Published in *What Kind of Tools Are Scientific Instruments? From the Psychology of Tools to Philosophy of Scientific Instruments*, in The Ethos of Theorizing, K. Murakami, J. Cresswell, T. Kono, and T. Zittoun (Eds.), Captus University Press, 2019

Chapter 9

What Kind of Tools Are Scientific Instruments? From the Psychology of Tools to Philosophy of Scientific Instruments

Maxence Gaillard
Rikkyo University

SUMMARY

This chapter aims to introduce new perspectives on the ongoing philosophical discussions about scientific instruments through an overview of the current literature on tool behavior in psychology and other fields. Philosophy of science has traditionally discussed concepts such as truth or reality and the meaning of theories and scientific method. There is now a growing interest in scientific instruments. The development and use of instruments are a large part of scientific activity in all research fields. Philosophy of science and theoretical psychology share a common interest in the role and status of instruments in scientific research. Psychology is concerned at two levels. In a reflexive approach, psychology can question the relevance of using instruments in psychological research (from pen and paper questionnaires to laboratory apparatuses); but psychology can also investigate the general mechanisms of tool development and tool use in cognitive systems and thinking animals, including humans. Indeed, as a major feature of human activity, tool behavior has been studied by many traditions in psychology, from neurology to cognitive psychology and activity theory. While relevant subfields of philosophy of science (e.g., philosophy of cognitive science or philosophy of neuroscience) have acknowledged the importance of instruments in psychological research (first level), there is almost no connection between discussions from empirical and theoretical psychology on tool cognition (second level) and discussions on instruments in philosophy of science. Here, I try bridge this gap by discussing some problems raised by instruments at the crossroads of philosophy of science and psychology of tools.

INTRODUCTION

Modern science relies heavily on instruments, machines, and technology. As scientists are aware of the significant role of tools in understanding and fostering scientific change, countless case studies have been conducted from historical or sociological perspectives on specific instruments, from Galileo's telescope to contemporary complex equipment. By contrast, philosophy has been traditionally more theory-oriented and was initially reluctant to acknowledge the importance of scientific instruments.

However, since the 1980s several philosophers of science brought issues related to instruments to the forefront. Such authors did not consider tools as mere auxiliaries of theory. One of the firsts to express epistemological concerns in the context of development and use of tools in science was Ian Hacking (1983). He took a close look at validation procedures: How do scientists understand the notion that a tool is actually observing what is it expected to observe? Allan Franklin, in *The Neglect of the Experiment* (1986, 3), claimed that "experiment often has a life of its own," a life that is partially made of technical constraints, availability of expertise and materials, and curiosity about the mere possibilities of the instruments. Peter Galison's (1987) history of particle physics proposed a similar idea: Several lines of research—theoretical, experimental, and instrumental—are coexisting at the same time and progressing rather independently. Not everything in experimental science is determined by theoretical investigation nor subordinated to theoretical purposes. In "Exploratory experiments" for example, tools are manipulated without a specific theory in mind (Steinle, 1997). But the interplay of tools and theory is complex, and Baird (2004) argued, for instance, that scientific knowledge is encapsulated in existing instruments. If there is a consensus to make more room for instruments in the study of science, a consistent philosophical understanding of the contribution of tools and theory in the dynamics of scientific research is still due.

One central idea is that tools are not neutral, in any sense of the word. The engagement with tools is shaping the course of scientific progress in a way or another—maybe more significantly than shifts in paradigms or theories. By using tools, we are not only "extending ourselves" (Humphreys, 2004), we are also changing ourselves. For example, Humphreys showed how computerization is not only about adding power to scientific observation and computation, but it is also a change in methods.

The history of psychology is intertwined with the history of its tools, from reaction time measurements to brain imaging, because tools are definining what is to be observed and recorded. Contemporary debates about neuroimaging illustrate that the introduction of a new tool goes together with strong assumptions regarding the status of science and the object of research (Uttal, 2001). Psychology simply does not have the same purpose when it focuses on life trajectories as when it focuses on brain processes. The insistence on methodology for building a scientific psychology has led to the domination of approaches focusing on biological mechanisms that can be studied at the individual level (Gao, 2014). By collecting individual and biological data, the inflation of laboratory equipment is part of this trend, at the detriment of other more integrative approaches. However, not only methodological factors can play a role in the choice of a tool, but also extra-scientific ones, such as the prestige associated with the technology (Shoenherr, 2017).

Instruments are certainly a matter of debate in psychology, but at another level, they are a subject of study. Among the processes under study in brain, mind, and behavior sciences, are: the identification of an object as a tool; grasping and manipulating it; discovering new potential functions for an existing tool; the modification and adaptation of an existing tool; the creation of a new tool for a specific purpose, and so on. The complexity and variety of tool use in human, compared to other animal species, are often emphasized.

At first glance, which cognitive faculties seem required for tool use and tool crafting? There must be a clear intention of achieving a definite end. By definition, a tool is a means to an end. There must be an end, and the agent should be able to isolate the end from the context and the environment. If one wants to crack a nut with a stone, one has to stop pressing or holding the nut for a while and look for an appropriate stone. The focus of attention is temporarily on the tool, not on the target. Is this stone heavy enough to crush the nut? Light enough to be manipulated? At the same time, an image of the target must be kept in mind. Planning, imagination, and anticipation are required to achieve the final goal. The more distant the goal, the more sequencing of actions is required. Training to master the tool can be included in the sequence of actions necessary for using it. Tool crafting is already an organized behavior of the second order. Auxiliary tool use (use of a tool to craft or use another tool) would be a behavior of the third order, and so on. Some knowledge of causal laws or mechanisms also appears to be necessary. At least the tool user expects some events to happen on a regular basis when using the same tool. Every time one hits the nail with the hammer, it will enter deeper in the wood. And somehow the skilled tool users know that the nail will not enter if they hit it with the handle of the hammer or if the wood was replaced with steel. For a successful action, the tool users can assess the strength of the materials or the shape of the tool—they know in advance what actions the tool is capable of carrying out in specific situations. In other words, no less than a folk physics, that is a rudimentary theory including basic physical principles might be required for appropriate tool use—although this point is questionable (Povinelli, 2003).

In the next sections I am going to discuss two issues. Both are major issues for the philosophy of scientific instruments and are also important features of the psychological debates on tools. I start with the problem of the knowledge required for tool use, then I extend the discussion to the nature of intentional actions involving tools and the general issue of organization of action.

WHAT SHOULD ONE KNOW ABOUT A TOOL WHEN USING IT?

For philosophy of science, the main issue regarding instruments is the nature of the knowledge brought by instruments or carried by them. What kind of knowledge is in a thing (Baird, 2004)? These questions can find echoes in mainstream information processing psychology. In this framework, one could ask what kind of conceptual knowledge is required to manipulate a tool. How far need a tool user understand laws of nature or properties of objects? I will show that there is a deadlock in the psychological debate, and that the corresponding debate in philosophy of science is in a deadlock for the same reasons. Considering both debates should suggest new ways to tackle this issue.

Neurological patients' deficits in tool use have been labeled "ideational apraxia" (De Renzi & Lucchelli, 1988). These patients are unable to use simple and everyday tools. For example, they try to eat soup with a fork or press a nail with a hammer without hitting the nail. This suggests that ideational apraxia is a sort of movement disorder, not a general sensorimotor deficit. It is not indeed a problem of motor command, and it has been interpreted as a sort of semantic memory disorder. Patients lost the understanding of the purpose of common tools, as if they forgot the conceptual knowledge about object function. The concept of the tool seems lacking, because memory, or access to it, is destroyed. The part of memory at issue would store typical actions associated with different types of tool—a functional tool repertoire that is deactivated in ideational apraxia. A limitation of this view is that it makes it difficult to account for flexibility in tool use, our very common ability to adapt various objects to a purpose without considering the typical use of the tool, or tool innovation. The hypothesis of a semantic repertoire of tools connected to internal models of each type of tool may be excessive.

Ecological psychology and the theory of affordances can propose an alternative to this view. Affordances are properties of the environment that elicit action. Tools are part of our environment: for humans, the handle of a hammer is a typically graspable surface, and once in hand it usually affords hitting. In this view, commands for object manipulation are not based on internal models stored in the head of the subject but occur in the interaction of the living organism and its environment. If a tool is an object of the environment that affords something, the most typical affordance should determine the typical use, along with the current needs of the organism. Now we can easily understand flexibility in tool use—from the point of view of the organism, the knife and the screwdriver will accomplish the action all the same, regardless of their similarity to a typical model of a screwdriver.

One limitation of this theory may be that it cannot elucidate tool crafting because tools are considered as given in the environment. According to Osiurak and colleagues (2010), another shortcoming of affordance theory regarding its contribution to discussions on tool use is the focus of the analysis. Tool use is not exactly a matter of organism-environment coupling, but rather a matter of tool-material (i.e., object-object) coupling. A tool can be graspable and afford manipulation, but this does not tell whether it is fit for a particular purpose or not. One can grasp a hammer, but this hammer might not be suited for the specific nail that one needs to hit. Conversely, one can conceive that a huge hammer would crush a big stone, even if one cannot lift this very hammer and crush this very stone for lack of the user's strength. The correct understanding of tool use, and the subsequent choice of the appropriate sequence of actions, is related not only to the interaction of the body with the environment, but to the way the tool itself will affect the environment, irrespective of its interaction with the organism.

In philosophy of science, there is a similar tension between two contrasting views regarding instruments. On the one side, the empiricist tradition considers instruments as extensions of the senses. Instruments are "artificial organs" (Hooke, 1665) that start where the body of the observer and the natural faculties of human beings end. Microscopes and telescopes are better eyes—they improve vision. As a consequence, use of instruments is enlarging the empirical basis of the sciences. Thanks to instruments, there is more to be observed, which observations lead to more facts. This experimental basis is preliminary to scientific knowledge. Extending our organs with tools, we extend the surface of contact of the organism and the environment. A parallel can be drawn with the affordance view. The more extended our organism, the more possibilities we see in the environment. A new tool opens up new avenues for research.

On the other side, observation is often conceived as "theory-laden". According to this view, every observation is presupposing theoretical hypotheses up to a certain point—and this point is widely debated in philosophy of science. An observation of the moon is a fact of astronomy, but before it can be established as a fact, we have to assume a theory of optics—for instance, how the rays of lights from the moon reach the eyes and through the telescope. The more scientists rely on instruments, the more their observations are dependent upon hypotheses, especially those related to how instruments produce data. The instrument is not a natural organ that we can trust on the mere basis of innate familiarity; it is a technical object that obeys laws of physics and mechanics. In this sense, tools are "materialized theory" (Bachelard, 1934). And one can contend that we cannot consider the output of the machine as an indubitable fact until we know these laws. The knowledge of the physical laws that explain how the telescope works and why we can trust it is required to validate the observation of the moon. Such as in the conceptual knowledge approach of tool use, there is a model of the instrument. Ideally, this model should be integrated in the scientific model of the world. If we do not have a proper model of the tool, then our model of the world is not complete. But this interpretation seems too ambitious. When can we ensure that we know perfectly how a tool works? Or that the theory underlying it is not going to be revised?

Both debates, in psychology and in philosophy of science, are trying to overcome the opposition between the knowledge-processing view and the organ-affordance view. In psychology, the proponents of the "mechanical reasoning" and "technical reasoning" hypotheses are proposing an intermediary understanding (Goldenberg & Spatt, 2009; Osiurak et al., 2009). Tool concepts and object representations in semantic memory and mechanical problem solving are different processes. We can have a repertoire of typical tools and recognize the properties of familiar objects—we can even recognize a tool in a painting—but we do not use this repertoire when we need to solve a practical problem with a tool (and we know that we cannot use a painting of a hammer to hit a nail). According to this theory, potential uses of tools are inferred from structural properties of the object and the environment. Performing this task requires some knowledge of general principles of physics and mechanics—the ability to reason about the technical possibilities offered by objects.

Against the affordance view, properties of objects are not only related to the organism but are embedded in a general conception of physical laws occurring in the external world. However, the reasoning occurs at the level of abstract technical principles; it does not involve the knowledge of properties and use of unique types of tools and objects. Against the view of a conceptual repertoire of tools, the relevant information for manipulation is directly extracted from the perceived object. One can hit a nail with something that is not a hammer, providing that this potential tool exhibits appropriate properties—for instance, heavy and solid enough. A stone is not solid or fragile per se, it might be solid enough to crack a nut, but it might break if one tries to hit a nail with it. Hence, technical reasoning is based on abstract principles of mechanics, connecting for instance percussion and solidity, but not bound to object representations.

Philosophy of science may need also a third way, similar to the "technical reasoning" model. Such a view would highlight the importance of technical features in scientific reasoning. It would do justice to the importance of technology, neither by integrating it into conceptual knowledge nor by reducing it to a material entity, but by recognizing its specific contribution.

As far as science is concerned, the focus is not on low-level processes of tool manipulation and gestures, but rather on instrumental reasoning: How are tools involved in scientific reasoning? This problem has been briefly raised by Duhem (1908), who introduced a distinction between the actual instrument in the laboratory and its symbolic counterpart as a mathematical representation in the head of the physicist. This problem is now on the agenda of philosophy of science, which has turned to experimental science and science in practice. Scientific reasoning occurs not only at the level of theories; rather, questions such as the validation of instruments (Chang, 2004), or the choice of the best experimental strategies (Silva, Bickle, & Landreth, 2014), are also important features of the dynamics of scientific research. This conclusion suggest that we turn to the more general issue of the organization of action.

INTENTION, ACTION PLANNING, AND INTERMEDIATE GOALS

A tool is not an ontological but a relational entity—we use something as a tool. From the crafting of the tool to testing and manipulation, tool use is inscribed in a sequence of actions designed to achieve several goals, intermediate ones, and final ones. Even at the basic level of tool manipulation, several components can be delineated: reaching the tool, grasping it, manipulating it. Several gestures are included in manipulation, and one has to know where to start and where to stop. Tool use requires the ability to form an intention and a subsequent organization of the behavior suited to this intention. If one needs to manufacture a tool ad hoc, tool manufacturing becomes temporarily the goal of the action, without obviating the ultimate goal.

Tool use involves the ability to organize a complex behavior and maintain a hierarchy of goals and subtasks. This is especially true when considering tool crafting before tool use. Tool development and tool use are two different but highly related components of tool behavior. As one has to develop a tool before using it; the development of the tool is already part of the process. Of course, one can use an existing tool that was manufactured by someone else or a simple natural object. But even in this case, the tool user can still compare several options before choosing the right tool. In a sense, there is only one long sequence of action going from tool development to tool use, and a full overview of tool behavior has to include tool development.

The development of scientific instruments can be integrated in experimental research, as a part of the inquiry. In order to observe and understand a natural phenomenon, experimenters produce their own tools. This would be the case of the pioneer astronomers, shifting temporarily from goal 1 (e.g., observe an unknown star) to goal 2 (e.g., build a better telescope). However, the technological equipment of modern science requires more than tools built in-house. Some engineers and researchers specialize in the manufacturing of instruments (Joerges & Shinn, 2001). This is a consequence of the complexity of tools and the division of scientific labor. Scientists devoting their entire career to developing tools that exhibit unique abilities different from those of other researchers (Shinn, 2007). For instance, they must be able to adjust their activity to different fields of knowledge.

Bruno Latour (1987) has characterized research as an enterprise made of juxtaposed "detours." As an example, Latour analyzed how Pasteur, in a letter to the ministry, progressively transposed the goals of his research in order to meet the terms of his funding provider: if France wants a better balance of trade, then we need to boost wine production, and for that we need to understand the mechanisms of fermentation, and for that purpose the government should precisely fund the chemistry research of Pasteur. Like in this small argumentation, the development of an instrument implies a temporary shift from one goal to another. The investment in tool manufacturing is a detour. The time devoted to developing the instrument is not devoted to its use—one cannot at the same time build the telescope and look through it. At each step of instrumentation, there is a displacement of goals and means. Months or years can be spent in the pursuit of means that become ends. The constant shift of ends and goals in the context of the development of instruments is a major feature of history of science.

How does the scientific community as a collective entity keep track of its goals? What is the ultimate goal of the inquiry? At the individual level, maintaining the predefined goal in mind is a prerequisite for tool use. One is going to collect a stone to crack nuts, then the attention shifts to stones, because there are all sorts of stones; if the prospective use is not in the background, then there is a risk that one brings a beautiful but inappropriate stone. In other words, a certain attention span is necessary to develop tools. This remark ties up with a recurring critique of contemporary technoscience. The ultimate goal of research would evaporate in the sequence of intermediate actions. Often, in developing technology, we forget the big-picture and long-term meaning of science. Because science is fascinated and diverted by its own tools, we would have lost the focus on knowledge.

In this last view, intentionality plays a large part in tool development. However, the emergence of a new tool can be described at a basic level as a minimal change in the sequence of actions. Anthropologists and primatologists have shown that transfer of gesture and skills from one material to another is a driving force of tool innovation (De Beaune, 2004). What is the difference between cracking nuts and carving stones? Chimpanzees are able to crack nuts with stones. Among the first human tools were also stones, carved by other stones. In the process of evolution, the technical ability to carve stones must have emerged from more primitive technical skills, and cracking nuts is one candidate. It is remarkable that the two activities share most of gestures and components: percussion with a stone as a hammer and another as an anvil. But the materials are different—instead of hitting a nut, hit a stone. Combining existing elements in a new arrangement (for instance, same gesture with a different material) is a source of technological innovation. Technological progress is a process of recombination of existing techniques, transposition of gestures, and rearrangement of materials (Leroi-Gourhan, 1943). This interpretation offers different perspectives on tool development. Tools may not be the only product of an intention, the exact realization of a predetermined objective. In fact, it is rather unlikely that hominids said to themselves one day "we need carved stones" and developed the technology.

The lesson is that a progress at a technical level (in that case, gesture and material) allows for new avenues at a higher level—it changes the meaning of the sequence of actions. One can think of the relation between science and technology in a similar way. If scientific instruments are defined as the technology mobilized by science, it is tempting to see technology as a subpart of science. Indeed, a lot of technology is developed for science, with the ultimate purpose of gaining knowledge. But there is also a separate evolution of technology that provides science with new, at times unexpected, tools. The dependence is reversed: This time it is not technology that is developed for science or derived directly from scientific knowledge, but it is science that relies on technology. This suggests a big picture of the dynamics of science, not driven by theoretical debates but by the evolution of technology (Shapere, 1998). This is not to say that the history of psychology as a scientific field should be reduced to the history of its technological equipment. Yet the dynamics of instruments—new tools introduced and old ones discarded—is to a large extent responsible for the general reconfigurations of the scientific field in terms of approaches, theories, and objects of research.

CONCLUSION

Psychological considerations on tool use may not answer issues debated in philosophy of science, but it may suggest some fruitful analogies, because scientific instruments are a subtype of tools. By considering tools as relational entities, we opposed two received views on scientific instruments.

The first view claims that a scientific instrument is "just a tool," i.e., a mere means subordinated to theoretical objectives. For instance, one cannot say that neuroimaging is "just a tool" in line with all the tools used in psychology before, because, compared to other tools, it brings different problems in the forefront and goes with severe inflexions in research objects and procedures.

The second received view considers scientific instruments as artefacts with fixed and clear boundaries. On the contrary, the tool is defined as such in the context of the action. It is engaged in a process, outlined and transformed by the action. Against the duality of the subject (the scientist) and the object (the instrument), we should consider the coupling of the agent and the artefact, as activity theory does (Rabardel & Bourmaud, 2003). The development and use of instruments are included in scientific activity, not a supplement to it. This is a major point when considering production of knowledge in general and the process of science itself, as it offers new perspectives in the philosophy of scientific instrumentation.

REFERENCES

Bachelard, G. (1934). *Le nouvel esprit scientifique*. Paris, France: Félix Alcan.

Baird, D. (2004). *Thing Knowledge: A Philosophy of Scientific Instruments*. Berkeley: University of California Press.

Chang, H. (2004). *Inventing Temperature: Measurement and Scientific Progress*. Oxford, United Kingdom: Oxford University Press.

De Beaune, S. (2004). The Invention of Technology: Prehistory and Cognition. *Current Anthropology*, *45*(2), 139–162.

De Renzi, E., & Lucchelli, F. (1988). Ideational Apraxia. *Brain*, *111*(5), 1173-1185. doi: 10.1093/brain/111.5.1173

Duhem, P. (1908). *La théorie physique, son objet, sa structure*. Paris, France: Vrin.

Franklin, A. (1986). *The Neglect of the Experiment*. Cambridge, United Kingdom: Cambridge University Press.

Gao, Z. (2014). Methodologism/methodological imperative. In T. Teo (Ed.), *Encyclopedia of Critical Psychology* (pp. 1189-93). New York, NY: Springer.

Galison, P. (1987). *How Experiments End*. Chicago, IL: Chicago University Press.

Goldenberg, G., & Spatt, J. (2009). The Neural basis of tool use. *Brain: A Journal of Neurology*, *132*(6), 1645–1655. doi: 10.1093/brain/awp080

Hacking, I. (1983). *Representing and intervening*. Cambridge, United Kingdom: Cambridge University Press.

Hooke, R. (1665). *Micrographia. Some Physiological Descriptions of Minute Bodies Made by Magnifying Glasses with Observations and Inquiries Thereupon*. London, United Kingdom: Martin and Allestry.

Humphreys, P. (2004). *Extending ourselves: Computational science, empiricism, and scientific method*. London, United Kingdom: Oxford University Press.

Joerges, B., & Shinn, T. (2001). *Instrumentation between science, state an industry*. Dordrecht, Netherlands: Kluwer Academic Publishers.

Latour, B. (1987). *Science in Action*. Cambridge, MA: Harvard University Press.

Leroi-Gourhan, A. (1943). *L'homme et la matière: évolution et techniques*. Paris, France: Albin Michel.

Osiurak, F., Jarry, C., Allain, P., Aubin, G., Etcharry-Bouyx, F., Richard, I., … Le Gall, D. (2009). Unusual Use of Objects After Unilateral Brain Damage: The Technical Reasoning Model. *Cortex*, *45*(6), 769–783. doi: 10.1016/j.cortex.2008.06.013

Osiurak, F., Jarry, C., & Le Gall, D. (2010). Grasping the affordances, understanding the reasoning: Toward a dialectical theory of human tool use. *Psychological Review*, *117*(2), 517–540. doi: 10.1037/a0019004

Povinelli, D. (2003). *Folk physics for apes: The chimpanzee's theory of how the world works*. London, United Kingdom: Oxford University Press.

Rabardel, P., Bourmaud, G. (2003). From computer to instrument system: A developmental perspective. *Interacting with Computers, 15*, 665-691. doi: https: 10.1016/S0953-5438(03)00058-4

Schoenherr, J. (2017). Prestige technology in the evolution and social organization of early psychological science. *Theory & Psychology, 27*(1), 6-33.

Shapere, D. (1998). Building on what we have learned: The relations between science and technology. *Philosophy and Technology*, *4*(2), 105–120.

Shinn, T. (2007). *Research-technology and cultural change: Instrumentation, genericity, transversality*. Oxford, United Kingdom: The Bardwell Press.

Silva, A., Bickle, J., & Landreth, A. (2014). *Engineering the next revolution in neuroscience*. New York, NY: Oxford University Press.

Steinle, F. (1997). Entering new fields: Exploratory uses of experimentation. *Philosophy of Science*, *64*, 65–74.

Uttal, W. (2001). *The new phrenology: The limits of localizing cognitive processes in the brain*. Cambridge, MA: MIT Press.