situation in a multimedia format (audio, images, and animations). Each story is about a character(s) who is (are) having a problem, so the child is asked to help the character to solve it (See procedure).

Photograph tasks consisted of three stories presented in a multimedia format (audio and photographs). In each story, the children are asked to help the people in the photos to choose the best objects to solve the problem they are facing by using the Archimedes' principle (See Appendix 1).

2.1.4. Procedure

In each session, the tasks set was presented using a laptop, with the following sequence: 1) Familiarization, 2) Animated cartoons tasks with three attempts, and 3) Photograph tasks with two attempts. The data collection took place in a quiet place, in the children's school or daycare center. Each session lasted between 20 and 25 minutes. The children's performance was recorded by multimedia software Archimedes Start, designed for the study.

2.1.4.1. Animated cartoon familiarization task. Consisted of presenting a small and simple task that children had to complete in order to continue to the next screen of the task. The purpose of this activity was to familiarize children with the different objects in the problem situation. In the activity, children were asked to help a character (e.g., a hippopotamus) to get water to take a shower. Children needed to drop objects in the tank in order to raise the water level, and therefore, displace water from one tank to a contiguous one, where the faucet was placed. In this activity the children have access to six objects, and they had the constraint of using a maximum of three objects to solve the problem. Once the child had tried at least once to solve the problem, he or she could proceed to the next task.

2.1.4.2. Animated cartoon tasks. It consisted of three versions of the same problem in which the child had to help the character to solve the problem with 18 objects. The task's constraints were: to use up to three objects during each attempt, regardless if it was the same object three times, or three different objects, and to perform three attempts. These tasks presented a sequence of events with four phases: 1) the introduction of the situation (e.g., a bird is flying); 2) the presentation of the problem situation (e.g., the bird finds a bottle with water, but cannot drink because the level of the water is too low); 3) the process of problem solution by the child (e.g., select the objects that will help the bird to raise the level of the water in the bottle); and 4) the reaction of the character depending on the outcome of the problem solution (e.g., the bird is happy because he could drink the water).

2.1.4.3. Photograph tasks. It consisted of two attempts of the same problem in which the child had to help the character to solve the problem with 18 objects. The task's constraints were: to use up to three objects during each attempt, regardless if it was the same object three times, or three different objects, and to perform three attempts. These tasks presented a sequence of events with four phases: 1) The introduction of the situation (e.g., a lady receives a beautiful flower); 2) The presentation of the problem situation (e.g., the flower is in a vase, but it cannot reach the water because the level of the water is too low); 3) The process of problem solution by the child (e.g. select the objects that will help the lady to raise the level of the water in the vase); and 4) An expression of gratitude from the person in the photography (e.g., the person is smiling).

2.2. Study 2—air pressure

2.2.1. Participants

The participants of this study were eight preschool children between 4 to 6 years old (3 boys and 5 girls; M_{age} = 5.2 years). The children were recruited from a school in the Netherlands. Children's participaton was subject to the informed consent of their parents. The children were paired with

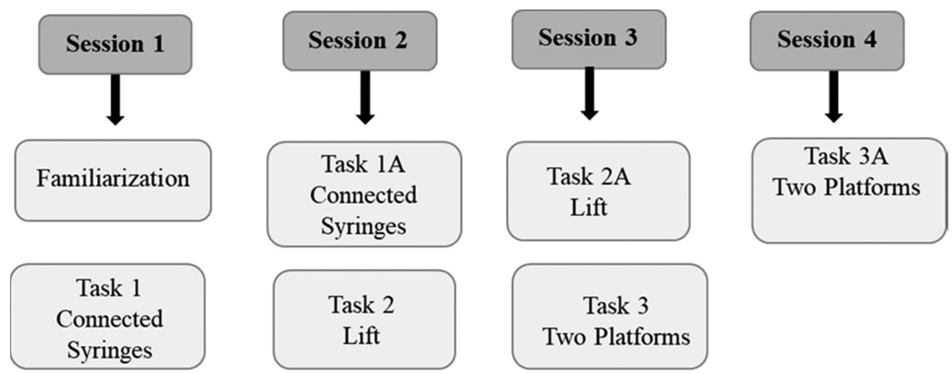


Figure 2. Schematic design of the repeated and overlapping procedure used in study 2.

a classmate (with a friendly relationship). As a result, four dyads were conformed based on the age criteria.

2.2.2. Design

A repeated measure design was used in a period of 6 months. The experiment consisted of three sessions, which were spaced 2 months apart. The tasks were presented in an overlapping design, introducing two tasks per session. Therefore, in each session, two tasks were presented: the last task introduced in the previous session and a new task. The dyads were given the opportunity to perform several attempts per task. Each task was presented for a second time two months later (See Figure 2 and Appendix 2).

2.2.3. Materials

In the context of an air pressure mechanism, a familiarization task and a set of three hands-on tasks (connected syringes, the lift, and the two platforms) increasing in difficulty were used (see Appendix 2). The tasks were available on the market as wooden toys. Regarding the task features, despite their perceptual difference, the tasks shared the same structure in terms of problem-solving: (1) each task required to reach a goal, (2) each task required the identification and use of similar key elements to get the solution, and (3) each task implied a mechanism of air pressure. In general, each task consisted of one container of air (syringes of different sizes or a pump), and tubes with different lengths (short, long) and shape (straight, Y shape). The solution of all the tasks, demanded from the children to build an air pressure mechanism to get the goal. For instance, to raise the plunger of a target syringe until a certain level, to lift an arm platform, and to raise a platform to a certain height.

The set of air pressure tasks makes it possible for the children to combine various elements. However, only a combination of key elements guarantees the success on the task.

2.2.4. Procedure

The data collection took place in a quiet place, in the children's school. In the presence of the researcher, each dyad worked independently in a classroom of the school. Each session lasted between 20to 25 minutes. The performance of the dyads was video recorded for all sessions. The sequence of the presentation of the tasks was the same for all dyads: Familiarization task (T0), connected syringes (T1), lifts (T2), and two platforms (T3). In the familiarization task, children were asked to explore some tubes and syringes in order to discover how they work (e.g. "what is this?," "do you know how it works?). Once the children had explored the material of the familiarization task and discovered the functioning of the syringe (i.e. pulling in and pulling out the plunge), the experimental task was presented.

In the three experimental tasks (T1 to T3), children had available several materials. They were asked to work together and find the best way to reach the goal. The protocol in this case leads the

Table 1. Number of key elements provided by each solving problem task

Study	Task	# Key elements	Total Elements per Task
Study 1 Archimedes Task	T1—Bird	3	18
	T1A—Vase	3	18
	T2—Tank	3	18
	T2A—Ships	3	18
	T3- Toys	3	18
	T3A—Flowers	3	18
Study 2 Air Pressure Task	T1, T1A—Connected Syringes	3	7
	T2, T2A—Platform Lift	3	7
	T3, T3A—Two platforms	3	7

children through two main steps: (1) the selection of the task elements, and (2) the experimentation with the elements to get the goal. After performing several attempts to solve the first tasks, if the dyad failed to solve the task problem within 12 minutes, a second task was introduced.

2.2.5. Coding scheme used in studies 1 and 2

In order to characterize the problem-solving process between tasks, three criteria were considered in both, Study 1 and Study 2. The categories were as follows: *not using a key element* (NK), *using a key element of a previous task* which is incorrect for the current task (PK), and *using a correct key element for the current task* (CK). Table 1 describes in detail the characteristics and key elements for each study.

According to the previous criteria, the success of transfer of the problem-solving process was considered not because children used an identical procedure from one task to another, but because they were able to adjust their procedure according to the new demands of the current task (i.e. restrictions, rules, and goal).

For studies 1 and 2, the same procedures of analysis were carried out as follows:

2.2.5.1. Analysis of the percentage of achievement in the problem-solving process. Because tasks and task elements differed in both experiments, the level of achievement was determined using the key elements required to the solution of each task. The key elements correspond to the selected materials that in each task lead successfully to its goal. For this reason, we calculated the proportion of key elements by attempt. For instance, in the Archimedes' task, children had three different objects to choose from, but the best object (key element) to solve one of the problems was only one (i.e.a stone).

2.2.5.2. Analysis by criterion used to solve the problem (key elements*).* Based on the three categories of the kind of elements used to solve the problem (NK, PK, and CK[2]), we calculated the proportion of use of these categories per attempt and per task. As a result, we show how children used their previous information into the new situations in different ways. For Instance, such as using none of their previous experiences in a similar task, as in a more exploratory action to solve the problem. A more advanced approach would be when children are able to use an element used previously, but it does not allow them to solve the current problem. Finally, when children based their solutions on their experiences of the previous task (understanding the structure of the problem), they can adjust their performance by using an element that allows them to solve the problem properly.

Figure 3. Percentage of achievement on *Archimedes' task*. T# = Type of task, A = second presentation of the task.

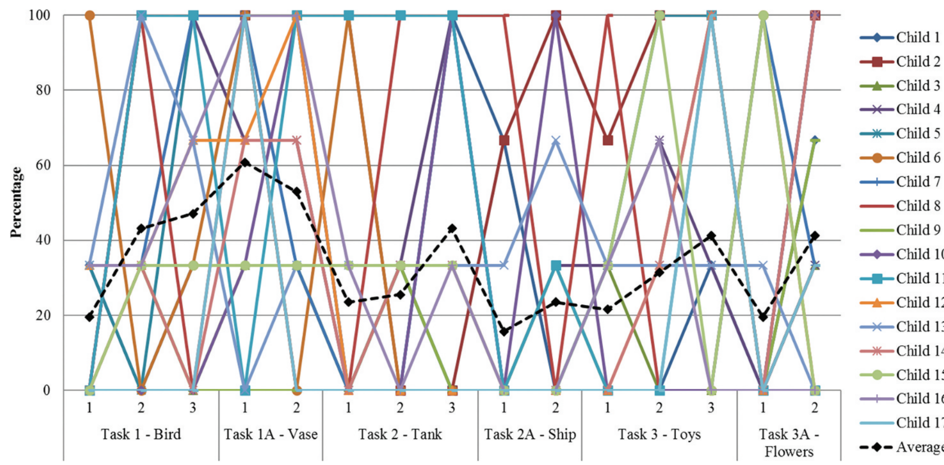
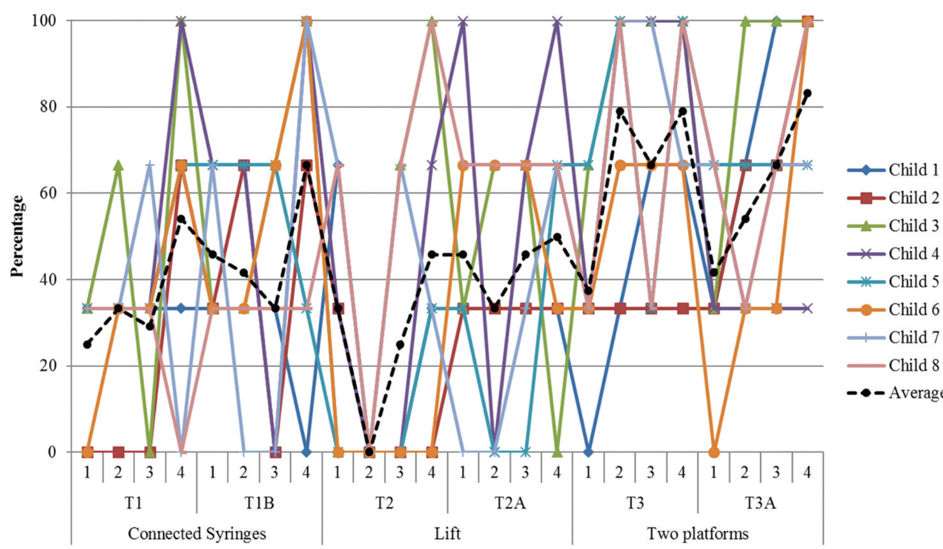


Figure 4. Percentage of achievement on t *Air pressure task*. T# = Type of task, A = second presentation of a task.



3. Results

3.1. Percentage of achievement in the problem-solving process

Figures 3 and 4 show a common aspect of children's performance in the problem-solving process, which is the bandwidth of inter-individual variability observed across all the tasks. Another important aspect is that despite the performance fluctuations it is possible to identify patterns emerging among the children. For instance, in Figure 3 the average line shows a peak between the two first tasks, and later, although the width of variability decreases, it shows a slight increase through the different observations, beginning with a 20%, ending in a 41% of achievement. In the case of Figure 4, the general pattern shows children's tendency to improve the performance across observations, beginning with a 20% and ending in 83% of achievement.

The average results shown in Figures 3 and 4 showed differentiated trends in the solving process. For the Archimedes Task it is possible to observe a more stable trend of achievement while in the Air pressure task, the trend shows a moment of low levels of achievement followed by a peak of improvement (ascending path) in the solving process. These results could be due to the structure of the tasks and their respective affordances.

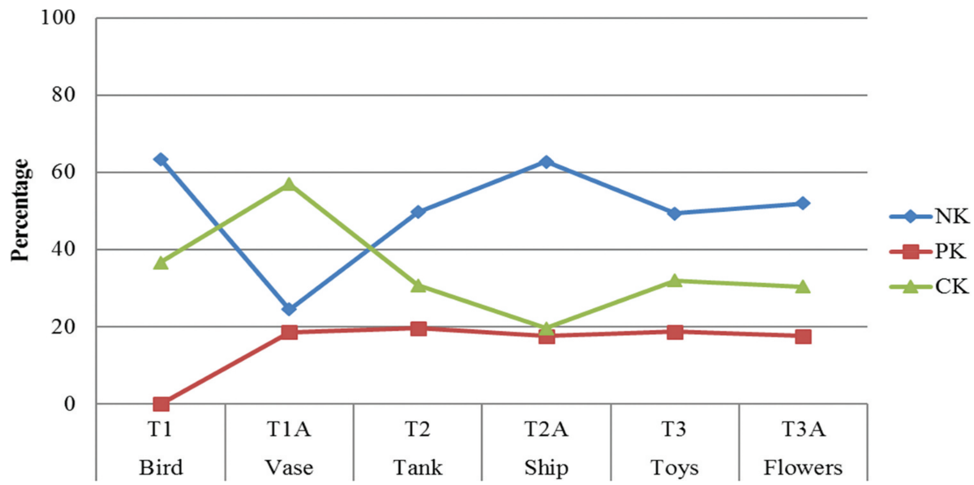


Figure 5. Trajectories of criteria used to solve the problem in *Archimedes' task*. NK: not using a key element, PK: using a key element of a previous task which is incorrect for the current task, and CK: using a correct key element for the current task. T# = Type of task, A = second presentation of the task.

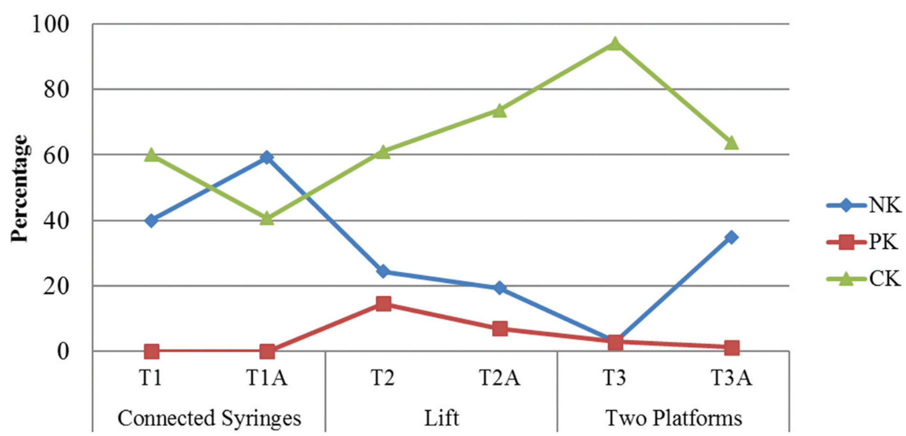


Figure 6. Trajectories of criteria used to solve the problem in *Air Pressure task*. NK: not using a key element, PK: using a key element of a previous task which is incorrect for the current task, and CK: using a correct key element for the current task. T# = Type of task, A = second presentation of the task.

3.2. Criteria of problem-solving process

Figures 5 and 6 are presenting children's performance according to the criteria based on the use of key elements to solve the problem (see Table 1). This depiction of the criteria used by children allows us to observe another perspective of the patterns in children's performance. These categories exhibit the information used by the children during the problem-solving of the task, such as 1) not using information from the previous task (NK), 2) using information from the previous task that does not apply to the new situation (PK), and 3) using information from the previous task, which is adapted to the current situation (CK). These criteria reveal that transfer is not an all-or-non-type of process, but rather a gradual process of constant transformation and reorganization, namely a process of continuing self-regulation.

In Figure 5, the problem-solving process shows the dynamics of the use of information from the previous task to the current one (CK and NK, respectively). At first, children use the relevant information for the task (CK) between T1 (39%) and T1A (59%). Later, the uses of the current key element decrease (CK, 30%), at the same time the use of irrelevant information for the task (NK) starts increasing and remains constant in a high proportion (50%-60%). This becomes the more predominant performance in task 2 and task 3A. In the case of Figure 6, children begin using both, relevant and no relevant elements for the task in similar proportions (CK, 60%; NK, 40%) in tasks 1 and 1A. Then, from task 2 to 3A children use the current key element in an

Figure 7. Trajectories of criteria used to solve the problem per task and attempt in *Archimedes' task*. NK: not using a key element, PK: using a key element of a previous task which is incorrect for the current task, and CK: using a correct key element for the current task. T# = Type of task, A = second presentation of the task.

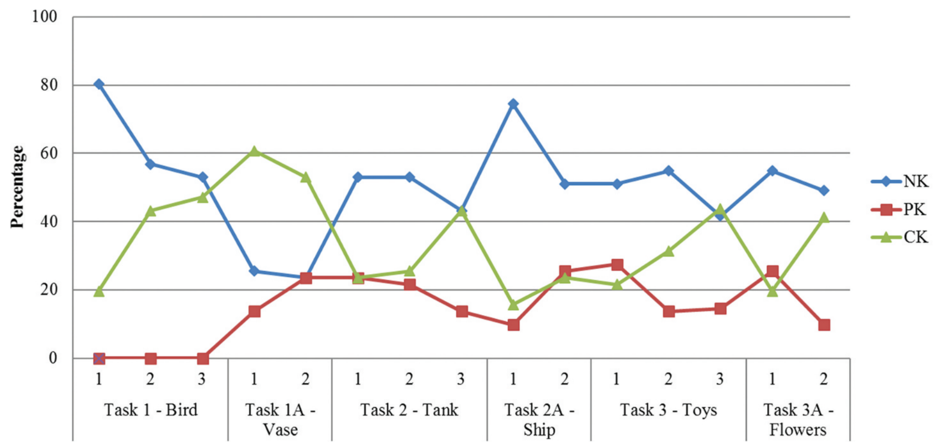
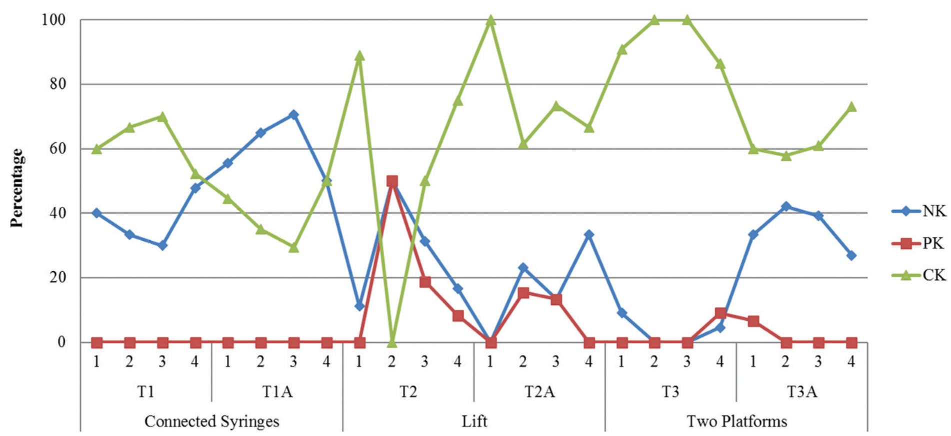


Figure 8. Trajectories of criteria used to solve the problem per task and attempt in *Air Pressure task*. NK: not using a key element, PK: using a key element of a previous task which is incorrect for the current task, and CK: using a correct key element for the current task. T# = Type of task, A = second presentation of the task.



increasing manner through the tasks (from 40% to 90%). This dynamic of problem-solving shows the opposite pattern of the one described in the Archimedes' task (Study 1).

Complementary to the previous results, Figures 7 and 8 depict in more detail the children's attempts to achieve the goal. These results emphasize the micro-change in the problem-solving performance in terms of the balance between the use of previous (PK) and current information of the task (CK). In addition, here we observe that the patterns described in the previous figures for both tasks (Figures 5 and 6) involve variability of children performances "inside" each session. Accordingly, this variability is present in both, between- and within-sessions.

4. Discussion

In this article, we have discussed the traditional approach of transfer, which involves a static view of transfer and a conception of learning as a finished process (i.e. from the perspective of its completed outcome). The basic assumption of this traditional transfer perspective is that knowledge is like an invariant component carried from task to task, for instance, from a familiar to a new situation (i.e. van Geert, 2019). Contrary to this traditional approach of transfer, we proposed a "dynamic process of transfer," emphasizing the argument of Larsen-Freeman (2013) who indicates that the "transfer process itself is likely to be much more dynamic, when in which students construct, rather than carry over the knowledge to the new situation" (p. 118). Therefore, every form of problem-solving, every form of task performance, is a process of so-called soft assembly, a process of emergence of a particular action pattern, which is the solving of the problem at issue (van Geert, 2019). Given that every process of problem-solving is a form of soft assembly, from a dynamic approach, transfer should be redefined in the following ways.

Transfer is a *multicausal process* that involves the active, time-varying contribution of different aspects in children's performance, such as the tasks' structure, the tasks' affordances, the information used by the children to solve the problem, the children's focus on elements that take relevance for them, their actions to solve it, and the effects of those actions on the problem. In opposition to the standard approach mentioned above, transfer is a result of active intertwining of multiple aspects present or emerging during the problem-solving process. It does not mainly depend on the level of initial learning reached by the child, as could be interpreted by the analogical reasoning perspective (Gentner, 1983, 1989; Holyoak & Thagard, 1989); or on the learner having reached a sufficient level of abstraction in the preceding tasks to allow him or her to apply the knowledge obtained into a new situation (Bransford et al., 2000).

From a multicausal consideration, the analysis of the descendent and ascendant performance patterns in Figures 3 and 4, respectively, indicate the possible relationship between the task structure and children's performance solving it. In the Archimedes' task, children's actions are limited to choose predetermined objects to solve it, but they do not have the possibility to explore them hands-on. In contrast, the Air pressure task has predetermined objects too, however, children also have the possibility to identify the relationship among objects in a hands-on activity. Therefore, the problem-solving process is the result of the possibilities children must interact with a task, which leads to an emergent process in the new situation that is highly similar to the process of the old one. It is this emergent similarity that—in our view, mistakenly in previous perspectives—suggests that a particular cognitive content or entity is transferred from one context to another. This kind of interaction possibility is mostly restricted in the research procedures of previous studies (Klauer et al., 2002; Roth-van der Werf et al., 2002; Tunteler & Resing, 2002, 2007b, 2010). In this way, from our perspective, the soft-assembly process changes depending on the tasks' affordances, allowing, or restricting the current understanding of the task. Vallacher et al. (2002) claim that "human experience reflects the interplay of multiple forces operating on various time scales to promote constantly evolving patterns of thought, emotion, and action" (p. 264).

The dynamic relationships among perception and action components typical of multicausality generate different trajectories in children's performance different trajectories in children´s performance over time, giving rise to *variability*, which is an essential feature of the problem-solving process (See Thelen & Smith, 1996). There is considerable inter-individual- and intra-individual-variability in children's performance, as seen in previous studies conducted by Tunteler and Resing (2002, 2007a, 2007b). In fact, the 2007b' study, performed with 5- to 8 years-old, showed that children's analogical reasoning improved with practice regardless of age. According to Siegler (2000) "variability is a central characteristic of the cognitive system, rather than reflecting measurement error" (Siegler, 2000, p. 30). Thus, variability in children's performance could be an indicator of the multicausal nature of learning. Variability is the result of the soft-assembly process that takes place during the problem-solving process and it is absolutely necessary for learning to occur.

The *soft-assembly process* corresponds to the continuous interdependent relationship between the children and the task, in a complex interaction depending on characteristics of the tasks (see Kloos & van Orden, 2009). This implies that transfer emerges as part of these interactions. In each attempt to solve the task, children adjust their performances in function of the task's structure, the task' s affordances, the feedback of their own actions, and the task goal. Our findings revealed that children working on the hands-on task (air pressure tasks), were more likely to integrate the relationship of the key elements of the tasks than children working on the multimedia task

(Archimedes tasks). In the latter case, the task structure allows for feedback only until children have selected all the elements. Therefore, children do not have the opportunity for ongoing adjustments while they are solving the problem.

Similarly, the traditional research on transfer uses an experimental design with a learning and a transfer phase, in which it is expected that the children use the solution displayed during the learning phase (Klauer et al., 2002; Roth-van der Werf et al., 2002; Tunteler & Resing, 2002, 2007b, 2010). However, this kind of procedure does not allow the children to explore and manipulate the material to solve the problem, or if they do, or it is only allowed during the so-called learning phase, or with time restrictions (Chen, 2003). These kinds of procedures also do not allow researchers to identify or infer the children's understanding of the task, and what the child is considering in order to solve the problem at that moment. Here, the limitations lie in the measure of behavior that could be understood as success or failure, in the use of only one attempt to solve the task or in the time restrictions imposed on the problem-solving process.

From the perspective of the studies, children either learned or not, and based on that, either showed transfer or not. Our claim is that children continue learning through the entire process from the learning phase to the transfer phase, and later. In that sense, transfer is an important feature of the learning process, and not an independent aspect of learning (see Larsen-Freeman, 2013; Nokes, 2009). Therefore, transfer emerges as a *soft-assembly process* that involves a continuous adaptation or adjustment of the learner in order to solve a problem. This is an expression of the process of self-organization and task performance of the child-task dynamic system. This process works as a constant update of child-task relationship on the spot. As stated by Siegler (2000) in his overlapping waves model: "Learning also can occur through increasingly precise fitting of strategy choices to the demands of problem and situations" (p. 29). For instance, a change in what is considered a relevant element for solving the problem influences the total performance on the task. This property can be observed in our data as the emergence of intra-individual (see Figures 3 and 4) and inter-individual patterns of transfer (see Figures 5–8), showing a path of change from low levels to higher levels of transfer. Besides, the paths are different from individual to individual. This is an indicator of the continuous transformation that takes place during learning. Then, transfer as a feature of learning, makes this ongoing process possible.

Finally, the history of changes is the result of the dynamics between the children and the task, in which the dynamic relationship in the present moment has an impact on a posterior performance. This happens because there is an *integration of different time-scales* that occurs not only in each attempt but also within and between sessions. Therefore, the impact of this interaction is not necessarily immediate in time (e.g., the short-term timescale of problem-solving activity and the medium- to long-term timescale of experience and learning across sessions). For example, children's performance during the problem-solving process in the first session could be useful on subsequent attempts or sessions; or, some information in which children focus on one attempt could be important than in a completely different session and even task.

In summary, transfer studied as a dynamic process reveals variability in children's performance characterized to solve problems with various levels of complexity. Our evidence about transfer as a dynamic process is consistent with Siegler's (2000) description of learning: "... models of children's learning, such as those constructed within dynamic systems theories (Smith et al., 1999; van Geert, 1998), differ in their particulars, but they share with overlapping waves theory a number of assumptions about how learning occurs. Within both approaches, children learn by doing; learning occurs through performance" (Siegler, 2000 p. 30). Therefore, studies on transfer should consider the variable and dynamic nature of learning in their theoretical as well as their methodological approaches.

5. Conclusions

In this article, we suggest transfer as a feature of the learning process, which is inherently variable. Our main purpose was to analyze transfer from a dynamic approach that recognizes the complexity of learning, and how it takes place in real context. From perspectives as the Structure-Mapping Theory (Gentner, 1983, 1989), and the Constraint-Satisfaction Theory (Holyoak & Thagard, 1989), transfer implies to capture information from one domain to be "applied" into another one due to a correspondence. In fact, this transfer of a common information our knowledge content is clearly described in structure mapping theory by the terms "pure matching" and "carry over." (Gentner, 1983, 1989). This traditional approach of transfer could be considered a static view for various reasons. First, learning is conceived of as a previous stage in which the individual acquires information that takes the form of a transferable entity. Second, the underlying assumption is that once the learning stage ends, the individual is ready to use that information in a new setting. Third, it is implied that the information can be "carried" from one setting to another by establishing correspondences, and fourth, transfer is based mainly on analogical reasoning. In this study, we have analyzed transfer from a dynamic approach, as an emergent process that involves a constant transformation of understanding. This transformation depends on the context's demands and the dynamic relationship between the individual and the situation (i.e. emergence, soft-assembly, and self-organization). In contrast to traditional perspectives, we consider transfer as a multicausal phenomenon, resulting from the ongoing interaction of task context and affordances, as well as the individual's knowledge and actions in the task. Therefore, we do not conceive of transfer as an isolated or mechanical process, independent of the contexts and individuals involved. On the contrary, it is a dynamic process in which complex relationships emerge from that interaction. For this reason, we claim that the classic methods to study transfer using the learning- and the transfer phase, should be reconsidered. We suggest the use of repeated measures or even microgenetic designs as a strategy to observe the dynamic nature of transfer, as the continuous transformation of the process of self-assembly of children's performance through repeated attempts. In addition, we consider that a useful way to capture this dynamic process is by open problem-situations that allow for genuine physical activity (i.e. hands-on problem situations). The advantage of these situations is to allow children to exhibit complex performance and to adjust and construct their understanding while they are solving problems.

As regards educational implications, the assessment of knowledge should go beyond a failure-success approach, and instead focus on the way children are able to transform knowledge according to new demands. Educators should be given a framework based on an intuitive and concrete formulation of main features of a complex dynamic system view on problem-solving, in which educators are given basic insights into features and principles such as soft-assembly, self-organization, emergence, and the dynamic nature of problem-solving. This framework could help them understanding the underlying structure of the tasks, interpreting their observations of these transformations, and fostering children's interaction with the task.

Regarding the limitations of our study, it is necessary to consider that cultural differences in both studies could influence the results. Examples of such differences are the educational system of the two countries where the studies were carried out, and the use of a second language to perform study 2. However, despite these differences between the samples of the two studies, it was possible to identify consistent patterns in children's performances. Which are likely to reflect, in some way or other, the long-term properties of the way they have been learning in their proper schools.

For future studies, it would be interesting to explore a variety of additional aspects. For instance, by studying the relationship between dyadic interaction or individual performance and the process of transfer in other cultural contexts. This could reveal whether there are consistent results of transfer in other cultural contexts. Future studies also could explore the process of transfer in more natural contexts, during longer periods, across varying domains of knowledge, and problem-solving tasks.

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Notes

1. Emergence “refers to the appearance of higher levels of system properties and behavior that even if obviously originated in the collective dynamics of system’s components—are neither found in nor directly deductible from the lower-level properties of this system. Emergent properties are properties of the ‘whole’ not possessed by any of the individual parts making up this whole” (Aziz-Alaoui & Bertelle, 2007, preface).
2. NK: not using a key element, PK: using a key element of a previous task which is incorrect for the current task, and CK: using a correct key element for the current task.
3. Study 1 was developed based on the method and raw data collected from the following dissertation: Rojas, T. (2013). The Role of Active Problem-Solving. In Promoting Far Transfer in Children. Doctoral dissertation. Doctor of Philosophy. University of Connecticut. United States.
4. Study 2 was developed based on the method and raw data collected from the following dissertation: Guevara, M. (2015). Peer Interaction and Scientific Reasoning Processes in Preschoolers: An intra-individual Approach. Doctoral dissertation. Doctor of Philosophy. University of Groningen, The Netherlands.

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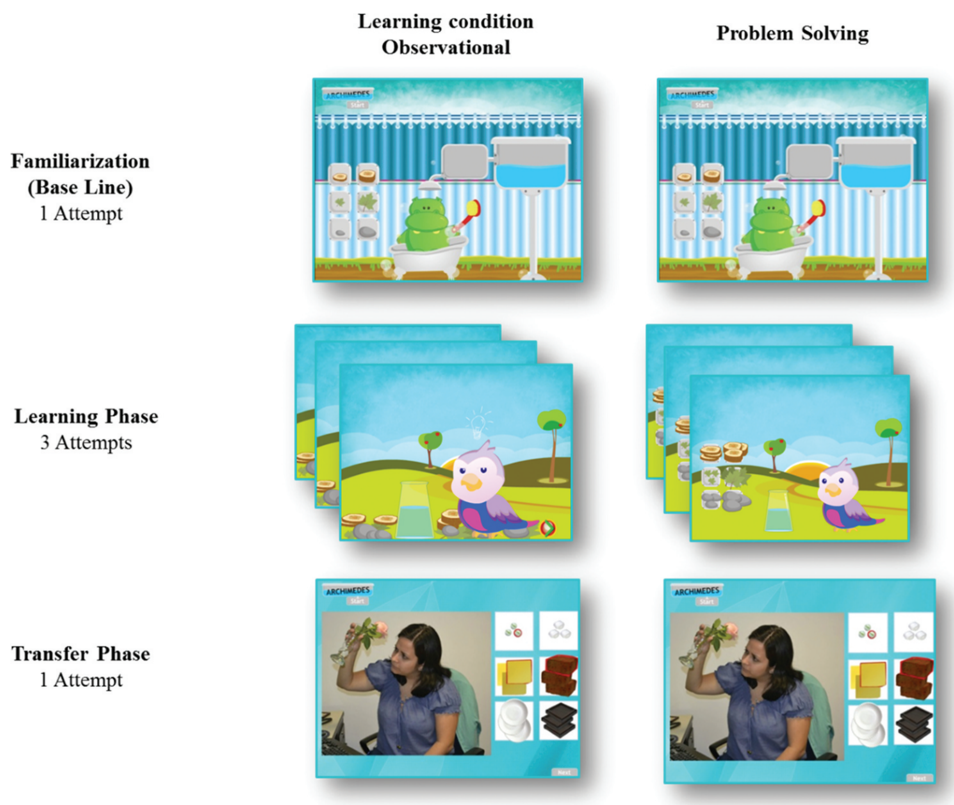
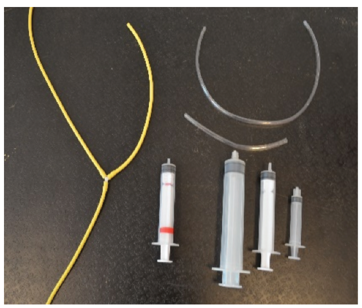
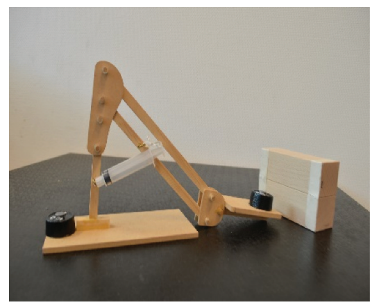
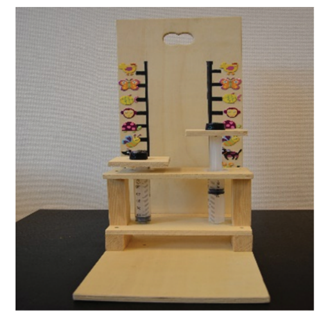
Appendices

Appendix 1. Archimedes task



https://doi.org/10.1080/2331186X.2020.1814512

Appendix 2. Air pressure task

Task 1 (T1)Connected Syringes	Task 2 (T2)Lift		Task 3 (T3)Platforms
			
Criteria	**Task 1 (T1) Connected Syringes**	**Task 2 (T2) Lift**	**Task 3 (T3) Platforms**
Goal	To push the plunge out until the red mark	To lift the weight until the edge of the wooden wall	To push the platform up until the "bee" mark
Target syringe/ Size of the Syringe to solve the problem	Medium size	Small size	Big size
Considerations to solve the task	• The **size of the added syringe** affects the result of the task→ The solution of the task requires to use the same size of the target syringe. • The **shape of the tubes** affects the result → The "Y" shape tube does not work to solve the task. The air scape from one of the disconnected tips. In contrast, a straight tube directs all the air to the target syringe. Both, short and long straight tubes contribute to solve the task. • The **size of the tube** does not affect the result → The size of the tube does not contribute to solve the task.		