Revisiting Piaget and Vigotsky: In Search of a Learning Model for Technology Education.

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Technology education has always aimed at forming knowledgeable adults, responsible citizens, and capable professionals. Among its central objectives are:

– Familiarizing pupils with the concepts, artifacts, and skills in a given domain of human achievement;

– Enabling pupils, through a cultural approach of that domain, to give it meaning and sense;

– Giving pupils a basis for grounding their future vocational choices and acquisistions; and

– Contributing, through the specific forms of cognitive involvement required by that domain, to the pupils' general intellectual development.

This article focuses on the last objective of education: cognitive development. Drawing upon Mitcham's (1978) observation that technology education achieves its objectives via a concern with making and using artifacts, I examine here the relationship between cognition and the use of artifacts in technology education. The idea is to try, from the context of technology education in France, to contribute to a fuller understanding of human-artifact interaction in order to provide more information and further guidance for curriculum design and delivery in technology education.

Epistemological and Psychological Status of Artifacts in French Technology Education

Technology education was first introduced into the national general education curriculum for French middle schools (pupils aged approximatively 13 to 15) in the early 1960s and has been present ever since, although under different forms (Lebeaume, 1996). In this first section, an attempt is made to trace the underlying evolution in general philosophy behind curriculum change during that period and to see how it affects the status of artifacts as didactical objects. Roughly three periods can be distinguished within this evolution. During the initial phase, technology was essentially taught by physics teachers. Curriculum design and curriculum delivery were, however, closely supervised by the influential technical education hierarchy which, within French public education, is in charge of separate technical and vocational school systems. Nonetheless, policy was that technology should be strictly general education and any vocational connotations were avoided. Consequently, the emphasis was non-artifact based, not making or using learning. Curriculum centered on an analytical, logical, and experimental approach of artifacts that were dominantly referred to as "technical objects." Textbooks presented elaborate theoretical fomalizations of morphology, function, and kinetics. While this described the scientific status of technology, it contrasted with the triviality of the devices-essentially mechanical-actually studied in class (e.g., the notorious door-latch, which left its brand on a whole generation of teachers and pupils). From the cognitive point of view, this first version of school technology clearly tapped the rational and abstract capacities of pupils, very much in the way that a science course could have.

In 1977 this first period ended with a dramatic shift in the official policy relating to technology education. Government and management had become gravely concerned about what they viewed as a general disinterest among young people in industry. Also school was seen as laying too much value on abstract knowledge and skills at a time when it was thought that increased automation would lead to a general "deskilling" of jobs. A sweeping educational reform was undertaken, and for the first time technology, renamed "manual and technical education" (EMT), became a mandatory four year subject for all pupils from 11 to 15 years of age. The stress was on acquiring a basic technical vocabulary; becoming familiar with technical plans, graphics, and drawings; and learning practical procedures such as analyzing a structure, relating an element to its function, organizing one's work space, rationally using tools or machines, being observant of method, precision and safety. Typical tasks were mostly of a domestic nature, such as laying wallpaper, plumbing and electric maintenance, or changing a window pane. However, pupils were also involved in woodwork and building coat hangers or mailboxes. In later years, plastics and electronics became frequent components in school production. Teachers of subjects such as handicrafts and housecrafts, which had been removed from the curriculum, were retrained for EMT, and new teachers were also recruited. Official rationale insisted on the importance of practical, concrete intelligence and manual skills as opposed to the more conceptual, abstract forms of cognition required for other school subjects, and low achievers were explicitely expected to benefit from EMT.

In the early 1980s, policymakers realized that the advent of new technologies in the workplace resulted in a demand for higher qualifications, rather than requiring fewer skills. Manual and technical education (with its emphasis on manual and craft skills) appeared to be completely out of sync with the emerging high-tech forms of management, production, and marketing. In 1985, technology education was completely overhauled. EMT was dropped and replaced by the new subject 'technology', which became mandatory through the four years of middle school. This was accompanied by an unprecedented effort by government regarding school equipment and teacher training. Technology classrooms were decked with computers, robots, and numerically controlled machine tools. For the first time, a new corps of specialized teachers was created and trained. Teachers of the former EMT underwent an intensive one-year retraining program.

Besides the emphasis on familiarizing pupils with advanced technology, the new curriculum, which essentially is still in effect today, stresses that pupils should be able to relate school activities to actual industrial practice. This is generally achieved through the "industrial project method" in which groups of pupils simulate 10 phases-from initial market study to final waste disposal. This sequence, meant to mimic the industrial production process, enables pupils to develop skills in negotiation and organization, varied complex problem solving, and both traditional and high-tech tool use. They also become familiar with industrial concepts and models. Noteworthy is the attention granted to marketing constraints. In many cases the method has led to stereotyped situations and routine activities that have recently come under widespread criticism. The curriculum is currently being altered in order to provide for more variety in the simulated industrial situations. Also, a number of conceptual and instrumental attainments have been redefined.

In each of the three periods that I have outlined, the status of artifacts as didactic objects varies. During the first period, technology education essentially saw artifacts as objects of study. The word 'technology' in French, implies an erudite discourse about the knowledge of techniques. During the EMT period, artifacts were embodied both by the handcrafted one-of-a-kind works made in class and by the material and graphic tools used to make them. developing skills with tools was a major objective and explicitly sought.

During the current phase, the characteristic role of artifacts is as industrial and marketable products. In the latest directive released in 1998, however, pupils are also expected to develop instrumental competencies with measuring instruments, fabrication equipment, and graphic means of representation. Such contrast in curriculum content and orientation during these successive changes certainly reflects instability in the social expectations regarding technology education's contribution to education and child development. It also reflects both uncertainty as to the epistemological status of technology and the lack of a coherent model of student cognitive functioning and growth in technical settings. Blame for this situation cannot be entirely placed on policy makers and educators. Anthropologist M. Godelier (1991) and historian J. Perrin (1991) have pointed to insufficient fundamental scholarship on technology and pleaded for an increase in interdisciplinary research.

Piaget, Vygotsky, and Artifacts

The same can be said about the psychological approach of human technical functioning. In this section, the relevance of two different conceptual frameworks is discussed in relation to modeling human interaction with artifacts. In Europe, during the first half of the century, several contrasting theoretical paradigms competed to explain human psychological behavior. Among these, one important current stressed the role of culture and society in the shaping of mental functions and processes and sought to articulate psychology within the wider realm of anthropological studies. Tool use, techniques, and work as fundamental dimensions of human activity were prominent topics for research. Some of the most influential psychologists of the time–Köhler, Vygotsky, Guillaume, Meyerson, Wallon, to mention a few– were major contributors of empirical evidence and theory. After WWII, however, scientific norms for psychological research favored methodologies and theoretical models inspired by the natural sciences and, later, by artificial information processing. Consequently, interest for complex and holistic, culturally determined behavior (which could no longer be treated as such) waned, and the authors and the tradition that had once tackled these problems receded into near oblivion.

Piaget

In France, Piagetian constructivism is the dominant psychological model that inspires educational theories of learning. One of the appealing features of the model to educators is its cultural, constructivist postulate. It is through action upon the outside world that humans are seen to generate both their cognitive structures and their knowledge. Cognitive structures are the more or less stable forms, that at a given stage of development, underlie a class of similar actions (e.g., the early grasping reflex, later, the prehension scheme, still later, mental manipulation). Knowledge is basically the awareness of the invariant properties of things (through the process Piaget calls empirical abstraction) and of the invariant properties-especially logical properties-of action (through reflecting abstraction). “All knowledge concerning reality ... results from actions or operations upon it which make it change thus revealing its stable and variational properties” (Piaget, 1980, p. 222). Cognitive growth can be represented as a spiral-like process: Interaction with some part of reality sets off an assimilation process ; existing structures are applied to the outside object. Either they are adapted and assimilation is successful or they fail. This creates a situation of cognitive imbalance that triggers accommodation. Through accomodation, cognitive structures are modified to take into account the resisting aspects of reality. Growth becomes a process resulting from the recurrent destabilization of the existing structure by novel and unexpected features of world objects, followed by the subsequent generation of a more powerful structure giving access to deeper reaches of the unknown, which eventually resists assimilation, and so on. Piaget, whose main concern was epistemology and who considered child psychology as an ideal testing ground for epistemological theory, saw this as a very general process, not limited to individual human cognitive growth but underlying, at one end of the development scale, biological evolution and, at the other end, the historical genesis of scientific knowledge.

However, he also very consistently stated that his work in psychology was restricted to what he termed the epistemic subject., that is, literally, a construct of the subject as a producer and processor of knowledge. Since the 1970s, when human problem solving emerged in the United States as both a new domain and a new paradigm in cognitive research, this focus on the epistemic subject has appeared as a limitation to some theorists. Inhelder and Cellerier (1992) pleaded for attention to what they call the pragmatic subject, claiming that if epistemic transformation-the alteration of the world for the pupose of generating knowledge-has been thoroughly researched in psychology, such is not the case concerning pragmatic transformation, in which knowledge is put to use for the purpose of altering the world.

Pragmatic transformation clearly embodies a caracteristic aspect of technology, and a theory of the pragmatic subject would certainly be welcome for technology education. Yet, this area of neo-Piagetian research appears, up to now, to have yielded only scant, even if interesting, results. One of the reasons may be that the Piagetian paradigm, because of intrinsic features, cannot be generalized to the study of the pragmatic subject. Pragmatic transformation in everyday situations departs from biological interaction with the world (such as animal interaction) in that it involves technical mediation-tools and corporal techniques. On the contrary, Piaget has always assumed a fundamental continuity between biological adaptative processes and higher forms of cognition. As a consequence, his model of interaction always boils down to a basically dyadic, face–to–face relationship between organism and environment, thus excluding any idea of mediation. This is, of course, true of other psychological models. As Norman (1991) pointed out, most of our scientific knowledge of human cognition focuses on the "single, unaided individual, studied almost entirely within the university laboratory" (p. 18). He also signaled the difficulty of "integrating artifacts into the existing theory of human cognition" (p. 18), notably because their approach cannot be undertaken within the restricted subject-artifact relationship. The appropriate unit of analysis in such situations, he claimed, is "the total system of human, task and artifact" (p. 19).

Vygotsky

Very similar views had been expounded by Vygotsky (1930/1985) more than half a century ago. Among the early advocates of a cultural approach of cognition mentioned earlier, he developed the most consistent and elaborate conception of the role of instruments. He radically criticized Soviet reflexology, Anglo-American associationism, and Piagetian genetic psychology-paradigms. Vygotsky felt these theories illegitimately "reduce complex superior psychic processes to natural processes and disregard the specific characteristics of the cultural development of behavior" (p. 27). He claimed that "alongside the acts and processes of natural behaviour, it is necessary to distinguish the functions and forms of artificial or instrumental behaviour" (p. 40). He argued that the introduction and use of instruments bring about far-reaching changes in cognition: "It activates a whole series of new functions linked to the use and control of the instrument selected; it replaces and renders useless a considerable number of natural processes, the work of which is developed by the instrument" (p.42).

Development is therefore seen as the result of a largely artificial process in which the mediation of instruments plays a leading role: The central point of our psychology, Vygotsky claimed, is mediation. Through artifactual mediation-both material and semiotic-human cognition engages in relationships with the material and social environment that are fundamentally different from nonmediated relationships.

It has been suggested (Rabardel, 1995; Vérillon & Rabardel, 1995) that one reason for this difference stems from the whole set of novel and specific possibilities and constraints that instrumented activity imposes on cognition. On the one hand, due to the mediation of instruments, the register of enabled action is enhanced in scope and in nature, opening new areas of potential development notably through access to novel means of action as well as to phenomenal and transformational properties previously out of reach. On the other hand, cognition is also oriented and brought to bear on specific structural and functional aspects of instrumented action. The activity required by mediated action is constrained both by artifact structure and the conditions linked to the specific nature of the transformations it enables. These constraints lead to generating artifact-specific forms of information retrieval and processing, of conceptualization, and of mental and motor skills. This tension between new enabling possibilities and new constraints is reminiscent of the Piagetian assimilation-accommodation cycle, but it differs considerably in that it cannot be represented by a dyadic model of interaction. In the following section an interaction model is proposed that provides a place within the classic subject-object relationship for an intermediary element: the instrument.

Towards a Psychological Model of Instruments and Instrumented Activity

Definitions: instrument, pragmatic, epistemic and semiotic interaction

An instrument is any object that a subject associates with his or her action in order to carry out a task. In most cases "instrumented" activity, this object is an artifact (i.e., a made object–such as a tool or a machine–that has been designed for a specific task.) However, natural objects-such as stones, sticks or even parts of the body-can be used as instruments. Also, artifacts are brought into play to perform actions for which they were not initially intended (e.g., using a wrench as a hammer), which shows that use is relatively independent from artifact design.

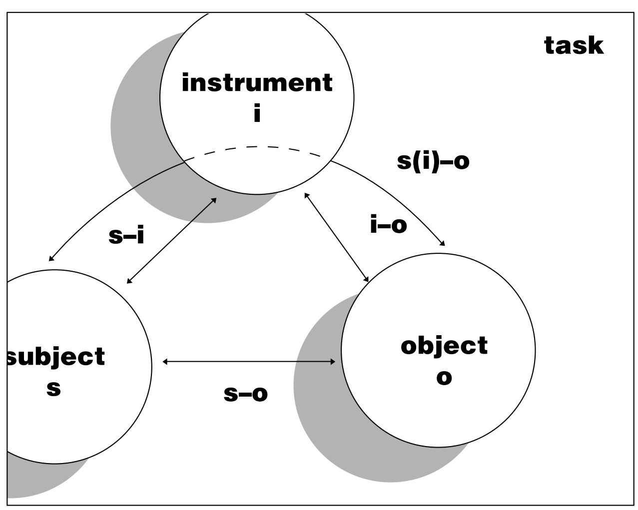
Instrumented action can be broadly distinguished according to whether it aims at producing transformations or affording knowledge. In technology education, instrumented actions (with tools or machines) generally aim at carrying out an anticipated transformation of some part of the environment in order to impart to it new desirable properties, consequently enhancing its value. Using Inhelder and Cellerier's (1992) terminology, such action can be termed "pragmatic". Bringing about transformations is, however, not the only purpose of instrumented interaction with the material environment. Artifacts (such as sensors, meters, for example) are also used to derive knowledge concerning the environment by detecting, registering, and measuring some aspect of reality not immediately accessible to the user. In this sense, this type of interaction is epistemic. Another distinction concerning instrumented activity in technological settings reflects the fact that action is not only directed towards objects but is also directed towards persons. Action in such situations can be seen as aiming at altering another subject's state of information. Communicative action is of this type, and industry requires the use of a wide array of verbal, gestural, and, especially, graphic codes. Such instruments may be designated as semiotic instruments. Of course, semiotic interaction may have either pragmatic or epistemic purposes.

As a matter of fact, instrumented activity whether material or semiotic usually comprises both pragmatic and epistemic phases. For example, a radar-monitoring task is dominantly epistemic, but it requires tuning, which is pragmatic. Inversely, a drilling task is essentially pragmatic, but variation in sound and vibrations during operation provide epistemic feedback concerning the ongoing transformation. Mountain climbers use their ice axes pragmatically to keep balance on the slope or to cut steps in the ice, and epistemically to measure snow thickness or to probe a crevice. They can even use their axes semiotically by planting them on the mountain top to signal their success to onlookers. In this instance, a single artifact serves as several instruments in different situations. In other instances, artifacts may be available but no instruments are elicited, such as when one is unable to operate an unfamiliar device or when archeologists or antiquarians come up with artifacts they no longer know how to use.

The point is that the instrument is a psychological construct distinct from the artifact. More exactly, the artifact, as a material or semiotic construct, is only a partial component of instrumented action. The other component is manifested by the complex set of representations, knowledge, mental operations, and motor skills that are brought into play by the user during operation. So that, in the words of Rabardel (1995), instruments are actually a two-fold entity-artifactual and psychological. Experience shows that instrumental genesis-the construction of such an entity-can be a drawn-out and difficult process. Appropriation is a word that describes the process by which an artifact becomes an instrument. It indicates the two directions in which this process takes place: towards the self and towards outside reality. The first meaning of appropriation requires the artifact to be integrated within one's own cognitive structure (e.g., one's existing representations, available action schemes, etc.) that in general, require adaptation. Rabardel termed this self-oriented construction "instrumentation." The second meaning indicates that the artifact has to be appropriated to an outside context. Specific ends and functional properties-some not necessarily intended by design-are attributed to it by the user. Adjustments are made to account for goal and operating conditions. Rabardel called this "instrumentalization."

The model in Figure 1 highlights the intermediary status of instruments in situated instrumented activity (SIA). Unlike the usual dyadic modeling of subject-object interaction, it underscores the multiple relationships that, in instrumented activity, bind together the subject, the instrument, and the object towards which instrumented action is directed. It shows that anlysis of such activity must take into consideration not only direct subject-instrument (s–i) and subject-object interaction (s–o) but also instrument–object interaction (i–o) and indirect subject-object interaction through the mediation of the instrument (s(i)–o). The task is shown as a back .ground to instrumented activity to indicate that instrumented action is always situated. The task is what gives meaning to the situation.

Figure 1. SIA Model.

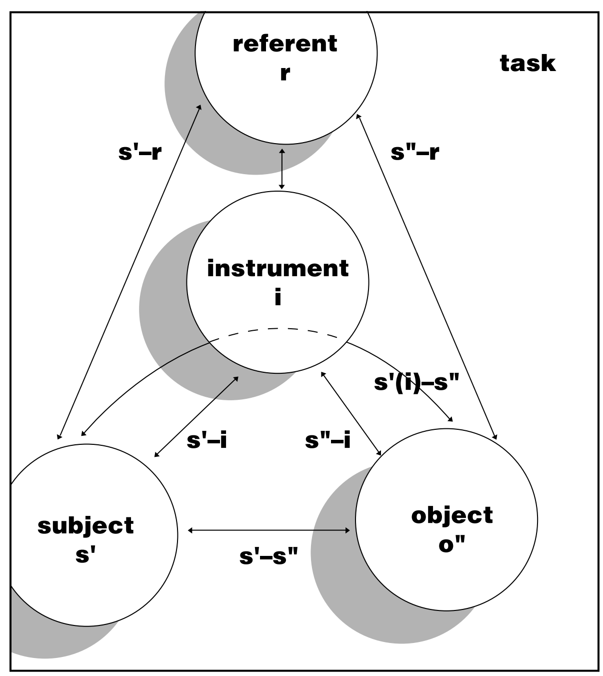


Consider middle school pupils familiarizing themselves with a hitherto unknown artifact, a lathe on which a cylindrical workpiece has been mounted (Vérillon & Rabardel, 1995). They have been asked to imagine the procedures to produce a smaller diameter cylinder using the machine. Their attention and first manipulations initially focus on the transversal and longitudinal handwheels. As they explore features of the lathe, they are likely to call upon prior representations and experiences with similar features with other artifacts (notably toys). Moreover, handwheels, by their very design, tend to elicit a certain specific and relevant type of manipulation (an example of what was referred to earlier as the constraints of required activity). Manipulation of the wheels causes the slide-rest to move and leads pupils to identify the possibility of directing tool motion. Coordination of the two wheels in order to obtain control of tool displacement requires a bit of time. Within the framework of our model, all this process involves mostly subject-artifact interaction. Attention is then drawn to tool-workpiece interaction (instrument-object interaction). A number of pupils initially view this interaction in terms of abrasion__metal cutting doesn't seem plausible to them. Their procedure consists of using one wheel to bring the tool in contact with the rotating workpiece and then, very slowly, with the other wheel, "wearing away" (their terms) matter along the part. Their fear is that uneven spreading of wear may result in an uneven cylinder. When asked how a tapered form might be obtained, these pupils suggest progressively longer wearing periods towards the extremity of the piece.

This example is illustrative of instrumental genesis. At this stage, these pupils have each constituted a similar instrument. A joint instrumentation–instrumentalization process has taken place that can be described in the terms of the model. Prior s-o interaction has led these children to form representations of metallic properties ("it's hard") as excluding any possibility of radical alteration such as cutting. Enabled action by the lathe (i-o interaction) is therefore seen in terms of wear or abrasion, which seems a "softer" approach. The subjects' actions (s-i and s(i)-o interaction) are consistent with this representation. They consist in bringing the tool into contact with the workpiece and monitoring the distribution of wear along its surface so as to obtain the desired shape. Of course this instrument eventually evolves. Dissatisfaction and/or discovery of new properties in the artifact or the object leads to change– generally interdependent– in instrumentation and instrumentalization. Progressive awareness that action with the longitudinal handwheel leaves tool–workpiece distance invariant is important headway and is often tied to the emergence of cutting as a possible transformation.

The SIA model has also been accommodated to apply to semiotically instrumented situations. Vygotsky (1930/1985) referred to semiotic instruments (symbols, codes, maps, drawings, etc.) as "psychic" instruments. "The psychic instrument basically differs from the technical instrument in the direction of its action." [Contrary to the technical instrument] the psychic instrument doesn't produce change in an object; it aims at influencing one's own, or someone else's, psyche or behavior" (p.43). Consistent with this view the model represents interaction as taking place between two subjects: a "transmitter" and a "receiver." Also, since semiotic instruments aim at modifying a receiver's information or its representations, a fourth element has been introduced in the SIA model: that about which there is information or representation-the referent (r). The referent is the object to which the transmitter's instrumented action on the receiver refers. The model consequently shows the two-fold function of semiotic instruments: a function resulting in the sensory and cognitive stimulation of the receiver and a referring function that enables relating to an external object. In other words,

Figure 2. SIA Model for Seniotic Instruments.



in semiotically-instrumented situations, mediation is two-fold: mediation of action of the transmitter upon the receiver and mediation to an object of reference common to both. A new set of relationships can be examined through this model. Instrument-referent relations (i-r) concern coding, that is, the semiotic solutions through which signified information concerning the referent is linked to signifiers (perceptible signifyng units within a given code). Subject-referent relationships (s'(i)-r and s''(i)-r) indicate a subject's relation to a referent object during coding and decoding. Direct s-r relationship points to knowledge, representations, and actual, virtual, or remembered perceptions that s' or s'' may have of the referent object.

This model has been used both for the analysis and the design of instruction in technical communication graphics, notably engineering drawing. It has been useful for focusing on certain aspects of technical graphic codes. For example:

–the intersubject relationship during the communication process (involving s'-s'', s'-i, s''-i, s'(i)-s'' and s''(i)-s' interactions). Subject interaction raises questions such as the nature of information, indices and symbols, and the need for common codes.

–the relationship between subjects, task, and referent (s-task, r-task, and s-r relationships): Technical tasks involve subjects with specific artifacts about which they need specific task-relevant information. What is at stake, at this level, is establishing descriptors of referents consistent with task demands (for example, the need for morphological and dimensional information in fabrication situations).

–the relationship between task, referent, and the semiotic properties of technical codes (r–task, s–task, r-I, and s(i)–r interactions). The structural characteristics of semiotic artifacts, just like those of material artifacts, can be related to the functions they are designed to carry out. The particular features of a given graphic code can be presented (notably to students) as specific solutions designed to convey specific information relating to a specific class of referents centered on a specific class of tasks.

The Psychological Basis for Instruction and Learning

In order to do their jobs, technology educators need epistemological and psychological frameworks to derive coherent representations encompassing their field of knowledge and their students' cognitive functioning. Such frameworks also help them to justify the importance of their teaching to students, parents, plus, teachers of other subjects. This is particularly true in France, where a centralized education system and a national curriculum favors strong disciplinary identity. In order to conceptualize their specific domain, teachers in disciplines relating to technology can rely on centuries of learned reflection within their academic community. In order to better understand their students' difficulties as well as their accomplishments, they can also benefit from the immense work of Piaget and his followers who minutely studied "the construction of reality in the child," as one of his influential books was titled. Piaget's "epistemic subject" can be seen as a model of how human understanding copes with the indistinctly made or natural world. Very much as a scientist, every child experiments and probes her environment in search of logical coherence. This work has produced a valuable framework for the comprehension of learning in mathematics and science education settings, and it is tempting for technology educators to look in that direction for a model of cognition in technological settings.

However, technology is concerned with making and using artifacts, and a purely epistemic approach would miss this essential dimension. An alternative model has been proposed, seeking theoretical guidelines in both post–Piagetian authors and the Vigotskian tradition. The former provides insight sin about "pragmatic" theories about cognition. Thus, action is not oriented towards the production of knowledge as in Piaget's conception. Rather, knowledge is activated and processed by the subject to elicit utilitarian transformations of his or her environment. This provides a basis for a psychological model of instrumentation, that is, a model of the cognitive process in which artifacts progressively acquire instrumental value and are integrated into one's mental and physical interaction with the world. Addressing these two dimensions, the pragmatic and the instrumental, seems quite crucial if we are to afford teachers a better understanding of cognition in technological contexts.

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