The use of instruments as a source of spatial knowledge

1. Introduction

Technological systems and work activities are filled with situations of a spatial or geometric nature—i.e., situations in which the subjects, whether students or professionals, must construct mental representations that involve spatial and/or geometric contents in order to accomplish their tasks or learn to do their work. For instance, drafting applies geometric concepts for analysing the shape of objects, and uses a system of graphics based on projective geometry in order to produce graphic representations [5]. Similarly, the production of mechanical parts on numerically controlled machine tools involves fully knowing in advance what the trajectories of the tools will be. It also involves the operator's having a mental image of the shape of the part—not only in its final state, but also in a number of intermediate states—and it involves spatially coordinating the part, the tool and the machine itself. Work situations, as well as professional and technical training, are therefore especially pertinent in the study of mental representations of technological systems and work activities are filled with situations of a spatial or geometric nature—i.e., situations in which the subjects, whether students or professionals, must construct mental representations that involve spatial and/or geometric contents in order to accomplish their tasks or learn to do their work. For instance, drafting applies geometric concepts for analysing the shape of objects, and uses a system of graphics based on projective geometry in order to produce graphic representations [5]. Similarly, the production of mechanical parts on numerically controlled machine tools involves fully knowing in advance what the trajectories of the tools will be. It also involves the operator's having a mental image of the shape of the part—not only in its final state, but also in a number of intermediate states—and it involves spatially coordinating the part, the tool and the machine itself. Work situations, as well as professional and technical training, are therefore especially pertinent in the study of mental representations of
Among the numerous problems in this area, the following are some of the main questions that arise: Do the tools and technological systems used by professionals in their work result in specific conceptualization? Do they lead their users to construct certain types of mental representations over others? Could those technological systems—and technology in general—perhaps even have an influence on cognitive functions in day-to-day life and, therefore, on cognitive development as well?

A number of authors, such as Leroi-Gourhan, Wallon and Vigotsky, have formulated anthropological hypotheses of a similar nature.

The crucial problem, however, is how such hypotheses can be explored in a research framework. How can one determine how the use of objects and technological systems affect cognitive functions and, especially, cognitive development?

The approach we adopted [4] consists in considering the tools and technological systems as *instruments* that serve as an interface between the subject and the situation on which he/she wishes to act. The instrument modifies the nature of the subject’s actions, not only because he/she will have to work with the instrument, but also—and especially—because he/she will have to use the instrument to modify the situation at hand. The instrument is therefore an intermediary in the subject’s relationship with the situation in terms of action. However, it also transforms that relationship in terms of information: for instance, technological tools often involve systems that allow for information feedback (formalized and coded to varying degrees). In other words, the instrument is a twofold mediator between the subject and the situation at hand: in terms of action and, conversely, in terms of feedback. Thus, from a constructivist point of view, in which concepts are formed by subjects on the basis of their actions, we have a means of explaining the possible effects of instruments on the cognitive functions and even the cognitive development of children. *Figures 1 and 2* illustrate the difference in the complexity and nature of relationships between direct-action situations and situations in which an instrument serves as an intermediary.

A mere visual comparison of *Figures 1 and 2* is sufficient to highlight the profound difference between situations involving direct action and those in which there is an a spatial and geometric nature.

Parmi les nombreux problèmes de ce champ, l’une des questions majeures posée par ce type de situation est la suivante: les objets, les systèmes techniques utilisés par les professionnels pour leurs activités sont-ils la source de conceptualisation spécifique? Conduisent-ils ceux qui les utilisent à construire plutôt certains types de contenus représentatifs que d’autres? Les systèmes techniques, l’univers technologique n’ont-ils pas même dans la vie quotidienne une influence sur le fonctionnement cognitif et de ce fait potentiellement sur leur développement cognitif?

De nombreux auteurs tels que Leroi-Gourhan, Wallon ou Vigotsky ont formulé des hypothèses anthropologiques de même nature.

Le problème crucial est cependant celui de l’opérationnalisation de ces hypothèses dans une perspective de recherche; comment mettre en évidence les effets potentiels de l’utilisation d’objets et de systèmes techniques sur le fonctionnement et plus encore sur le développement cognitif?


Ainsi, dans une perspective constructiviste, où les conceptualisations sont développées par les sujets à partir de leurs actions, nous avons une voie d’explication des effets possibles des instruments sur le fonctionnement voire le développement cognitif des enfants. *Les figures 1 et 2* illustrent la différence de complexité et de nature des relations dans les situations d’action directe et dans celles où l’action est médiatisée par un instrument.

Une simple comparaison visuelle des *figures 1 et 2* suffit
intermediary instrument. The latter involve greater and more diversified interaction, and we shall see that such situations have other characteristics as well. In addition to these models, we shall identify the possible effects on cognitive functions and explain, or at least describe, the underlying mechanisms. That has been the focus of our research, some of the results of which will be presented in this paper.

2. Instruments and testing apparatus
We used an educational robot with a remote arm (Figure 3) to carry out movement in space. The properties of the control device were systematically varied:
- remote articular manipulation: control over the movements of different parts of the robotic arm by means of a microcomputer keyboard;
- remote positional manipulation: control over the positions in space of the "claw" portion of the arm by means of a cursor assembly (Figure 4).

In each of the test situations, the subjects were faced with identical tasks involving the displacement of objects. The subjects were thirteen secondary-school students between 13 and 15 years of age (five tested individually and eight divided into two groups).

The stimuli for the mental representations formed by the subjects consisted of graphics and spontaneous or prompted verbalization—a set of elements that were explicitly produced in a communicative context with the test administrator or peers within the group. We endeavoured to determine how the mental representations of the instrument evolved as they related to both the situation they affected and to the actions of the subjects.

In the first situation, remote manipulation of the robotic arm was carried out by means of a control assembly consisting of three orthogonal cursors distinguished by colour: yellow, red and blue (Figure 4). The three cursors correspond to the three reference axes in the work space. As we explain to the students in the initial instructions, the shaded area represents the base of the robot in the work space.

We refer to the cursor device as the control space. The simultaneous positioning of the cursors on each of the axes defines a point in the control space which corresponds to the position of the claw of the robotic arm in the robot's work space. The term work space refers to range of points which can be reached by the claw of the robotic arm. The
The use of Instruments as a source of spatial knowledge

Figure 5
A priori task analysis. Differing complexity according to control device used.
5a. Cursor control.
5b. Keyboard control.

A priori de la tâche. Différence de complexité dans la gestion des déplacements de la pince en fonction des dispositifs de commande.
5a. Dispositif de commande par curseur.
5b. Dispositif de commande clavier.

work space, which encompasses the robot, has a frame of reference which is coordinated with the control device. For the claw to reach a given point within the work space, the cursors simply have to be positioned on the corresponding point in the control space. The term robot space refers to the space in which the positions corresponding to parts of the robot are located in relation to each other, independently of the frame of reference in the control space and the work space. The opening and closing of the claw is directly controlled by commands keyed into the microcomputer.

The terms work space, control space and robot space are used by the researcher alone, and do not influence the students’ concepts which, as we shall see, evolve and are not necessarily expressed in terms of space.

We also advanced the hypothesis that students would find the cursor approach relatively simple given 1) the direct relationship established between the control space and the work space, and 2) the homogeneity of the two spaces, as each has a corresponding frame of reference consisting of three orthogonal axes.
A final hypothesis was that students would undoubtedly find using the cursors easier than using the microcomputer keyboard to control the robotic arm. It is evident from an a priori analysis of the task that the two methods of controlling the robotic arm are not of equal complexity:

- The cursor control has a direct bearing on the position of the mechanical claw in the workspace; therefore, the user need not be concerned with the movements of the various segments of the robotic arm and the rotations of the joints.
- With use of the keyboard, the primary level of control affects the joint rotations which, in turn, determines the second level, the movement of the claw in the workspace. Thus, control of changes in the claw's position in the workspace is not achieved directly, as with the cursor-control device, as illustrated in Figure 5. It should therefore be more difficult to operate.

In actual fact, however, learning to control the robotic arm by means of the keyboard proved faster and easier than with the cursor system. That does not mean, of course, that the students had no problems at all using the keyboard-based system; however, they simply needed a few minutes to achieve adequate control of the device and successfully carry out their assigned tasks of moving objects. On the contrary, the tasks were much more difficult with the cursor system. Certain students needed more than two hours to achieve a comparable level of performance.

We shall now examine the different stages in the mental representation process, not only to understand the nature of the difficulties encountered by the students, but also to analyse their representations so as to verify our hypotheses concerning the contents of the representations.

3. Mental representations and remote control by means of cursors

A1. Direct extension of students' actions (Figure 6)

All students go through the first representation stage, which consists in trying to associate an observable movement of the robot (i.e., a movement of a segment of the robotic arm, a rotation of a joint, etc.) with a movement of the control device—e.g.:

- the blue cursor makes the base turn
- the red cursor controls the elbow

The problems encountered will not be elaborated upon here, as the results are presented by M. Bélanger in another article in this volume which explains the nature of the difficulties in controlling that type of system.

Nous ne les détaillerons pas ici: les résultats présentés par M. Bélanger dans un autre article de ce numéro mettent en évidence la nature des difficultés pour le contrôle d'un système analogue. Le lecteur pourra donc s'y reporter.

3. Les représentations mentales en télé-manipulation par curseur

A1. Le système, simple prolongement des actions cle l'élève (figure 6)

Tous les élèves passent par ce premier niveau cle représentation. Ils cherchent à associer une transformation observable sur la machine (un mouvement d'un segment de bras, la rotation d'une articulation...) avec un type d'action sur le dispositif de commande. Par exemple:

- le curseur bleu fait tourner la base
- le curseur rouge fait bouger le coude
- le curseur jaune fait bouger l'épaule

L'élève semble penser action plutôt qu'espace: Le dispositif de commande est le lieu où il peut agir directement, le bras manipulateur est le lieu où se liront les effets des actions et, c'est en contrôlant perceptivement, pas à pas, ces effets que l'élève va gérer les évolutions de la pince dans la zone de travail. Il pourra ainsi saisir et transporter des objets. A ce niveau, le robot et son dispositif de commande constituent pour l'élève l'équivalent d'une prothèse. Elle prolonge son
The use of instruments as a source of spatial knowledge

L'utilisation d'instruments est-elle une source de savoirs spatiaux?

Figure 6
Diagram of mental representation when system is considered an extension of subject's actions.
Schématisation de la représentation lorsque le système est considéré par l'élève comme un simple moyen de prolonger ses actions.

- the yellow cursor controls the shoulder joint

Students seem to think in terms of action rather than space. The cursor device is a means of acting directly; the results of those actions can be observed in the robotic arm. It is through perceptive, step-by-step control of the arm that the students will control the movements of the claw in the work space, and will thus be able to use the claw to pick up and move objects. At this stage, the robot and the control device are like an artificial limb to the students. It extends their actions in a space which they undoubtedly consider of a similar nature to that in which their own movements are carried out. The hardware certainly imposes specific constraints which must be taken into account, but at this stage, that does not yet lead to the formation of a specific mental representation of spatial properties. In reality, even if the students' mental representations allow for approximate control of the robot's movements in the forward area (Figure 3, zone 3), it becomes inadequate as soon as the side zones are involved (zones 1 and 2), which therefore incites them to develop their mental representations further.

A2. Les effets des actions sont différenciés en fonction des zones de l'espace de travail
Comme dans le type de représentation précédente, la machine a, pour les élèves, une fonction qui la rapproche d'une prothèse. Elle prolonge l'action propre et elle est gérée par le déplacement des curseurs considérés comme indépendants les uns des autres. Mais l'effet des actions est conçu comme variant en fonction des positions de la pince dans l'espace de
A.2 The results of actions differentiated according to zones within the work space

As in the previous type of representation, the role of the hardware is similar to that of an artificial limb. It extends the students' actions, and is controlled by movement of the cursors, which are considered independent from one another. However, the students perceive that their actions have different results according to the position of the claw in the work space. Thus, when the claw is operating in zone 1 or 2 (Figure 3), the primary result of moving the red cursor is movement of the elbow, with simultaneous movement of the base (though minor). However, when the claw is in zone three, the same cursor has an effect on the elbow only. In their mental representations, the students thus try to differentiate between the characteristics of the "artificial limb" and the space in which they actually move. The robot's work space is still seen as a space for movement, but not a homogeneous one, as the same movement will not have the same effect in each zone. When the students realize that the effects differ according to zone, their mental representations acquire greater operational validity. Representations of the properties of the instrument and the space which it affects simultaneously evolve and become more complex.

A.3 Cursor movements seen as interdependent

In the third stage, the representation of the instrument's properties becomes more specific in relation to a more subtle differentiation among the properties of the robot's work space. In certain zones within the work space, the effects of the cursors are no longer disjointed; they are now seen as interdependent. For example, a student may observe added effects in the boundary area between zones 2 and 3: the blue cursor normally causes the base to turn, but when the red cursor, which makes the shoulder turn, is operated in that area, it causes the base to turn slightly as well. It is as if the red cursor had an adjunct effect on the blue one. In the previous stage, the mental representations concerned the properties of the operative part of the robot (for the subjects, the place to observe the effects of their actions) and the robot's work space; at this stage in development, the properties of the work space, as well as those of the control device, are taken into account: in certain instances, movements of the cursors will be simultaneous. The cursors are thus considered interdependent. Nevertheless, it seems that
The use of instruments as a source of spatial knowledge? L'utilisation d'instruments est-elle une source de savoirs spatiaux?

**Results:** movements and trajectories of the claw in the work space

**Subject:** Information on movements of the claw in the work space

The control device remains merely the locus of the subjects' actions and has not yet given rise to spatial representation.

In the three stages we have outlined, mental representations develop through an interrelated process of differentiation and specification of the properties of space (which becomes heterogeneous for the student) and those of the instrument (both the operative part and the control part).

However, the representations belong to the same category: the operative part of the robot remains the locus in which the effects of the subject's actions can be observed, while the work space of the hardware itself seems to be considered as a space for movement, in which movements of the body are replicated.

**B.1 The work space:** an area for subjects to observe the effects of their actions (Figure 7)

At this stage, an important transformation can be observed in the contents of the students' mental representations. The results of the subjects' actions are no longer interpreted in terms of articular rotations or movement of segments of the d'autre part en ce qui concerne sa partie dispositif de commande. Cependant, ces représentations appartiennent à une même catégorie: la partie opérative du robot reste le lieu pertinent de lecture des effets des actions pour les sujets, tandis que l'espace de travail de la machine reste semblable-t-il considéré comme un espace de motricité, de déplacement à l'image de celui du corps.

**B1. L'espace de travail devient le lieu de la lecture des effets des actions (Figure 7)**

Avec ce niveau, nous voyons apparaître une transformation importante du contenu des représentations. Les effets des actions ne vont plus être interprétés en termes de rotations articulaires ou de déplacements des segments du bras les uns par rapport aux autres, c'est-à-dire par référence à l'espace propre de la machine, mais en termes de relations d'une partie du robot (la pince) à l'espace de travail de la machine. L'espace de travail, initialement espace de déplacement devient le lieu par rapport auquel le sujet va lire les effets de ses actions, tandis que l'espace de commande va...
robotic arm in relationship to each other—i.e., with reference to the **robot space**—but in terms of the relationship between a part of the robot (the claw) and the **work space**. The work space, which was initially a space for movement, becomes the area in which the subjects can observe the results of their actions, whereas the control space will not only be considered the locus of those actions, it will be viewed in terms of the relationship between its spatial properties and those of the work space. For example, a student may observe that the blue cursor cause a right to left move of the claw while the red one cause a front to back move. The claw movements are then directionally identified in the work space. The next step will be the realization that the movements of the cursors and the mechanical claw are proportional. Once again, the concepts pertaining to the robot and to the situation affected by it develop alongside each other. The control device takes on the status of a **control space**, and the movement within that space is directly related to the transformations achieved in the work space. Correspondingly, the operative part of the robot and the transformations it performs cease to be a pertinent locus for the subjects to observe the results of their actions.

**B.2 From movement to positions: the construction of reciprocal relationships, a control space and a work space (Figure 8)**

The properties of both the instrument and the situation affected by the subjects' actions become restructured in an integrated way at the final stage. The effects of the movement of the cursors are no longer thought of in terms of movements alone, but also in terms of the positions of the claw in the work space. The positions of the cursors in the control space are viewed in relation to those of the claw in the work space. At the same time, using the cursor comes to mean assigning it a position in the control space. The control space and work space are represented in positional terms.

First, the positions are defined as the positions of objects in space in relation to each other—for example, if the student positions the blue cursor near the area that represents the base of the robot on the control device (Figure 4, shaded area), the claw will be positioned near the base in the work space. **It is only at that point that the control area takes on representative properties for the subject.** Only at that stage is the significance of the shaded area on the control device (Figure 4, representing the base of the

B.2. Des mouvements aux positions, constructions de relations réciproques, espace de commande, espace de travail (figure 8)

Enfin, à un dernier niveau, apparaît une nouvelle construction conjointe des propriétés de l’instrument et du réel objet de l’action. Les effets des actions sur les curseurs ne sont plus pensés uniquement en termes de mouvements, mais aussi de positions de la pince dans l’espace de travail. Les positions des curseurs dans l’espace de commande sont mises en relation, en correspondance avec celles de la pince dans l’espace de travail. Simultanément, agir sur un curseur devient lui donner une position dans l’espace de commande. Espace de commande et espace de travail sont représentés comme des espaces de positions. Elles sont d’abord définies comme les positions des objets de l’espace les uns par rapport aux autres: par exemple, pour un élève, si le curseur bleu est positionné près du dessin du socle sur le dispositif de commande (zone hachurée, figure 4), alors la pince sera près du socle dans l’espace de travail. L’espace de commande acquiert à ce moment et à ce moment seulement des propriétés représentatives pour le sujet. C’est seulement à ce niveau que la signification de la zone hachurée (figure 4 image du socle du robot sur le dispositif de commande) est prise en compte dans la représentation des propriétés du système, alors que la signification en avait été explicitée aux élèves dès les consignes initiales.

Les positions sont ensuite définies par référence à des systèmes de coordonnées qui concernent à la fois l’espace
4. Discussion and Conclusions

As stated previously, the nature of the instrument used to carry out transformations in space has a profound influence on the content of the mental representations formed by the users. Thus, a device that controls articulation leads to representations that are developed in relation to the robot (robot) taken into account in the representation of the system's properties, even though it was explained to the students in the initial instructions. The positions are then defined with reference to the coordinate systems that pertain to both the control space and the work space. Therefore, in the students' mental representations, there is a bijective correspondence between the set of points that the claw can reach within the work space and the set of points that can be defined by the cursor positions in the control space and the control space of the robot. The lines along which the cursors move correspond to the axes in the work space, and the combined positions of the cursors define the position of the claw in the work space. Hence, in the students' mental representations, there is a bijective correspondence between the set of points within the work space and the set of points defined by the cursor positions.

Figure 8
Schematisation de la représentation lorsque les relations géométriques entre l'espace de travail et l'espace de commande sont constituées.

4. Discussion et conclusions

Nous avons constaté que la nature de l'instrument utilisé pour effectuer des transformations dans l'espace influe profondément sur le contenu des représentations construites par les utilisateurs. Ainsi, un dispositif de commande permettant de contrôler les mouvements articulaires conduit à des représentations éloignées des mouvements possibles des articulations, tandis que l'espace de travail, qui correspond à la machine, est facilement accessible dans l'espace des points définis par les positions des curseurs dans l'espace de commande. Donc, dans les représentations mentales, il y a une correspondance bijective entre l'ensemble des points atteignables par le robot dans l'espace de travail et l'ensemble des points définissables par les positions des curseurs dans l'espace de commande.
space (i.e., with respect to the different segments of the arm and the possible movements of the joints), while for the subjects, the work space is closely related to the space in which they move. However, when the robotic arm is controlled by cursors, which use the principle of coordinates, the situation is quite different: the formation of mental representations is a much longer and more difficult process. The subjects, who initially focus on discovering the effects of their actions on the operative part of the robot (in the robot space), develop their representations in relation to the properties and characteristics of the robot and those of the situation affected by the transformations. That situation, which is initially dealt with by the students as a space for movement (in the physical sense) progressively becomes a space with a frame of reference. These results coincide to a certain degree with facts that are known or are anticipated intuitively: it is necessary to have mental representations of technological systems to be able to use them. The contents and even the nature of such representations can vary greatly, according to the system and the individual. In the field of mathematics, regarding the use of calculators, J. F. Richard [6] demonstrated that certain representations are centred on use and others on the function of the calculator itself. However, the findings go a step further, as they demonstrate that the development of representations of the “instrumental” aspect of technological systems is closely linked to the development of representations of the situation affected by the instrument. Different instruments involve different conceptions, not only of the instrument itself, which is insignificant, but especially of the locus and objective of the action. It could be said that our two control devices do not encompass the same conception of space because of the nature of the actions and representations they require of the subjects and the transformations that can be achieved by such actions. Thus, contrary to common intuition, the instrument is in no way neutral with respect to the situation in which it operates. Transporting a cube from point A to point B via each of the control devices implies the formation of different mental representations of spatial properties by the users. In addition, we strongly advance the hypothesis that this conclusion should be able to extend beyond material instruments to conceptual instruments, which coincide with Vigotsky’s hypotheses [7] (but, as Kipling would say, that is another story). On that basis, to conclude, we shall
extend our reflection towards geometrically and spatially oriented teaching.

The use of material instruments is common practice. Rulers, compasses, set squares, etc., are used to draw lines and graphics of various sorts. They are often considered as mere accessories—neutral objects that do not affect students’ concepts. However, is that really the case? The results that we have obtained raise questions about the actual cognitive value of instruments and how they can contribute to the structuring of students' geometrical and spatial thought. An initial study of this issue [3] demonstrated that the notion of orthogonal symmetry is formed differently and has different contents according to the means used to produce graphics (set squares, compasses, folding techniques). That would merit reflection and could lead to fruitful research, which could extend to conceptual instruments such as the various types of graphics used in mathematics, and to the codes used to convey and interpret information in such graphics.

Another idea worth developing would be to design specific instruments that require students to develop and work with specific concepts and skills in accordance with particular teaching objectives. The cursor device for controlling the robot is consistent with that approach. As we have seen, it initially leads students to represent space in terms of a referential system. It can subsequently lead to more complex pedagogical developments, such as frames of reference established by the students themselves, coordination between the control space and the work space, and transition to direct programming of movement in relation to coordinates. The students therefore shift from an activity space with retroactive control to an operative space in which transformations are calculated in advance within a proactive control framework.

Instruments are not conceptually neutral. To some extent, they impose a conception of reality on their users. From that perspective, it would be appropriate to not only analyse the instruments we commonly use, in order to gain greater mastery of their pedagogical applications, but also to construct new instruments specifically founded on this principle so that we might explore all paths that lead from action to conceptualization and formalization.

flexion en direction des enseignements à caractère géométri-que et/ou spatial.

L’usage d’instruments matériels y est de pratique courante. On utilise règle, compas, équerre... pour réaliser de multiples tracés et constructions. Ces instruments sont souvent considérés comme de simples auxiliaires, neutres et n’intervenant pas en tant que tel sur les conceptualisations des élèves. Mais est-ce bien certain? Les résultats que nous avons obtenus inci-ent, au contraire, à s’interroger sur leur statut cognitif réel, sur la façon dont ils peuvent contribuer à la structuration de la pensée géométrique et spatiale des élèves. Un premier travail dans cette voie [3] a ainsi montré que la notion de symétrie orthogonale ne se construisait, chez les élèves, ni de la même façon, ni avec les mêmes contenus selon les instruments utilisés pour faire les constructions graphiques (équerre, compas, pliages). Il semble donc qu’il y a là une piste de réflec-tions et de recherches fructueuses, d’ailleurs susceptible de s’étendre aux instruments conceptuels tels que les divers types de graphismes utilisés en mathématiques, ainsi qu’aux codes qui en permettent l’écriture et l’interprétation.

Une deuxième voie nous paraît portante d’avenir. C’est celle de la création, de la conception d’instruments spécifiques conçus pour exiger des élèves, dans leur usage, la construction et la manipulation de conceptualisations et de compétences dont l’acquisition est objectif d’enseignement. Le dispositif de commande en coordonnées du robot s’inscrit dans cette perspective. Dans un premier temps, il conduit les élèves, comme nous l’avons vu, à se représenter l’espace en termes de système de repère. Au-delà, il se prête à des développe-ments pédagogiques beaucoup plus élargis: réalisation par les élèves de repères, coordonnées entre l’espace de commande et l’espace de travail, puis passage à une pro-grammation directe des déplacements en coordonnées. L’élève passe ainsi d’un espace « agi » avec régulation rétroac-tive à un espace « opéré » dont les transformations sont calculées par anticipation dans le cadre d’une régulation proactive.

Les instruments ne sont pas conceptuellement neutres, ils contiennent une « conception du monde » qui s’impose peu ou prou à leurs utilisateurs. Analysons de ce point de vue les instruments habituels de nos pratiques pour mieux maitriser leur emploi pédagogique et construisons des instruments nouveaux explicitement fondés sur cette propriété qui per-mettront de parcourir les chemins qui mènent de l’action à la conceptualisation et à la formalisation.