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Analysing an Interactive Problem-Solving Task Through the Lens of Double Stimulation

Analyse d'une tâche interactive de résolution de problèmes sous l'angle de la double stimulation

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Abstract

Problem-solving activities have been studied from a diversity of epistemological perspectives. In problem-solving activities, the initial tensions of a problematic situation led to a cognitive dissonance between conflicting motives and instruments to reach the activity goal. We analyze problem-solving in the continuation of Sannino and Laitinen's (2015) approach to the analysis of a decision-forming apparatus. The originality of this study is in consideration of the materialistic nature of double stimulation that appears during the activity of the CreaCube problem-solving task. This activity engages the participant in solving tasks with interactive robotic instruments. To solve a task, the subject is required to build interactive robotic modules into a specific configuration which will cause the artifact to move from an initial position to a predetermined final position. The conflict of stimuli in the CreaCube is strong and observable because of the tangibility of the artifact, which is manipulated by the participant into different configurations with the goal of solving the task. We discuss double stimulation in relation to the artifactual interactive affordances of educational robotics.

Keywords: Conflict of stimuli; Double stimulation; Educational robotics; Decision-forming apparatus; Problem-solving

Résumé

Les activités de résolution de problèmes ont été étudiées à partir d'une diversité de perspectives épistémologiques. Dans les activités de résolution de problèmes, les tensions initiales d'une situation problématique ont conduit à une dissonance cognitive entre des motifs et des instruments contradictoires pour atteindre le but de l'activité. Nous analysons la résolution de problèmes dans le prolongement de la démarche de Sannino et Laitinen (2015) pour l'analyse d'un appareil de formation de décision. L'originalité de cette étude réside dans la prise en compte de la nature matérialiste de la double stimulation qui apparaît lors de l'activité de la tâche de résolution de problèmes CreaCube. Cette activité engage le participant dans la résolution de tâches avec des instruments robotiques interactifs. Afin de résoudre une tâche, le sujet doit construire des modules robotiques interactifs dans une configuration spécifique qui fera bouger l'artefact d'une position initiale à une position finale prédéterminée. Le conflit de stimuli dans le CreaCube est fort et observable en raison de la tangibilité de l'artefact qui est manipulé par le participant dans différentes configurations dans le but de résoudre la tâche. Nous discutons de la double stimulation en relation avec les affordances interactives artefactuelles de la robotique éducative.

Mots-clés : Conflit de stimuli ; Double stimulation ; Robotique éducative ; Appareil de prise de décision ; Résolution de problèmes

Introduction

This paper focuses on an interactive problem-solving task mediated using modular robotics. Research in problem-solving presents many challenges, including the need to consider temporality and dynamic events through micro genetic approaches (Ludvigsen et al., 2018). Problem-solving is described as a process which develops through the four stages in the PISA framework for problem-solving (OECD, 2013), like the four stages defined by Polya (1985): a) identification of the problem, b) planning, c) developing actions toward a solution, and d) evaluating a solution. These stages are described as general behaviours, specifying neither the underpinning volitional processes nor the conflicting motives and stimuli during the problem-solving activity. To more deeply understand why and how an ill-defined problem is being solved, the relation between the subject's processes (conflicting motives, decision-forming process, agency, activity) and the specific task in which the participant is engaged must be pinpointed. Vygotsky's principle of double stimulation (DS) can be used as a lens to understand how subjects make sense of a complex problem (considered the first stimulus) and the process that they commit to pursue an activity as they construct a second stimulus bringing new meaning to the activity. Vygotsky's principle of DS, an epistemological principle in third-generation activity theory, is fruitful to understand how agency emerges when an individual constructs a second stimulus in response to a problem involving a conflict of motives (Sannino, & Laitinen, 2015). The DS principle "refers to the mechanism whereby human beings can intentionally emerge from a conflict situation and change the circumstances in which they find themselves or solve problems" (Engeström & Sannino, 2013, p. 6). The conflict is resolved by invoking a neutral artifact as a second stimulus which is turned into a mediating sign by investing it with meaning.

This study considers problem-solving as an activity developed by a subject engaged in an ill-defined task which presents a conflictual situation that constitutes the first stimulus. This stimulus is a necessary element to trigger transformative agency in response to a cognitive conflict (Engeström & Sannino, 2013, p. 4). To overcome the problematic situation, the subject must demonstrate agency in the form of building a second stimulus that will give new meaning to the situation and overcome the initial tensions of the problem situation. The building of the second stimulus is one of the key concepts in activity theory that is required to understand how subjects emancipate themselves from a given problematic situation. This approach to problem-solving considers the situation as a system. Despite the studies of decision-forming apparatus developed within the socio-cultural approach (Engeström & Sannino, 2013), this approach has not been developed in complex and systemic problem-solving tasks engaging technology as mediating tools. This study proposes to address this challenge and study a complex and systemic problem-solving task through the analysis of the decision-forming apparatus. Vygotskian activity theory perspective implies that we cannot consider the initial situation to be dealt with directly. Neither can such a perspective permit us to establish a plan to address the problem-solving process. Through reconfiguring of the initial situation and as a second stimulus is brought forward, the subject creates new meaning to the artifact that advances the problem-solving process. In the next section, we analyze the role of conflict of motives from the initial to the final stages of problem-solving.

The Key Role of Conflicts of Motives

The principle of double stimulation considers all initial tensions in the problem situation as a necessary foundation; conflicting stimuli lead to conflicting motives, which produce cognitive dissonance. Conflicting motives can be expressed in the form of dilemmas and double-binds and can be even paralyzing if they are not prioritized (Engeström & Sannino, 2011). The conflicting motives emerging in an ill-defined problem-solving task are essential to trigger the decision-forming process (Barma et al., 2015). Conflicting motives are also considered from the neuroscientific perspective under the term of concurrent goals (Charron & Koechlin, 2010) whereby the subject is required to evaluate the different goals and motives in a certain context. Within the problem-solving task, the subject engages in different decision-making processes that are subordinated to the different goals and motives. From a neuroscientific perspective, problem-solving is dynamic and engages a self-correcting process of the actions within the activity.

The materialist aspect of the educational robotic task requires us to consider not only language as a mediating tool but also studies which have been addressing manipulative tasks in robot computer interaction (Norman, 1986), but also recent works in neurosciences related to value-based decision making (Rangel et al., 2008). From Rangel and colleagues' perspective, the subject updates the value of an action as they advance in the problem-solving process. Solving conflicting motives is an important aspect of that process that needs to be addressed before engaging in the task and throughout the entire process as the task progresses toward a final resolution. Despite the overly simplistic view of acceptance of the task instruction and engagement on the task, both Vygotskian and neuroscientific approaches consider the human to have multiple and conflicting motives before and during a certain task. Sannino and Laitinen (2015) point out that in one of his texts, Vygotsky (1997) brings to our attention how the emergence of "volitional action by means of auxiliary stimuli and involving a conflict of motives as a central component" is key in self-control (p. 6).

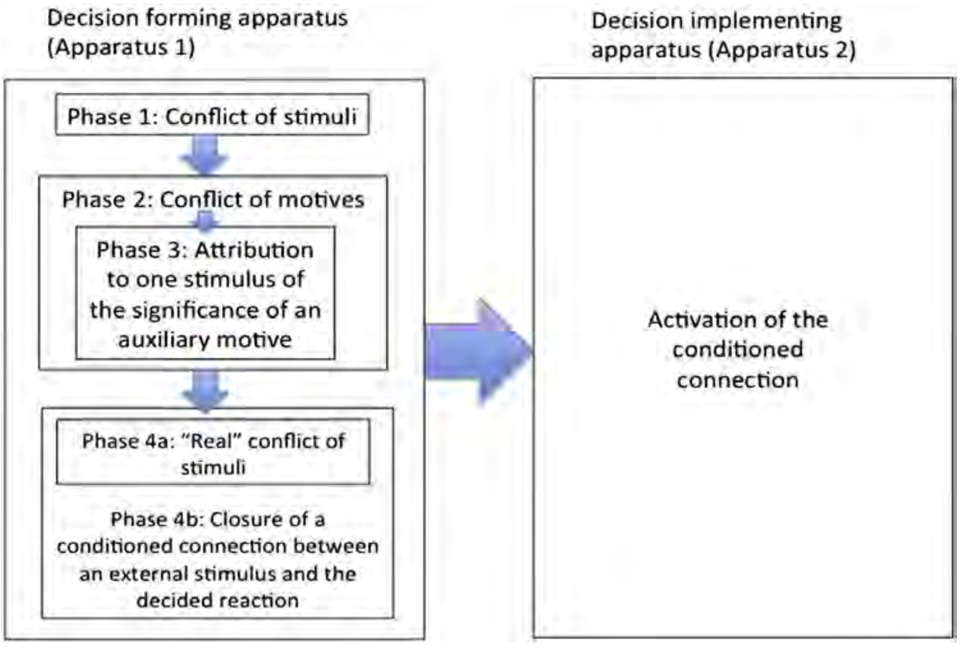
Presenting an ill-defined task to participants may create instability and insecurity in the form of cognitive dissonance (a first stimulus). Double stimulation can also be used as a methodology to elicit agency as well as a theoretical framework that will enable a better understanding of the process of building higher mental functions. Vygotsky's principle of DS can help us better understand how agency emerges when a person constructs a second stimulus in response to a problem involving a conflict of motives. To break away from a situation of conflict of motives, agency needs to emerge. Agency refers to "the subject's willed quest for transformation. It transpires in a problematic, polymotivated situation in which the subject evaluates and interprets the circumstances, makes decisions according to the interpretations and acts upon these decisions" (Engeström & Sannino, 2013, pp. 3-4). The conflictual situation constitutes the first stimulus and is a necessary element to trigger transformative agency (Engeström & Sannino, 2013) to internalize, create and use new mental functions to break away from a paralyzing situation (Engeström, 2007).

Conflicts of motives resolution have often been analyzed in time periods going from a few days to weeks; nevertheless, the resolution of the conflictual motives can also be applied in much shorter periods of time. Sannino and Laitinen (2015) develop their results in the context of the waiting experiment, which happens in minutes. The "waiting" is considered "a state of oscillation, confusion, and indecisiveness for some time" (Vygotsky, 1987, p. 356). Through the waiting experiment, Vygotsky (1997) observes the emergence of volitional action. The actions that the subject develops to overcome the conflict become a second stimulus. Sannino and Laitinen (2015) describe the emergence of volitional action with DS as a process involving two apparatuses which "are relatively independent of each other" (p. 213) and also correspond to "two stages in the genesis of will" (p. 218). Figure 1 introduces the model of double stimulation by Sannino and Laitinen (2015).

- Apparatus 1 consists of deciding to act in a certain way with the help of an auxiliary motive (e.g., the striking of a clock).
- Apparatus 2 consists of implementing the decision-formed in Apparatus 1. Apparatus 1 is the most complex and can be depicted as involving four phases.

Figure 1

Model of Double Stimulation (Sannino, 2015)



Materialistic Dialectic and Affordances

Problem-solving with manipulable material engages the participant in a concrete interaction between the subject and the object. In these contexts, problem-solving is observable in the building process of the participant through the different configurations of the material during the problem-solving task. The tool proposed to the participants is a set of four robotics cubes engaging the participants to manipulate "visuo-spatial constructive play objects" (VCPOs) (Ness & Farenga, 2016) for building the different configurations during the problem-solving task. In the problem-solving tasks with manipulable VCPOs, activity theory can help in analyzing the *materialistic dialectic* to understand the process of interaction between the subject and the object. In the materialistic theory of activity, it is only this relation that is regarded as fundamental: the concept of activity necessarily includes the concept of its object. This is a constituent feature of activity that is concrete. Activity here is to be understood as purposeful activity and not as synonymous with process or continuum in general.

In their attempts to solve problems in the context of scientific practices like the ones of engineers, Nersessian (1984) proposes that concept formation and conceptual change arise from the interplay of conceptual and material resources provided by the problem situation. It does, however to a large extent, demand reflection on one's activities as a process of cognition. For Davydov (1990), a learning activity is a form of creative appropriation of knowledge and concepts. In that sense, knowledge cannot be understood without reference to activity, and activity cannot be understood as purposeless activity without reference to content (Fichtner, 1999).

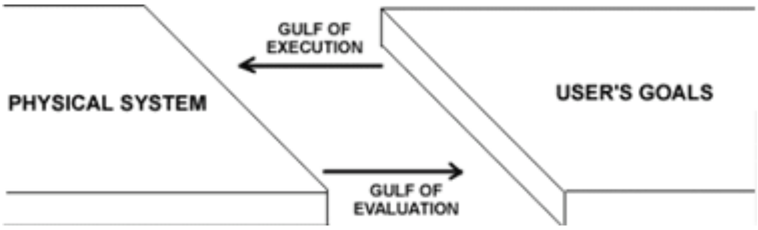
In problem-solving with tools to which the subject has not yet attributed contextual meaning to the task, we can refer to the work of Ilyenkov (2007) on materialist dialectics. Ilyenkov discusses the insoluble contradiction for which the usual methods of operations cannot provide an answer. From a neuroscience perspective, the ill-defined problem-solving situation does not allow the transfer of existing knowledge to solve the task but rather requires the exploration of the system in a new way. There is a contradiction in the way the subject goal can be achieved with tools available in the situation (Norman, 1986). In those conflicting problem-solving situations, the subject must be able "to formulate a contradiction and then find its real resolution through the concrete examination of the thing, the reality, (and not through) means of formal verbal manipulations that fudge contradictions instead of resolving them" (Ilyenkov, 2007, p. 21).

The term "concrete" refers to the functional relation of the activity system, and it "is reserved for a lawfully connected aggregate or real facts, or system of determining facts understood in their interconnection and interaction" (Ilyenkov, 2007, p. 33). Concrete is "rather the holistic quality of systemic interconnectedness" (Engeström, 2014, p. 191). We can consider "concrete" as a systematic and evolving state of the activity, in which instruments and actions are interconnected to solve the situation. The process of actualization of "concrete" at the subject level is influenced by artifact actualization through the enactment of the building of the second stimulus (second apparatus).

The concept of affordance is meaningful in understanding the artifact evolution through problem-solving activities with manipulatives. In problem-solving with tools to which the subject has not attributed meaning in the context of the task, the uncomfortable situation is also due to the impossibility of using the available tools to solve the situation in an already known way. According to Hutchins et al. (1985) and Norman (1986), a materialistic problem situates the subject in front of a *gulf of execution*, the distance between the user's goals and the means of achieving them through the system. The gulf of execution represented in Figure 2 should be crossed through the exploration of the means or tools available to the participant to achieve a certain goal or solve a certain problem situation (execution bridge) and evaluate the effectiveness of these actions (evaluation bridge). The actions of exploration of the artifact (physical system) can support the emergence of knowledge from the abstract to the concrete, but also, in interactive systems, the actualization of the artifact's configuration. Through this process of actualization at the user level and at the artifact level, there is an enactment of the building of the second stimulus (second apparatus).

Figure 2

Gulf of Execution as Distance Between User's Goals and Physical System (Hutchins et al., 1985).



Research Objective: Analysis of an Interactive Problem-Solving Task

This study focuses on a problem-solving activity mediated by educational robotic technologies. Additionally, the dynamic process of problem-solving is described in the context of a modular robotic task. The dynamic process is described through a materialistic dialectic with the principles of DS. For this objective, we analyze two case studies engaged in the CreaCube task and compare a child and an adult to study problem-solving from a broader developmental perspective. The Sannino DS model is unique in the sense that it allows apprehending an analysis through a generic lens. What the DS proposes is founded in Vygotsky's work, arguing that conflicts are at the core of problem-solving in a dialectical way. Building on Leontyev's (2009) reflections on conflicts of motives, Sannino (2015) emphasises that engaging in volitional actions is more than just about "choice and decision making" (p. 15). Making a choice supposes that "duality is at the very foundation of the volitional act, and this duality becomes especially prominent and vivid whenever several motives, several opposing strivings, clash in our consciousness" (Vygotsky, 1997, p. 167-168). Conflicts of motives are important components in Vygotsky's principle of double stimulation and key elements to trigger agency. They act as the first stimulus to begin the process of will formation (Barma et al., 2015; Sannino, 2015).

Methodology

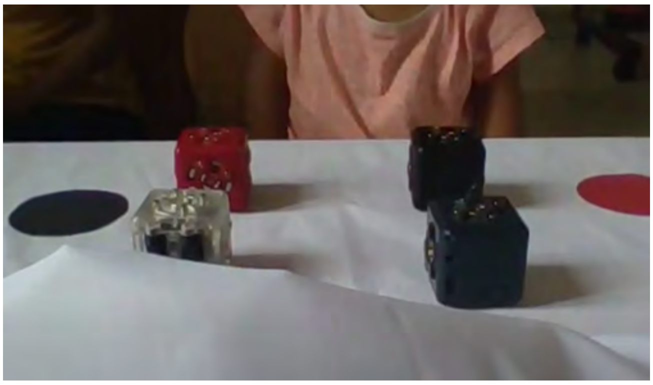
Participants engage in the task through a well-established protocol. The cubes are initially covered while the participant is listening to the instruction. Fractions of the cubes are uncovered, allowing the subject to engage in the activity. There is no time pressure while doing the task; nevertheless, the experimenter is in front of the participant, and there is a video recording of their hands during the problem-solving task.

CreaCube Task

The CreaCube task aims to engage the participant in an ill-defined problem-solving task. The participant is exposed to unknown, hidden cubes which need to be manipulated to achieve the game's objective: creating an autonomous vehicle that eventually reaches the finish point (Romero, 2019). The CreaCube task has been designed as a problem-solving task in which the participant is engaged towards the objective of creating a vehicle that is able to move in an autonomous way from a starting red point to a final black point. The material components are four modular robotic cubes, selected from the *Cubelets* toolkit, considered build-bots composed of modular parts. Figure 3 shows a participant seated in front of a table, upon which there are four robotic modular cubes. The participants engaged in the CreaCube task notice the cubes' different colours, but they are required to engage in the manipulative exploration of each cube to notice further differences between cubes. The participant should grasp the cubes, manipulate them to understand their features, and experiment with different constructions to find a solution.

Figure 3

The Four Robotic Cubes at the Initial Configuration of the CreaCube Task



Instructions

Instructions for the CreaCube task engage the participant in creating a vehicle moving from a starting point (red point on the playmat in Figure 3) to a final point (black point on the playmat) by assembling four "pieces". The pieces are constituted of four different Cubelets modular robotic cubes.

Participants

The study is developed through two cases; the first case is a child in elementary school and the second case is a pre-service adult teacher. These participants have not previously played with the Cubelets toolkit. They are voluntarily engaging in the task presented to them as a game. The child solved the activity in 11 minutes 37 seconds while the adult solved it in 6 minutes 44 seconds.

CreaCube Task Material Artifacts and Characteristics

This study focuses on a problem-solving activity mediated by educational robotic technologies. The existing literature on materialistic dialectic has not been focused on educational robotics but on other types of artifacts (Nuttall & Brennan, 2016). In educational robotics, the interactive affordances introduce complexity to the problem-solving task. Each of the modular robotic cubes has different *visual affordances* (magnets, wheels, a switch, "two eyes" or holes) and *technological affordances*, which are features of the cubes that can be observed when the cubes are assembled. The red cube has six identical faces. The three other cubes have five identical faces and one specific face with a visual affordance: the black cube has two eyes which corresponds to the distance sensor feature (technological affordance), the dark blue cube has a switch which allows the provision of energy into the system, and the white cube has two black wheels which are the visual affordances for the servo-wheels allowing the system to move (technological affordance). To successfully configure the cubes so that they move autonomously from an initial point to the final point, the four cubes must be assembled in a specific way: the switch should be activated, the wheels should be in contact with the floor, and the red cube (inverter) should be situated before the black cube (distance sensor).

Figure 4

The Four Robotic Cubes Visual Affordances

In tinkering tasks, the tools are an important mediating factor in the problem-solving process (Parekh & Gee, 2019). Not only do the cubes need to be manipulated to be understood, but each has different features. These differences are part of the complexity of the task. The participant evaluates the initial problem based on the instructions inviting the participant to build a vehicle that can move autonomously (task goal) with the four cubes provided as a set of tools to build an artifact to solve the problem. This initial conflictual situation requires the participant to explore the tools to make sense of the task and build a second stimulus.

Due to the task's complexity, the configuration of the cube requires the participant to assemble and disassemble the cubes several times through a tinkering process in which the *objects-to-think-with* (Papert, 1980) engage the participant in a materialistic dialectic. The situation requires the participant to go beyond their current knowledge; they are required to be creative in establishing functional relations between the cubes' behaviour and the meaning given to the technological affordances that make each behaviour possible. The problem space is expected to be reduced when the participants establish meaningful functional relations contributing to advance toward a solution.

Results

The results start by introducing the decision-forming at the different stages of the problem-solving task: the initial stages of the child and the adult forming apparatus. The analysis is developed for each of the phases: conflict of stimuli (phase 1), conflict of motives (phase 2), attribution to one stimulus of the significance of an auxiliary motive (phase 3), real conflict of stimulus (phase 4a), and the closure of a conditioned connection between an external stimulus and the decided reaction (phase 4b). The results conclude by describing the DS as a meaningful approach to understanding creative problem-solving.

Decision-Forming at the Initial Stages of the Problem-Solving Task

Before engaging in an action to solve the task, the subject should identify the problem. At this stage of the task, the decision-forming apparatus of Sannino and Laitinen (2015) to describe the four phases of the decision-forming of the CreaCube task is considered. The analysis of the occurrences of the decision-forming apparatus of Sannino and Laitinen (*ibid*) in the experiments involving the child and the adult is described in the following tables and figures.

The analysis of the child decision-forming apparatus shows a non-linear iteration of the different phases, with a prevalence of phases 1 and 3 initially and phase 4 at the end of the activity. The conflict of stimuli appears through the task interaction and brings about the way the meaning is generated through the task. In Vygotsky's (1997) theory, an initial stimulus situation involves a conflict of motives. After the child receives the instructions, a conflict of motives (deciding to explore and touch the cubes versus not engaging) is observed prior to a conflict of stimuli (contact with the material physical artifacts). Even if it happens in a short period of time, the decision-forming Apparatus 1 details what can happen during the initial phase. Nevertheless, in the video analysis of the task, the conflict of motives is not identified. However, the tangibility of the task allows different loops of conflict of stimuli to be observed. The tangibility of the manipulated tools contributes to the rapid generation of conflict of stimuli. Additionally, it helps to advance towards the generation of new configurations contributing to learning expansion through the problem space to the problem solution.

Figure 5

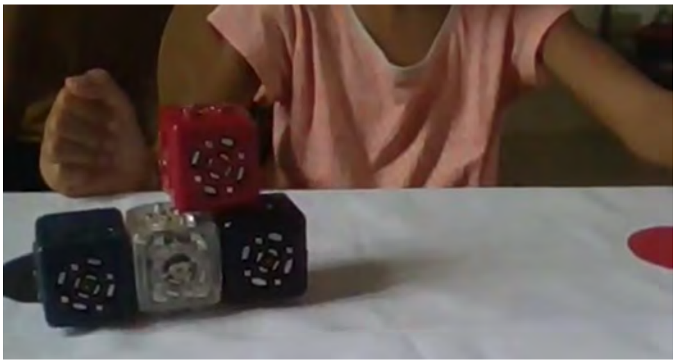
The Child is Paralyzed in Front of the Cubes

Figure 6

The Child Starting to Build a Configuration by Assembling the Cubes

Figure 7

The Child Expands their Knowledge by Creating a New Configuration



The full process of the child decision-forming apparatus is described in Table 1.

Table 1

Analysis of the Child Decision-Forming Apparatus

Phase	Time	Observed Behaviour (Video analysis)
Phase 1. Conflict of stimuli	0 sec	The child listens to instructions.
	40 sec	The child evaluates the situation without touching the material (Figure 5). The child seems initially paralyzed by the conflict of stimuli between the instructions (task goal) and the tools to achieve the goal. The paralysis lasts 26 seconds.
	50 sec	The child explores the cubes and observes the differences among them. They move the cubes and bring them closer.
Phase 3. Attribution to one stimulus of the significance of an auxiliary motive	1 min 12 sec	At this stage, the child has attributed the wheels' affordance stimulus to a significant amount of movement. This attribution is meaningful for moving the object as proposed by the instructions. They have internalized the meaning of one of the features of the drive cube. From this moment on, they have attributed a partial meaning that brings them forward in the process of problem-solving, which constitutes a germ cell in terms of Engeström and Sannino (2010). Germ cells contribute to bridging the gap between the initial situation and the solution of the problem activity.

Phase	Time	Observed Behaviour (Video analysis)
		Once the person catches the germ cell related to the wheels' feature, the activity system will no longer be the same, and the participant is a step closer to the solution. The germ cell is developed through the interactions between the subject and the educational robotic tools proposed to be reconfigured towards the object of the task.
Phase 1. Conflict of stimuli	1 min 14 sec	Even though the child found the wheels' *visual affordance,* the wheels do not react as they intended (*technological affordance*).
	1 min 19 sec	The child starts assembling the cubes and realizes the cubes are magnetic. They start trying to randomly connect the cubes to build a vehicle.
Phase 1. Conflict of stimuli	2 min 5 sec	After trying to solve the conflict of motives by assembling the cubes, they then return to the initial stage of conflict of stimuli and start exploring the cubes individually again. They focus on the wheels' affordances and confront the expectations of technological affordances by making the wheels move with their fingers and through a friction movement on the table.
	2 min 18 sec	The child engages in iterations of conflict of stimuli. They engage in different ways of assembling the cubes in a trial-and-error behaviour looking to generate new stimuli for overcoming the conflict of motives. Nevertheless, these iterations do not permit overcoming the situation.
	5 min 4 sec	At 5 min 4 sec, after having tried different trial-and-error attempts, they return to the analysis of each cube individually.
Phase 3. Attribution to one stimulus of the significance	10 min 49 sec	At this point, the child has attributed significance to the stimulus corresponding to the switch's visual affordance by understanding the technological affordance associated with the switch. They have internalized the meaning of one of

Phase	Time	Observed Behaviour (Video analysis)
of an auxiliary motive		the features of the power cube and are able to activate and deactivate the power voluntarily. From this moment on, they have assigned a partial meaning that advances them through her problem-solving process (a germ cell).
Phase 4a. Real conflict of stimuli	11 min 05 sec	The power cube as a stimulus is transformed from a “simple cube” to a “power cube with a switch” when they understand that the switch allows them to power the assembled cubes. Phase 4a seems to be a critical moment in the formation of voluntary action. This is when “the real or actual conflict” of stimuli takes place (Vygotsky, 1997). The voluntary action of the child is now rendered possible by having given meaning to the power cube and being able to activate it when they decide to.
Phase 4b. Closure of a conditioned connection between an external stimulus and the decided reaction	11 min 20 sec	The child expands their knowledge, creating a new configuration (Figure 7) by mobilizing the germ cell (switch of the energy cube. They have expanded their knowledge to solve the problem and developed the meaning of the activity. Although the conceptualization can be considered by the teacher as “naive” (not the same conceptualization as in the curriculum), the closure of the connection allows them to engage in artifact configuration that will shape the solution into an activity goal. The role of the teacher after this playful activity is to discuss the “naive” knowledge developed through the interaction and help connect it to domain-recognized concepts in the curriculum.
Apparatus 2	11 min 37 sec	The child effectively solves the task and is conscious of the achievement of a valid outcome for the problem situation.

The phases of decision-forming are also non-linear in the adult, with a prevalence of phases 1, 2, and 3 initially and finishing by phase 4. The switch in the conflict of stimuli is the same as observed in the child’s problem-solving, yet the adult also encountered a conflict in spatial structure which was solved by configuring the cubes horizontally, which is a more stable configuration.

Table 2

Analysis of the Adult Decision-Forming Apparatus

Phase	Time	Observed Behaviour (Video analysis)
Phase 1. Conflict of stimuli	0 sec	The adult listens to the instructions.
	22 sec	The adult evaluates the situation without touching the material for some seconds.
	26 sec	The adult explores the cubes and observes the differences among them.
Phase 3. Attribution to one stimulus of the significance of an auxiliary motive	44 sec	The adult conceptualizes the first germ cell by noticing the magnetic feature and starts to assemble the cubes one after another in a vertical way. They build a tower of cubes.
	55 sec	The adult tests the tower, trying to see if the tower moves.
Phase 1. Conflict of stimuli	1 min 5 sec	After failing the trial, they go back to the instructions. They show agency in terms of resource seeking. For this goal, they click on the system allowing them to listen to the instruction again.
	1 min 13 sec	The adult tries to build the cubes as a tower (Figure 8). Although the adult tries the tower configuration, they need to understand the cubes individually. After listening to the instructions, they try to test the tower again. They attempt to make the tower move, but there is a conflict of stimuli due to the need to separate the cubes to better understand them individually.
	1 min 23 sec	They decide to disassemble the cubes and start assembling them into a tower, which moves but also constantly falls. They persist with the idea of creating a tower despite multiple iterations where the tower falls apart.

Phase	Time	Observed Behaviour (Video analysis)
Phase 1. Conflict of stimuli	2 min 31 sec	After multiple failures of the same incorrect configuration (a tower structure which falls when the power is activated), the adult goes back to the instructions. They show agency in terms of resource seeking by clicking on the system which allows them to listen to the instructions to solve the conflict of stimuli. The spatial representation of the solution as a tower is a persistent idea (germ cell) which is inadequate to solve the problem. They are not able to inhibit this idea, which iterates the conflict of stimuli.
Phase 2. Conflict of motives	2 min 56 sec	After listening to the instructions, they try to test the tower figure again and again. They develop the same incorrect solution several times. They are stuck on the conflict of motives, so in between making the figure (built as a tower) and understanding how the cubes could assemble to overcome the problem encountered from the tower structure, which either falls or stops the movement.
Phase 3. Attribution to one stimulus of the significance of an auxiliary motive	6 min 40 sec	The adult realizes that the tower is not a stable structure after having experienced it more than ten times.
Phase 4a. Real conflict of stimuli	6 min 41 sec	The adult builds a horizontal figure (Figure 9). They compare the efficiency of the position of the cubes by building a horizontal figure instead of a vertical one (tower).
Phase 4b. Closure of a conditioned connection between an external stimulus and the decided reaction	6 min 41 sec	After comparing the position of the cubes, they decide to change the previous figure (vertical configuration) into a more stable one (horizontal configuration). They started by attributing the spatial configuration to a characteristic of stability, then went on to a more functional one.
Apparatus 2	6 min 44 sec	They succeed at the task with a horizontal configuration.

Figure 8

The Adult Tries to Build the Cubes as a Tower

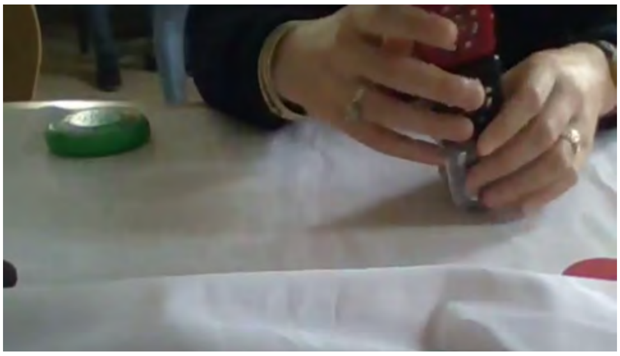
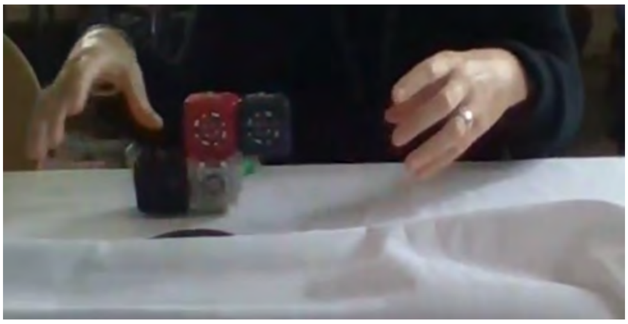


Figure 9

The Adult Builds a Horizontal Figure



Detailed Analysis of the Phases of the Decision-Forming Apparatus

Each phase is further described based on the analysis of the child's and the adult's experiments.

Phase 1. Conflict of Stimuli.

The initial situation leads to a conflict of stimuli between the instruction and the material artifacts. Even if instructions are given to the participants (creating a moving vehicle), it is not perceived as a problem if the participant internalises them through the manipulative exploration of the cubes. Therefore, there is no problem until the participant has perceived the situation as such. Then, the conflict appears between the instructions of the task (creating a moving vehicle) and the manipulation of the four cubes (at 50 seconds for the child and 44 seconds for the adult). The instructions are meaningless and decontextualized, generating a conflicting situation between the instructions and the tools if the participant has not yet explored the cubes. Instructions are not neutral and equally perceived, but they are enacted in each situation by a participant having a certain historical-cultural background.

This initial conflict of stimulus generates a certain perplexity. As described by Yew and Goh (2016), in problem-solving, Dewey (1933) observes how the learners should "make connections to this 'perplexity, confusion, or doubt' by activating their individual and collective prior knowledge and finding resources to make sense of the phenomenon" (p. 76). Dewey explains the "cognitive element of learner engagement by describing the origin of thinking as 'perplexity, confusion, or doubt' that is triggered by 'something specific which occasions and evokes it" (p. 12).

Phase 2. Conflict of Motives.

The resolution of the conflict of stimulus activates different motives (Sannino, 2015) which are necessary for a problem situation to be recognized as such. The initial tensions on the problem situation given by the instructions, as an absolute and necessary foundation related to conflicting motives, lead to cognitive dissonance. In some cases, conflicting motives are double-bind dilemmas and can be paralyzing if they are not prioritized. We can have a double-bind analysis: how to connect the faces of different cubes, but also how to activate the technological affordances on the cubes (e.g., wheels or switches). We can observe a certain paralysis at this stage of conflict of motives, especially in the child (which lasts up to 26 seconds during the initial phase). At this stage, where the participant doesn't know what to do, the tinkering interaction with the material helps to solve the conflict of motives. Being in a context of evaluation with an experimenter, these conflicting motives need to be solved because of the implicit time constraint to respect through the performance. During this period, the person doesn't know how the participant will go ahead with the task.

The child is engaged in the task but is at first paralyzed in front of the material after listening to the instructions (at second 16). After the initial paralyzing, they need the instructions to be repeated twice, then do not engage in any action before second 48. Contrarily, the adult engages rapidly in the manipulation of the tools. They are only initially paralyzed four seconds before starting the interaction. The analysis of the three persons engaged in the triangulation of data analysis has permitted the identification of momentary paralysis expressed in the form of conflict of stimuli. The time taken is not only a pause but an observable conflict of stimuli which needs to be overcome.

Phase 3. Attribution to One Stimulus of the Significance of an Auxiliary Motive.

After analyzing the characteristics of the cubes and their respective faces, the participant can try to invoke a cognitive strategy invested with meaning and engage in building a second stimulus. By exploring the cubes, the participant can find the cubes' technological affordances, such as the switch button or the wheels. This discovery generates a second stimulus for solving the task. For example, when the participant sees the wheel (stimulus), the participant can create meaning (something to move the vehicle), and then can try to verify the significance, e.g., by touching the wheels or putting the wheel on the table to test if they move as expected. In this case, the child gives an auxiliary motive to the wheels and is required to overcome this misconception to update the meaning given to the wheels.

Phase 4a. Real Conflict of Stimulus is Described as Conflicting Different Receptors on the Brain.

> A struggle is always going on in the body between different receptors for a common motor field … As Sherrington explains it, any consummated reaction, any victorious reflex, has won out only after a struggle, only after a conflict at a point of collision. Behavior, then, is a system of 'victorious' reactions. … All behavior is an unabating struggle, which does not subside even for a minute. (Vygotsky, 1925/1979, p. 15-16)

Vygotsky's description of conflicting perception stimuli is also observed in the field of neuroscience (Passamonti et al., 2009). In the CreaCube task, having four different cubes leads to an important number of conflicts of stimuli, including the cubes' position, colours, and different affordances. The subject needs to solve these different conflicts of stimuli to focus on one of them to explore it.

The CreaCube task avoids scaffolding the stimuli by giving the participant a complex set up of unknown robotic material. In this context, the complexity is more authentic than in tasks in which the stimuli are organized sequentially.

Phase 4b. Closure of a Conditioned Connection Between an External Stimulus and the Decided Reaction.

Participants should decide to focus on a certain stimulus. The case studies lead us to observe the focus of the child on the wheels and the switch. The focus of stimuli in the adult is initially on the magnetic properties of the cubes and then on a vertical configuration. They require several failures with this configuration before trying a new horizontal structure that will ensure the stability of the artifact.

To solve the task, the participant engages in a series of decisions regarding the arrangement of the apparatus to grasp the different salient stimuli provided by the proposed material. Through these different loops, the participant advances in the problem-solving task by activating DS in a series.

Double Stimulation: A Meaningful Approach for Understanding Creative Problem-Solving

The principle of double stimulation can be observed through a creative problem-solving task that engages the manipulation of tangible robotic cubes. The first stimulus is the problem situation, and the second stimulus emerges through the interiorization of the manipulative experience of the material. When the subject observes the existence of wheels, they are stimulated to think about the possibility of using or activating the wheels to move the vehicle. They can overcome a crucial tension and develop a new understanding of the problem.

Through the continuous exploration of the technological affordances of the cubes, the participant engages in further third (e.g., finding the magnetic capability of the cubes), fourth (e.g., finding the switch button), and more stimuli (e.g., understanding the interaction according to the cube positions) which help the participant reduce the problem space and get closer to one of the possible successful configurations that will complete the task.

Discussion

This study is situated in the continuation of Sannino and Laitinen’s (2015) approach to the analysis of decision-forming apparatus, however, in this study the nature of the object manipulated in the CreaCube problem-solving task is materialistic. The study could reveal fruitful methodological research perspectives but also support teachers’ capacity for understanding problem-solving tasks in any formal learning environment. This study provides new perspectives for understanding the difficulties learners can encounter when they face a complex problem-solving task. The conflict of stimuli in the CreaCube is observable because of the tangibility of the artifact, which is also a source of conflict of motives. In this task, the modular robotic cubes are simultaneously the tool and the object. The dialectical approach to the cubes is the object to be shaped into a certain configuration as well as being the instrument to be built into a movable vehicle. A rapid and tangible interaction of the first and second stimulus across the problem-solving process is developed when the participant manipulates the object/tool. Manipulable VCPOs (Ness & Farenga, 2016) engage the participant in the rapid and concrete activity of problem-solving that is observable through the building process of the participant. Affordances of interactive VCPOs create new opportunities for generating conflict of stimuli. These affordances are actualised in their meaning for the subject through interactive manipulation. Interactivity of robotic tools provides powerful *objects-to-think-with* (Papert, 1980) and contributes to the generation of second stimuli. What is initially perceived as a “simple cube” is transformed at a certain moment into a “power cube with a switch” the moment the child understands the switch allows them to give power to the assembled cubes. Affordances are updated at the moment the conflict of stimuli is solved. There is a clear link between affordances and DS in the problem-solving process with interactive tools. This approach to the micro genesis of the activity can be also related to the prior work of Rabardel (1995), in the instrumental genesis which operates between the participant’s perception of the potential of the material and the construction of knowledge using the artifacts.

CreaCube is an ill-defined robotic problem-solving task provoking a cognitive dissonance by using DS and through which we can document conflict of stimuli and conflict of motives, both being important in engaging the subject into volitional action by giving new meaning to the task and by resolving the problem in a creative way. In creative problem-solving, as opposed to algorithmic problem-solving (Norqvist et al., 2019), current knowledge cannot be used by the participant to solve a task. The situation necessarily requires being creative, engaging in an interactive way to explore the tools, generating additional stimuli that solve the conflict of stimuli, and then overcoming the conflict of motives. As Ilyenkov (2007) stresses, through the *materialist dialectics* perspective, the participant engages in exploring unusual methods of operations. According to Ilyenkov, we should engage learners in “formulating contradictions and then find its real resolution through the concrete examination of the thing, the reality, and not by means of formal verbal manipulations that fudge contradictions instead of resolving them” (p. 21). This process that allows the generation of *germ cells* (Engeström & Sannino, 2010) is key in the decision-forming apparatus to solve the task successfully.

A short but complex task, such as CreaCube, challenges usual problem-solving methods due to the cognitive dissonance generated at the start of the task. In this study, the participant is required to engage creatively in generating stimulus by configuring the four cubes in different ways and to arrange these cubes, with important differences in terms of functional features, in a way that allows them to move autonomously, representing a “gulf of execution” (Norman, 1986) in the dissonance observed between the given tools (four cubes) and the goal of the task. The gulf of execution is considered in relation to the initial system of activity and the object which will require a reconfiguration of the activity system. Through the different interactions, the participant should build a bridge of understanding by actualising their understanding of the object affordances. This requires generating conflict of stimuli (phase 1 of decision-forming apparatus) through interaction, solving conflict of motives (phase 2), converting stimuli to auxiliary motives (phase 3), and then starting to engage in the closure of a conditioned external connection and an unmediated stimulus to decide to react (phase 4a), to finally forming the second apparatus to generate a creative solution to the ill-defined problem (phase 4b). The consideration of problem-solving using educational robotics engages a materialistic dialectic in problem-solving through the configuration of the artefacts mediating the activity. The materiality of educational robotic tools engaged in the task requires a wider range of studies to characterize the activity within its complexity. The enlarged way of considering materialist dialectic is one of the research contributions of this study on solving as a dynamic process consisting of different cycles of decision-forming.

Conflicts of motives are essential components of the principle of DS (Hopwood & Gottschalk, 2017) however we lack empirical evidence based only on these two cases, in which only one conflict of motives was observed in the adult activity. Further studies would be required to interview the subject after the activity and identify the different motives and their role in the decision-forming process. More instances of conflict of stimuli than conflict of motives were observed in this interactive tangible task. The dynamic relationship of the resolution of conflicts of stimuli can be observed in the CreaCube task through the materiality of the artifact which allows us to observe the focus of the participants, through the way the stimuli are understood but also through the misconceptions that require resolution to solve the task.

Even though the case studies are happening in a very short timeframe, the principles and features of the model of DS are coherent in a micro genetic analysis like the one of the CreaCube problem-solving task. The temporality of the problem-solving task permits one to focus on the DS process which allows one to observe behavioural gestures and artifact configurations to understand the decision-forming process. Within the interactions developed by the subject with the educational robotic tools, there are different cycles of decision making in which the concept formation allows advancing towards the activity's object.

Our study enriches the understanding of the genesis of the volitional act at the micro genetic level. Through this study, we have observed the non-linear process of the decision-forming apparatus (Sannino & Laitinen, 2015), which requires consideration of the micro genetic level in relation to conflict of stimuli, conflict of motives, and the evolution of the artifact which materializes the process of tangible problem-solving with interactive modular robots.

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