Chapter 2
A Philosophy for the Place of Technology in STEM

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Abstract This philosophical reflection focuses on the 'T' of technology in STEM as it appears to stand out as the product or artefact resulting from the practices of science, engineering, and mathematics. This interpretation is enriched by a historical and cultural comparison of technology to 'techne', the Greek word for craft that had a deep influence on European educational practice and draws attention to the value of traditional, tacit practices that are not taught through theory alone. The meaning of technology, as artefact and artful practice, is further analysed from viewpoints of linguistics, cognitive psychology, anthropology, and ethics. Technology is thoroughly human in the sense that it solves problems from a human point of view, and therefore we all should, in principle, be able to understand the technology and recognize its affordances. Technology has shaped us as much as we shape technology: the development of our cognitive system goes hand in hand with making and using technology, both in the development from birth to adult as in the evolution from our prehistoric ancestors to the creative and responsible Homo sapiens we may one day become.

Keywords Philosophy of STEM · Tacit knowledge · Embodied cognition · Craft · STEM education

2.1 Introduction

Do we need to think from a philosophical point of view about STEM? We already have well-established philosophies of science, of technology, and of mathematics. This book focuses on the 'T' of technology in STEM. Does technology change in nature when it becomes a constituent of STEM, requiring additional philosophical reflections? Will the combination reveal new or emerging properties of technology,

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like gelatine can reveal its ability to turn juice and sugar into a tasty dessert, or molecules of H_2O, which are not liquid or wet themselves, can form a drop of water?

A reflection on the origin of STEM shows that STEM was not proposed from a theoretical, let alone a philosophical point of view. The first mention of STEM was in the USA in the last decade of the twentieth century, in the context of workforce shortages related to technical professions. Reportedly, the juggling with nouns towards STEM started with Science, Mathematics, and Technology (SMT), after which Engineering was inserted to make the acronym easier to pronounce (SMET). Apparently, this did not resonate well enough, so the order was changed, and STEM was born. Clearly, STEM is not a natural phenomenon, out there, waiting to be observed, analysed, and defined. It is a social construct, which implies that its meaning is 'in the eye of the beholder' and to be found in the social and cultural practices where STEM is discussed, taught, learned, and applied.

Adding 'engineering' to the mixture of science, technology, and mathematics is an act that potentially changes meaning and opens a venue. It suggests that technology and engineering are different enough to justify the inclusion of both. What could be this difference? Science, engineering, and mathematics can be regarded as practices and not as material things. You cannot pick up science and let it fall on your feet. The word technology, though, is often used for material things, artefacts (Mitcham, 1994), the products of a practice that may be informed by engineering and the application of mathematics and science. So, thinking about the 'T' in STEM is thinking about the special position of human-made artefacts resulting from practices that are informed by the bodies of knowledge and skills of science, mathematics, and engineering.

But perhaps this is true only when and if we speak English. English is the language of academia, but native speakers of other languages will recognize difficulties when translating STEM. For example, in Germany, the acronym most widely used for STEM is 'MINT', which stands for Mathematik (Mathematics), Informatik (Computer Science), Naturwissenschaft (Natural Sciences), and Technik. 'Technik' may be translated into 'technology' but not in the sense that it refers to artefacts. Its meaning is much closer to practice. 'Technik' has an ancient origin in the Greek word 'τέχνη' (techne), which refers to the artful making of useful things. For Germans, 'Technik' and 'Ingenieurwissenchaften' (engineering) are therefore too similar to be used both in a combination like STEM. This is also true for several other related languages that use 'techne', more or less, in its original Greek meaning, like Dutch and Swedish.

2.2 Historical and Cultural Aspects

What this means is that philosophical reflection on STEM and on the 'T' in STEM has historical and cultural connotations. Are we reflecting on technology-as-artefacts that result from scientifically and mathematically informed engineering practices (American style) or on technology-as-artful practice with roots in craftsmanship, rather than in academic science (Greek-German style)? For the ancient Greeks, making things and working with their hands out of necessity was not held in high regard. Craftsmen were respected when their work had quality, but they were artists rather than scientists. They may have had a certain knowledge base, but this was often unarticulated, implicit, tacit, personal, and not the explicit and undeniable, 'scientific', theorems the philosophers sought, to learn about and understand the eternal truths. 'Science', from the Latin 'scientia', means 'knowing' or 'understanding'. Knowing and using your mind was for the Greeks not related to making and using your hands. The school of Aristotle, although he himself a keen of observer of nature and a proto biologist, became known as 'Peripatetic', which means so much as philosophizing by walking around, with hands behind the back. Aristotle's ideas and theories were brilliant, and his influence lasted for centuries, but they were eventually questioned when experimenting became the companion of theorizing and observing. Experimenting implies using your hands; bare hands and the naked eye can be reinforced with tools; and tools and instruments require making. Science and technology, understanding and making, became fundamentally entangled in the age of the scientific revolution with its front runners Galileo, Huygens, and Hooke. But 'Technik', as the practice of non-academic craftsmen, retained a parallel position, still creating artefacts based on tacit approaches that were mastered through imitation, rather than through theory. In 'The Craftsman' (Sennett, 2009), a wonderful book on how craft is taught and learned through the ages, Richard Sennett gives the example of Stradivari, who build violins like never before and after, because he was unable (or unwilling) to articulate his secrets to his pupils. Artefacts made through tradition do not necessarily lack quality; on the contrary, they come into being through pathways that are alien to academia and tend to be ignored or even refuted, precisely for their lack of theoretical transparency and rationale.

Combining academic science, mathematics, and engineering for the sake of producing technology could easily become self-evident and dominant in the US education system since this only came into being well after the seventeenth century. Europeans, however, inherited their school system from classical and mediaeval times. The oldest universities (Bologna, Paris, Oxford) were established around 1200 and were utterly impractical. Just like it was in Greece, the gymnasium (secondary education) and the university were for the elite, who did not need to work for a living but sought intellectual challenge, like reading Plato, writing poetry, excavating Egyptian treasures, or collecting exotic butterflies. Greek, Latin, and History were the important subjects. Medicine was studied through the works of Hippocrates and Galamus, with the result that for the sake of your health, you'd better go to a midwife or herb collector than to a medical doctor.

The Industrial Revolution with its increasing need for workers with advanced knowledge of mechanics, chemistry, transportation, steel production, et cetera, initiated radical changes in the school system. For example, in 1863 the Dutch Government created a new secondary school, the 'Hogere Burger School', with an emphasis on mathematics, physics, and chemistry. Translating the name of the school into American English nicely illustrates the cultural stance towards the 'techne' of Europe. It seems obvious to translate 'Hogere Burger School' into 'high school' or 'higher education for citizens' ('burger' means 'citizen'). But in 1863 'higher' did not refer to the next step in a sequence from primary to tertiary education. Rather, this school was meant for ‘higher citizens’ as opposed to ‘lower citizens’: the new elites that made their money through trade and industry and, like the old elites, did not work with their hands. The difference was perhaps that they preferred reading Von Humbold above reading Plato. Theory, and not making, fleshed out the curriculum, and teachers in these schools nowadays still perform experiments mainly to illustrate the theory, not to develop practical skills. The children of the real labourers and craftsmen, on the other hand, did not go to secondary school until well into the twentieth century, and they still are underrepresented in the schools that prepare for academic learning. Many European countries with a Greco-Roman heritage maintain a two-tiered educational system, with a theoretical and a vocational column, with approaches to the material world that are often incompatible.

So, a philosophy for STEM emphasizes a historical and cultural reflection on the place of artefacts, theory, making, and the appreciation of tacit craft in educational settings. If this analysis is adequate, curriculum developers on both sides of the Atlantic may draw different lessons on how to elaborate STEM into their school systems: interest in non-theoretical traditions on the one side and equity for craft on the other. This also has repercussions for the cultures with native craft traditions in Asia, Africa, Oceania, or the Americas. They are exposed to the powerful self-evident views concerning the STEM curriculum from Europe and North America, and the world may lose valuable ways of making artefacts when a one-size-fits-all STEM approach is thoughtlessly implemented. History can inspire reflection on the role of technology in STEM, and there are more points of view that can enrich our understanding of the T in STEM. In the next sections, we will explore viewpoints from linguistics, cognitive psychology, anthropology, and ethics.

2.3 Linguistic Aspects

The reflections above already show how important language is. Greek techne is not identical to American technology. Therefore, what ‘STEM’ can mean to an American is not what it can mean to a German, a Dutchman, or a Nigerian. The fact that the meaning of a word depends upon historical and cultural contingencies, however, does not imply that we cannot cross the boundaries and understand other viewpoints. The laws and constants of physics require precision up to five decimals and apply everywhere in the world, but cultural and social concepts typically are fuzzier. ‘Play’, for example, has no definition that includes all instances that everybody agrees on are play; compare tennis to patience. Such constructs are called ‘categories’: they have instances but no all-encompassing definition.

Words, like STEM, have origins. Words occur in a context. The meaning of words is not a matter of definition from scratch, and teaching is not forcing learners to reproduce these definitions. Rather, students should be taught how to derive meaning from the context. This is a personal act (Polanyi, 1962), not something that is produced by an AI algorithm. This is the domain of hermeneutics, an approach to understanding texts that are not self-evident. The meaning of an unknown word, for example, can be derived from its place and apparent role in a sentence, a paragraph, or a book. Likewise, the meaning of an artefact can be derived from the interaction of the artefact with its material and immaterial context. Interpretation is a key activity: a correct interpretation leads to a fruitful application. The ability to apply correctly implies understanding. This is the hermeneutic circle. For the German hermeneutic philosopher Hans-Georg Gadamer (Gadamer, 1960, 1972), this is how we should also approach technology (in its meaning of artefact): the technology will impose its affordances on me, that is, how it should be used if I encounter it in its proper context, and if I apply all my knowledge of the context to find out what it can do for me.

Technologies that are too new or disruptive, however, cannot exist or come into being in a context that cannot interpret them. That is why the first motorized cars looked like horse-drawn chariots. Imagining a Corvette was beyond imagination. Typically, technology is a solution to a problem, and we cannot understand solutions to problems that have not (yet) been articulated. Currently, e-books have page numbers like printed books, but who knows how we will find our way into texts in the future? Gadamer compares the assessment of technology to the experience we have when we are confronted with a piece of art. Conveniently, the German language uses the same word for a piece of art as for a technological artefact: 'Kunstwerk'. We can recognize what is a true work of art, and the same experience of truth can be obtained when we are confronted with technology. Good technology fits a solution to a problem in a specific context, in our life, experienced as the flow of things and events that makes sense to us. We intuitively appreciate buildings, structures, tools, and utensils when we recognize an applicability that is consistent with the surroundings and our needs, whether they have been created by theoretically informed engineers or by illiterate craftsmen.

To many people, STEM should make room for the 'A' of Arts and evolve into STEAM. What do proponents mean by the A? Does it express the interest of the STEM community in craft and traditional ways of making? Or is meant that painters, sculptors, musicians, dancers, et cetera, are also creative problem solvers whose approaches can inspire STEM professionals? Both interpretations have merit, and linguistic analysis can help to prevent misunderstandings. For a set of articles that are mutually inconsistent in this respect, see the special issue 'STEM and Arts Education' of the European Journal of STEM Education (2021).

Linguistics is also important to understand where the words we use within STEM come from. Living and surviving in the material world means correctly understanding the affordances of this world and effectively applying this understanding to our daily life. To some extent, this can be tacit. But there is a gap from daily life to the highly abstract theoretical language of scientists and engineers, to be bridged by education (Collins, 2010; Sullivan, 2017). A starting point is needed. A new and unknown phenomenon has to be named: deictic pointing and using words like 'this' and 'that' may work on the spot but do not transfer to an audience that does not participate in the practice. Lakoff and Johnson (Lakoff & Johnson, 1980) elaborated the role of metaphor in STEM. Typically, we start with improvising on a concept we know and map its characteristics to the unknown, to develop an initial understanding (Nersessian, 2008). ‘Electrical current’ is a good example: we recognize the similarities between a river flowing from high to low altitude while transporting useful stuff. We conveniently forget about the differences: electrical current does not evaporate or make you wet. ‘Current’ has received a new meaning. In this way, well-known phenomena with an explicit vocabulary keep on inspiring scientists to explain the not-yet-well-known (Abrahamson et al., 2012; Browne, 2003). Reflecting on technology in STEM thus is reflecting on language.

2.4 Cognitive Psychology

Technology is material, and so are we. Understanding technology is for a part embodied, in the sense that artefacts like we are subject to similar forces and influences, and artefacts typically are solutions to human problems and challenges to cope with the material world (Niebert et al., 2012). A cup can contain water much better than our hand. Present-day technology is not an incomprehensible black box but a set of babushka dolls: it uses other technology which again uses other technology (Arthur, 2009), but after some peeling-off in the end you reach your body. A cell phone at the bottom is your voice but with the ability to reach others over a greater distance. We may lack the mental and physical facilities to ‘really’ understand string theory, quantum coupling, or four dimensions that are perpendicular to each other. But we are fundamentally related to artefacts and every child, student and citizen should in principle be able to understand the devices we are confronted with, however complicated they may seem at first sight. A challenge for education!

We experience the world through our senses, and we interact with the world with our hands. We feel gravity pulling us down from the moment we are born, and the struggle to stand on our feet is a yearlong intense effort, so when we feel ‘down’, we can notice that we also keep a low body posture. Therapists know this and advise you to actively keep your head up and lift the corners of your mouth to automatically feel better. More important people sit in a higher place, suggesting that they were stronger than others in the struggle to move up against gravity. Our understanding of this metaphorical use of such words is embodied (Lakoff & Johnson, 1999). In contrast to feeling high or low, we never feel ‘left’, because there is no force acting on the horizontal as there is a force like gravity acting on the vertical, and consequently moving left or right is emotionally irrelevant.

For many psychologists, cognition and language, therefore, are embodied (Abrahamson et al., 2012; Gibson & Pick, 2000; Glenberg & Kaschak, 2002; Zwaan & Kaschak, 2009; Marechal et al., 2013). We develop our concepts through perceiving affordances and acting on these. What fits our bodily experiences is easier to understand. Technology is meant to solve our material problems, and therefore we should always be able to connect with it. It should fit like a glove. Surely, a dolphin won’t understand this metaphor: dolphins concentrate on other affordances. For children, is far easier to understand the meaning of ‘up’ and ‘down’ and apply this knowledge when opening a drawer than to understand the meaning of ‘left’ and ‘right’.

When we learn to walk, we become aware of the meaning of shades, recognizing what we have to do with our feet to prevent stumbling. When the sun is behind you and the shade is behind the obstacle, you must lift your feet because it is an elevation. When the shade is before the obstacle, there is a hole to step over. Through learning, our brain and our cognition become adapted to this specific material world (Dehaene, 2020). We are accustomed to a world in which the sun is above us and not below us, otherwise, our automatic interpretation of shades would have led to the opposite behaviour. Also, we do not experience a change in our clothes when we move from the dark into the light: we assume that these are the same clothes and thus must retain their colour. Computer scientists have only recently mastered the animation of shades in such a way that the animation appears somewhat realistic to the human observer because our brain has learned to create an awareness of what makes sense to us, not what is objectively visible (Ware, 2013; Wolfe et al., 2009). So, in a sense, reflecting on technology in STEM is reflecting on early childhood education and cognitive psychology.

2.5 Anthropological Aspects

Our body allows us to work with technology, especially with artefacts that elaborate on our body. A hammer is like a fist, but heavier and less vulnerable. A file is like nails but harder and, again, less vulnerable. The brain we are born with allows us to understand and operate these tools. The first learning takes place at a very early age before we can speak or think with words. We shape technology, or so we think. Developmentally, however, there is a case for technology shaping us and thinking as preceded by making. Anthropologists have studied how we learn to make stone tools (Malafouris, 2013). It was two million years ago that the first stone tools were made, by ancestors that were not yet evolved into Homo sapiens (‘wise’, ‘understanding’, ‘thinking’). Was the tool designed and developed from the imagination of a prehistoric mastermind? Anthropologists think not. With *f*MRI techniques, they studied how expert tool makers use their brains when tool-making and compared this to novices learning to make stone tools. Experts use the brain regions associated with conscious thinking, especially the prefrontal cortex. They have learned what to do and what to observe, and they act on purpose, doing what they want to do. Novices, however, when trying to make stone tools, primarily use the motor regions of the brain. They act randomly at first, and they are unable to repeat a lucky strike at will. Eventually, when the body tacitly understands what to do, the prefrontal cortex enters the stage, and novices slowly start to become conscious about what they are doing and what they see, feel, and hear. It is through this sustained doing that stable connections between neurons in the brain will be made, and these will connect the motor region with perception, emotion, and language, allowing us to remember, describe, explain, rejoice in success, and repeat and improve the action till perfection (Hurford, 2007). Learning is a permanent change in the brain, and the development of the prefrontal cortex is correlated with the advent of the 'maker movement' (Feinberg & Mallat, 2016). Between the first primitive stone tools and conscious technological advancements lies a vast amount of time, enough to evolve a brain suitable for tool-making, speech, and thinking. Within our lifetime we will not notice how technology shapes us, but our successors will. Reflecting on technology is reflecting on human development (Bickerton, 2014; McGinn, 2015).

2.6 Ethical Aspects

Tool making and tool using shaped us. Tools and technology shaped the world. This process has accelerated enormously, especially since the nineteenth century. And not just for the good. Kevin Kelly advocates the view that if technology is 51% beneficial, in the long run, humanity will benefit (Kelly, 2011), but who pays for the collateral damage? Maybe these trade-offs remain inevitable when thinking about the impact of technology on society is restricted to scientists, engineers, and mathematicians and predominantly plays a role in the introductory and closing paragraphs of grant proposals. Scientists and engineers nowadays know they can use help from ethics, various religions, and other sources of wisdom (Goorden, 2017). Jacques Ellul, both a philosopher of technology and a Christian theologist, pointed out that it all started in a Garden but, at least for those willing to believe the Book of Revelations, it will end with a City, requiring architects, constructors, and craftsmen (Ellul, 1970). Perhaps, optimists like Kelly are right and technology, used wisely, will help create the sustainable and safe society we all hope for. What attracted and seduced Eve and Adam in the Garden may not have been an apple but a stone tool, perhaps with a warning tag 'to be used creatively but responsibly'. Thinking about the consequences is, yet, not hard-wired in our DNA, unfortunately. There is a resemblance with the problem of obesity: our body can handle scarcity much better than abundance. Likewise, we are well-equipped to recognize the affordances of new technologies, but we fail to recognize the trade-offs. Will this capacity ever evolve? Reflecting on the 'T' of technology in STEM thus is reflecting on how we should live.

2.7 Conclusion

Technology is the central concept of STEM. Technology-as-artefact complements science, engineering, and mathematics, as the product of practices. Technology-as-techne reminds us that not all practices that create valuable products have a rational foundation in evidence-based academic theories. Technology-as-art has the double connotation of valuing traditional craftsmanship and present-day Art School creativity. Technology-as-embodiedness reminds us that technology is not a black box but reflects our material selves. Situating technology in both a developmental and an ethical context appeals to us to apply our creativity and problem-solving capacities freely to design technology as a solution to a problem, but always in a responsible way.

References

Abrahamson, D., Gutiérrez, J. F., & Baddorf, A. K. (2012). Try to see it my way: The discursive function of idiosyncratic mathematical metaphor. *Mathematical Thinking and Learning, 14*, 55–80. https://doi.org/10.1080/10986065.2012.625076

Arthur, W. B. (2009). *The nature of technology—What it is and how it evolves*. Free Press.

Bickerton, D. (2014). *More than nature needs. Language, mind, and evolution*. Harvard University Press.

Browne, T. L. (2003). *Making truth. Metaphor in science*. The University of Illinois Press.

Collins, H. (2010). *Tacit and explicit knowledge*. The University of Chicago Press.

Dehaene, S. (2020). *How we learn*. Viking.

Ellul, J. (1970). *The meaning of the city*. Eugene, Wipf and Stock.

European Journal of STEM Education. (2021). *Special issue on STEM and arts education*. https://www.lectitopublishing.nl/european-journal-of-stem-education/stem-and-arts-education

Feinberg, T. E., & Mallat, J. M. (2016). *The ancient origins of consciousness*. MIT Press.

Gadamer, H.-G. (1960). *Wahrheit und Methode [Truth and Method]*. Frankfurt, J.C.B. Mohr.

Gadamer, H.-G. (1972). Theorie, Technik, Praxis. In *Neuere Philosophie II* (pp. 243–266). J. C. B. Mohr (Paul Siebeck).

Gibson, E. J., & Pick, A. D. (2000). *An ecological approach to perceptual learning and development*. Oxford University Press.

Glenberg, A. M., & Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bulletin & Review, 9*(3), 558–565.

Goorden, L. (2017). *De sprong in de techniek. Nadenken over wat we doen [Jump into technology. Thinking about what we do]*. ISVW Uitgevers.

Hurford, J. R. (2007). *The origins of meaning: Language in the light of evolution*. Oxford University Press.

Kelly, K. (2011). *What technology wants*. Penguin Books.

Lakoff, G., & Johnson, M. (1980). *Metaphors we live by*. University of Chicago Press.

Lakoff, G., & Johnson, M. (1999). *Philosophy in the flesh*. Basic Books.

Malafouris, L. (2013). *How things shape the mind*. The MIT Press.

Mareschal, D., Butterworth, B., & Tolmie, A. (Eds.). (2013). *Educational neuroscience*. Chichester.

McGinn, C. (2015). *Prehension*. The MIT press.

Mitcham, C. (1994). *Thinking through technology*. The University of Chicago Press.

Nersessian, N. (2008). *Creating scientific concepts*. MIT Press.

Niebert, K., Marsch, S., & Treagust, D. F. (2012). Understanding needs embodiment: A theory-guided reanalysis of the role of metaphors and analogies in understanding science. *Science Education*, *96*(5), 849–877. https://doi.org/10.1002/sce.21026

Polanyi, M. (1962). *Personal knowledge*. University of Chicago Press.

Sennett, R. (2009). *The craftsman*. Yale University Press.

Sullivan, K. (2017). Conceptual metaphor. In B. Dancygier (Ed.), *The Cambridge handbook of cognitive linguistics* (pp. 385–406). Cambridge University Press.

Ware, C. (2013). *Information visualization. Perception for design*. Morgan Kaufmann.

Wolfe, J. M., Kluender, K. R., & Levi, D. M. (2009). *Sensation and perception*. Sunderland, Sinauer.

Zwaan, R. A., & Kaschak, M. P. (2009). Language in the brain, body, and world. In P. Robbins, & M. Ayede (Eds.), *The Cambridge handbook of situated cognition* (pp. 368–381). Cambridge University Press

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