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Learning: A technological perspective

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Abstract

This paper frames technology as a phenomenon that is inextricable from individual and collective cognition. Technologies are not "the other", separate from us: we are parts of them and they are parts of us. We learn to be technologies as much as we learn to use them, and each use is itself a technology through which we participate both as parts and as creators of nodes in a vast technological connectome of awesome complexity. The technological connectome in turn forms a major part of what makes us, individually and collectively, smart. With that framing in mind, the paper is presented as a series of sets of observations about the nature of technology followed by examples of consequences for educators that illustrate some of the potential value of understanding technology this way, ending with an application of the model to provide actionable insights into what large language models imply for how we should teach.

Keywords

learning; technology; cognition; education; generative AI

1 Introduction

This paper presents a model for thinking about cognition and learning as, in part, a technological phenomenon comprised of both intracranial and extracranial technologies. Though therefore related to theories of extended mind (Clark, 2008; Paul, 2021), distributed cognition (Hutchins, 2020; Norman, 1993; Saloman, 1993), and other 4E (embodied, extended, enacted, and embedded) models and theories of cognition (Hug, 2023; Newen et al., 2018), this is less a theory of mind or learning than a theory of technology. The gist of the argument presented here is that not only is individual cognition partly technological in nature but that all technologies have a cognitive component and role. To illustrate the value of viewing technology in this light, the paper provides examples of some of its material consequences for how we conceive of and go about teaching.

The model draws extensively upon the co-participation model of education developed in Dron (2023a) that treats teaching as a highly distributed, complex technological system. In his book, *How Education Works: Teaching, Technology, and Technique,* Dron (2023a) argues that technologies – including words, pedagogical methods, and theories - are orchestrated assemblies that, through technique (technologies enacted by people), include humans in their assembly. Good technologies can be enacted badly, bad technologies can be enacted well. In an educational system, there are vast numbers of co-contributors to the orchestration, most notably the learners themselves but also their teachers, campus architects, programmers, legislators, textbook authors, and countless others, all of whom may add critical parts to the assembly. It is the complex, situated, emergent whole that teaches rather than any one individual, so we can learn little from researching the parts in isolation. Education itself is a massively complex technological assembly, among the primary purposes of which is to support development of both hard technique (in which the human role is to be part of the orchestration) and soft technique (in which the human role is to orchestrate) though, ultimately, these are means to the very non-technological ends of forming identities, values, attitudes, relationships, and ways of being, in the company of others. This paper reiterates the main theoretical foundations of the co-participation model, extending them to develop a technological perspective on cognition itself. As the model unfolds, illustrations are provided for how and why this is relevant to the practice of teaching, concluding with its application to large language models, providing actionable insights into their unique promise and risks.

2 Method

By the definition of "technology" that underpins it, the model of technology presented here is itself a technology. Except in very special cases such as propositions, technologies are neither true nor false: rather, their value is measured in terms of their potential utility, typically extrapolated from and justified by their current or past utility. Therefore, the intent of this paper is not to prove the model to be true, only to demonstrate that it is and may be useful.

The full range of a technology's future utility is, though, as Kauffman (2019) demonstrates, unprestatable because there are indefinitely many future assemblies in which any technology might play a role. Even when potential uses are identified in isolation, their consequences when assembled cannot be predicted. All that can be identified are some of the more salient assemblies that are enabled by it, which is what this paper sets out to do.

Methodologically, the model is presented as a sequence of sections, each building on the last, containing observations about the nature of technology. Following each set of observations is a non-exhaustive list of insights for teaching that emerge from them and that illustrate their utility. Many further insights could be drawn: these examples are intended only to demonstrate the potential value to teachers of understanding cognition in technological terms, not to be research findings in their own right. They, too, are technologies, and could thus be assembled in many useful and non-useful ways.

3 About technology

3.1 Observation: technology is the organization of stuff to do stuff

To understand the cognitive nature of technology we must know what we mean by "technology". Unfortunately, "technology" is a nebulous term that continues to evolve numerous shades of meaning from "how things are done around here" (Franklin, 1999) to the objects sold in computer stores. For an in-depth discussion of the complexities see (Dron, 2023a), which concludes that Brian Arthur's (2009) definition, "the orchestration of phenomena to our use" works as an inclusive and discriminative definition with several key benefits:

- It is neutral as to whether "technology" is a thing or a verb for, as Kelly (2010) observes, it can be either or both. I am writing (verb) some writing (noun), for instance.
- It is neutral as to whether the phenomena are physically instantiated, so it allows for common uses of the term to describe, say, management processes, methods, language and techniques as well as things that are better described as "tech" or other physical manifestations such as wheels and houses.
- The term "orchestration" implies active assembly of phenomena in an organized way, so it speaks to both process and structure.
- It clarifies that technologies have a purpose. Together with "orchestration" this lets us distinguish technological from non-technological phenomena. It is, though, notable that the purpose for which they are used may not be and often is not the purpose for which they were designed. This interpretive flexibility (Bijker et al., 1989) is explained by Kauffman (2000) in terms of the adjacent possible empty niches (adjacent possibles) that are latent in every technological invention, from a sentence to a spacecraft. Each invention makes more invention possible.
- It avoids seeing technologies as the appliance of science. Rather, it clarifies that science is a set of technologies, the use of which is to provide us with ways of examining and understanding the world. Some technologies may incorporate resulting discoveries in their orchestration but far more – from poetry to prayer to pedagogy – do not, and technologies as often inspire scientific discoveries as build upon them (Arthur, 2009; Nye, 2006).

3.2 Illustrative implications for teaching

- Pedagogical methods (pedagogies) are technologies: they are orchestrations of phenomena, including beliefs about how learning happens as well as other phenomena, in order to bring about learning.
- Teaching opens avenues to more learning by increasing the adjacent possible, not just because of the facts or skills that are intentionally taught, but also because it is itself a technology that can be replicated and repurposed in other learning contexts. Students learn to learn from how they are taught.
- Every learner is a teacher, if only a self-teacher. In making sense of what other teachers teach, and applying ways of learning that they have learned in past they are (intentionally or not) using pedagogical methods.
- Teaching may not be the appliance of science, though scientific discoveries may be among the things that teaching orchestrates.

4 About assemblies

4.1 Observation: technologies are assemblies of technologies

My own (2023a) reformulation of Arthur's definition, "the organization of stuff to do stuff" better captures another of his key insights: that technologies evolve as a result of combination and recombination, and can be properly understood only in relation to one another as mutually interdependent assemblies. The stuff that technologies organize includes the stuff that other technologies do, utilizing the adjacent possibles they provide. The vast majority of, if not all, technologies are assemblies, mutually constituted and mutually constituting, and many of the phenomena that they orchestrate are provided by other technologies from which they are assembled, from nuts and bolts to words and theories.

4.2 Illustrative implications for teaching

- There is no such thing as a standalone pedagogical method. As it is instantiated, it must be assembled with other technologies, such as language, writing, computers, desks, classrooms, schedules, and potentially vast multitudes of other technologies (including the billions of transistors in a computer's CPU) in order to achieve its purpose.
- Any one of those multitudes of technologies may have an impact on the success or otherwise of the teaching but, alone, none will.
- Different technologies provide different adjacent possibles, and afford different constraints, so there is value in learning to being able to organize more of them. As well as the popular TPACK (technological, pedagogical, and content knowledge) framework (Koehler et al., 2013) this includes all the many organizational, conceptual, procedural, interaction design, graphic design, and other techniques that may have a bearing on learner success.

5 About participation

5.1 Observation: we are parts of the assemblies/the assemblies are parts of us

We are not just users *of* but participants *in* technologies. Some are instantiated wholly intracranially. For instance, technologies such as words, symbols, models, theories, processes, procedures, and methods may have no tangible existence beyond our private experience. Often, they are manifested as what Heyes (2018) refers to as "cognitive gadgets", technologies that are more or less pre-conscious parts of our cognition, not just a subject of it. Our cognition is not just enhanced by technology but partly composed of it: we perceive what we can label, for example, differently than what we cannot (Lupyan et al., 2020). Some such technologies also involve our bodies: meditation, dance, yoga, competitive swimming, and marching, for example, are intrasomatic.

Many technologies appear to be instantiated entirely extrasomatically: the physical, organizational, and procedural objects that we create, from poetry and management procedures to transistors and traffic regulations, are either tangible and extended objects in the world, or processes that dictate how objects may interact. However, these too form parts of technological wholes in which humans must play roles as either parts of their orchestration, if only to turn them on and off, or as orchestrators of the phenomena they afford. It is common to describe this participatory role as "technique" (Dron, 2023a). A technique is a technology enacted by a purposive agent, normally but not necessarily human.

When we talk of "using" a technology that use is itself a technology: it is our own orchestration of the phenomena provided by the technology we are using for some purpose. We are inseparable from its instantiation. For example, if one were to ask "what does a mechanical watch do?" an intuitive answer would be that it tells the time. However, all it *actually* does is to tick, and its hands move. A cat can perceive these attributes but, for them, it is not a technology for telling the time: the ticking is no less salient than the movement of the hands. It only becomes an instantiated timekeeping technology when we add techniques for interpreting the position of the hands as times, and it only remains one if we participate in the watch by applying techniques for winding it. We are an irreplaceable part of the assembly, without which, though we may describe it as a timepiece for the purposes of (say) buying or pointing to one, it does not tell the time.

5.2 Illustrative implications for teaching

- Much of what we teach is how to *be* a technology: it is concerned with developing intrasomatic techniques that we can use as part of what we orchestrate to do things in the world, from writing poetry to calculating the paths of spacecraft.
- It is pointless to attempt to isolate a single technology – say, a computer or a pedagogical method – in an attempt to make generalizable claims about its value for learning, because there are countless other ways that it could be organized with different techniques and other technologies. The complete instantiation, including all parts of the assembly (the whole), is all that matters in a given context.
- There can be no useful science of teaching. Teaching is a technological assembly that can be implemented with or without skill, in virtually limitless ways. The refutable theories of learning that we might use in it are only components in the assembly. By analogy, it is useful to know about theories of friction and inertia if you are building a car but applying those principles alone will not result in a drivable vehicle, let alone one that anyone would want to travel in. Teaching assemblies rely on many components that have little if anything to do with science or, for that matter, pedagogy.

6 About technique

6.1 Observation: we participate in technologies as part of the orchestration, and/or as orchestrators

We can participate in a technology in two distinct ways. The first of these can be described as *hard technique* in the sense of being inflexible, the second as *soft technique*, in the sense of being malleable (Dron, 2023a).

Hard technique is what must be done correctly in order for a technology to achieve its purpose: for example, telling the time with a watch, or ticking the answers to a multiple-choice quiz can be performed in one and only one way for the technology to work as intended. We are components of the stuff that is organized to do stuff.

Soft technique is what we may do better or worse, but never perfectly and seldom repeatably: for example, drawing a picture, writing a report, or teaching a class. The stuff that is done is, almost always, in some ways different from anything else that has ever been done before. Soft technique is how we organize stuff to do stuff. It is where creativity, adaptation, and evolution occur.

The vast majority of technology assemblies contain a combination of both hard and soft technique. We may, for instance, need to learn hard techniques to make musical noises from a musical instrument, but it is typically our soft technique – the expression - that matters when others listen to what is played. Similarly for handwriting: we must form recognizable letters but every one of us writes idiosyncratically and every time we write even something as familiar as a signature, we write it differently. The same is true for something as mundane as vacuuming the floor, which has probably never been done in precisely the same way twice.

Some technologies seem to inherently demand that we use soft technique and are incomplete without it. As Kauffman (2000) demonstrates, the number of possible ways that, say, a screwdriver can be used apart from driving screws, from paint stirring to murder, is unprestatable and, most likely, infinite. Unlike the watch, in which a human must play a precise role as part of its orchestration, there are gaps in the orchestration embedded in its design that must be filled by humans. It is useful though potentially misleading to describe such technologies as soft or, at least, at the softer end of a spectrum.

Other technologies, such as regulations, cash registers, and watches, must be used correctly, with humans playing a proscribed role as part of the technology, or they are either non-functional, or should be labelled as a different technology altogether. These can be described, again potentially misleadingly, as hard, or at the harder end of a spectrum.

Softness can be understood in terms of the adjacent possible: the softer a technology, the greater the number of adjacent possible empty niches it provides. The caveats above relate to the fact that softness or hardness is not normally therefore a fundamental property of the technology itself, because we can combine any technology with another to create a new assembly with different adjacent possibles. A watch, for example, can be softened to become a compass, a prop, an artwork, or a status symbol, and, taken apart, its cogs and wheels are endlessly repurposable. Some hard technologies, most notably laws, rules and regulations, may be more prescriptive but the existence of lawyers and judges suggests that even they have adjacent possibles. Likewise, an archetypally soft technology such as pen and paper can be hardened by combining it with a set of rules that determine precisely what may be written or drawn, from painting-by-numbers to a fillable form.

As hard technique improves, so does the adjacent possible. For example, though both may make beautiful music, an expert musician may intentionally make many more musical sounds and sequences of greater complexity and nuance of expression than a beginner. The more we develop our technique, the further it can develop, the more assemblies we can orchestrate. Likewise, knowing more of what extrasomatic technologies are available, for instance through browsing catalogues, stores, or libraries, in itself creates more adjacent possibles.

For similar reasons, it also matters from whose perspective we consider a technology. The teacher setting a quiz may find it to be a very soft technology while, from a learner perspective, it may seem very hard. This again speaks to the fact that an instantiated technology – its use – is not just that technology but also the technique with which it is assembled with other technologies. We may call it by the same name, but the quiz for the teacher and the quiz for the student are not the same technology. They are different orchestrations of phenomena with different uses.

Technologies that demand softer technique of their participants require more creative effort. They tend to be slower, less efficient and, by definition, are less reliable and less consistent than harder technologies. There is often a trade-off between flexibility and speed, efficiency, and consistency. What matters is not whether a technology is soft or hard per se, but whether it is soft or hard enough to meet current needs. There must always be some hardness, or it could not be described as a technology at all: absence of hardness would, essentially, imply infinite adjacent possibles, which is no better than none at all. In providing constraint, the hardness is, to a large extent, what makes creativity possible (Boden, 1995).

6.2 Illustrative implications for teaching

- A teacher's soft technique matters at least as much and often more than the hard technique of the pedagogical methods they use. No matter what the pedagogy, it can be enacted well or badly.
- A teacher's poor hard technique may be compensated for by good soft technique. Talent, attitude, values, and many other intangible, volatile, and idiosyncratic personal traits always play a large role in the success or failure of teaching. It is also possible to teach badly with good methods.
- Learners must learn the hard techniques of whatever activity they are engaged with, even and perhaps especially if the learning goal (such as in art or poetry) is to be able to subvert them. It is normally best to try to limit the hard technique, such as roll-calls or logins, needed simply to participate in a learning activity.
- For time-strapped or skill-limited teachers it may be expedient to use pre-orchestrated tools that embed hard technique, be they learning management systems or pedagogical models. Ideally, though, those technologies should be selectively softenable (customizable) so that teachers can gradually take more control as they learn more. The more monolithic or black-boxed the technology, the more difficult that tends to become.
- The same applies for learners: following a hard set of pedagogical methods using restrictive tools may provide necessary scaffolding, but there are high risks that parts will be boring and other parts will confuse, and it should never be forgotten that the main purpose of learning hard technique is usually to enable soft technique for creating or problem solving in an authentic context not to, say, pass a test.

7 About the whole

7.1 Observation: what matters most is the configuration of the parts as a whole, not the parts

To understand a technology, we must consider its entire instantiation, including the hard technique required to use it, the soft technique it enables, and the assemblies of which it is a part. Parts do matter, especially to the one who is assembling them, whose design will inevitably be massively affected by them and on which its successful operation depends: we need to know the adjacent possibles and constraints they provide. However, for the whole, it is the configuration of the parts that matters. Even when a part is harmful, other parts can mitigate the damage. The risks of high currents in capacitors in electronics devices, for instance, may be dealt with by enclosing or insulating them. There is probably no harm or good in a technology that cannot be reversed by organizing it with other technologies.

Many technologies exist only as counter-technologies to others. This is inefficient. If, for instance, we are polluting the air by burning fossil fuels then it is far better to make use of technologies that do not burn them than to design technologies to capture that pollution. Dubos (1969) rightly condemns this as a philosophy of despair, because further counter-technologies will be needed to counteract the unwanted effects of those technologies, and so it goes on. This is inevitable for, as Postman (2005) observes, all technologies are Faustian Bargains, with side effects and consequences.

However, technologies are born into a vast entangled ecosystem, inheriting parts that already exist, needing to fit with many others, and there may be many additional constraints, from economics to physics to skill to availability. Counter-technologies are often the only viable solution. Typically, these are soft techniques that latch onto latent adjacent possibles and bypass or take advantage of constraints. Skilled use of a poor tool can often compensate for its shortcomings and, when a tool is sufficiently soft, soft technique is the dominant part of the technology itself, which is why we cannot reliably generalize about the effects of inherently soft technologies like pedagogies or computers.

7.2 Illustrative implications for teaching

- It is possible to teach using very poor methods or other tools but to combine them with counter-technologies that mitigate their weaknesses. This, in part, accounts for the occasional effectiveness of, say, lectures because although, we have known for many years that they are usually poor ways of imparting information lectures (Greene, 1928; Laurillard, 2002), they can sometimes be performed very well.
- What we recognize as good teaching is often a counter-technology to technologies used to teach. This is especially true of ways to support motivation that is lost because students are forced to learn the same things at the same time, hence diminishing autonomy and causing some students to be bored and others confused (Dron, 2023a).
- On average, harder, more prescriptive "learning science-based" approaches like Direct Instruction (Stockard et al., 2018) are more effective in terms of marks achieved than active learning approaches like problem-based or inquiry-based learning (De Bruyckere et al., 2015; Hattie, 2013; Kirschner & Van Merrienboer, 2008). This is because active learning approaches demand more soft technique of the teacher and, on average, teachers are average in their skills and talents. Done well, there is copious evidence – the majority from qualitative case studies that seldom figure largely in metastudies about what works - to suggest active learning may be more effective, but done badly, it is worse. Harder techniques leave less orchestration to the teacher so, assuming teachers follow the well-honed strategies that such methods specify, the average outcomes are better.
- Quantitative research into whether particular methods or tools are better (on average) than others will invariably favour harder pedagogies and systems because they are repeatable. There is a need to research ways of developing the skills and talents of teachers to more effectively implement softer pedagogies. Equally, we need to be very wary of how such things are measured, to which we will return when discussing non-technological concerns.

8 About structural dynamics

8.1 Observation: the influence of the hard is greater than the influence of the soft

In any complex technological assembly, pace layering (Brand, 2018)) occurs: the slower changing parts of the system are inherently more structural than the faster changing parts, that must fit around and adapt to them. Path dependencies also play a significant role, from significantly limiting which word may come next in a sentence (a feature that makes predictive text possible) to determining the size of a space shuttle's engine (Kelly, 2010).

Because they are, by definition, rigid and invariable, harder assemblies, including techniques and the orchestrations embodied in physical or virtual objects, play a greater role in determining the form that the whole assembly may take than soft techniques that must fit around them. Harder assemblies are not just the result of thought: they embody and enact thought itself, replacing the need to perform the orchestrations ourselves. They become parts of the assemblies along with the techniques we employ in their instantiation, whether we act as parts of their assemblies, or they are parts of our own.

Conversely, every technology we create, including those that take form in soft technique, creates new adjacent possibles that further technologies can fill. Every invention can then become part of another (sometimes, like words, and wheels, many others) and, as that happens, combinatorial possibilities with other technologies emerge to create still further niches waiting to be filled.

The formation of adjacent possibles accounts for the exponential increase in number and complexity of technologies for at least many thousands of years. It is a punctuated evolutionary process because some technologies – language, writing, communication, travel, printing, the Internet, mass production, artificial intelligence, etc. – have greatly increased the reach for others, so allowing faster and more ubiquitous uptake and reassembly into new technologies of not just themselves but other technologies. Other technologies, such as copyright or patent laws, or religious prohibitions, may have had the opposite effect, but the overall trend has always been. The same effect can be seen at every scale. Every word that is written here both constrains what words might follow and creates adjacent possibles for me to exploit. The hard technologies – words, correctly spelled- participate as partners in the soft whole.

8.2 Illustrative implications for teaching

- A great deal of the technology of teaching is not instantiated by teachers. They work within a context that is designed to teach: classrooms, textbooks, schedules, codes of conduct, regulations, learning management systems, curricula, standards bodies, examination boards, government legislation, and a host of other elements in the system provide a series of harder, slower-moving structures into which their teaching must fit. Pedagogy never comes first. Educational systems are replete with structural elements that strongly influence and sometimes determine the possible ways that teaching can occur within them. It is therefore possible for students to be successful when teachers are poor or even absent.
- Wherever adjacent possibles can be found there are ways to insert counter-technologies to overcome them. For example, if teachers are forced to teach in lecture theatres, they may use methods such as pyramiding or goldfish bowls, or they may make themselves available outside the lecture theatre. If a learning management system restricts (say) opportunities for non-threaded forms of dialogue, other systems may be added to the assembly to compensate. The cost lies in difficulty and time: the softer the system, the more effort and skill is needed to make it work.
- Teachers should actively seek to develop the techniques needed to make use of more technologies, be they online tools, institutional systems, pedagogies, or legible writing. The more we can use, the greater the adjacent possible, the more likely it will be that we will be able to organize the stuff needed to learn more effectively and adaptively. If this is too difficult, delegating to others such as learning designers, multimedia specialists, editors, or generative AIs, can provide us with hard components to assemble.
- Openness and sharing is an extremely good idea, because it increases the number of components available to be used in an assembly. The more openly we share, the greater the adjacent possible for all.

9 About non-technological phenomena

9.1 Observation: non-technological phenomena are critical parts of the assembly

Non-technological phenomena are part of every technology's orchestration, from laws of physics to biological dispositions. Equally, many of the uses to which technologies are put are to meet non-technological ends, from entertainment to slaking thirst. Some of the phenomena that make our ability to perform complex technological tasks possible come for free as a result of our mammalian instincts, capabilities, and propensities: memory, planning, modelling of possible consequences of actions, self-awareness, the capacity to sense and control muscles, and so on, seem common to at least higher mammals, birds, and cephalopods, if not to other classes of animal.

Central among the innate phenomena that our technological cognition relies on are the things that motivate us - that excite, satisfy, amuse, bring comfort, enthral, satiate, or cause aversion or pain – without which we might never learn at all. Learning – or the need to become competent - is, though, motivating, as are the other prerequisites of intrinsic motivation, relatedness and autonomy (Ryan & Deci, 2017).

Almost certainly long prior to their use of anything we would normally identify as technologies, our ancestors were social beings, evolved to share discoveries and ways of being from those around them. Though beneficial at a species level, some of our innate social drives may harm or at least disadvantage individuals, such as the drive for power and social status.

9.2 Illustrative implications for teaching

- Discoveries from the science of learning should be used in the orchestration where possible, and associated soft techniques, both in using and in teaching them, should be nurtured and practiced. They are, however, not always the most important parts of the assembly, and may even be harmful in some assemblies. For example, forcing students to use a science-supported memorization technique will backfire, because the use of rewards or punishments orchestrates phenomena that extinguish intrinsic motivation to learn (Kohn, 1999).
- It is at least as important to develop the teacher as it is to develop more effective teaching methods. Much of what makes teaching successful lies in human attributes such as excitement, empathy, humour, caring, and so on. We may use technologies, from method acting to meditation, to nurture and develop such phenomena in teachers, and teachers may use them to inspire or nurture students.
- Technologies of communication, in both in-person and online environments, are critical to learning. Communication is at least as much about coordinating joint activities and actions as sharing of information. Where possible, pedagogies and supporting technologies should therefore support opportunities to perform activities, not just talk with other humans.
- In any act of teaching there is always a hidden curriculum of communicated values, attitudes, and approaches (Margolis, 2001; Rossouw & Frick, 2023). It often communicates not just hidden but tacit knowledge (Polanyi, 1966) that cannot be directly expressed or measured. This is exposed in sharp relief when we consider the value of children's stories, that only rarely teach children facts, but that almost always teach values, ways of being, and ways of relating to others and to the world around them. Education is a process of developing people and societies, not just techniques. We should therefore be wary of generative AIs that teach, because they also teach hidden curricula, and it may not be advisable to learn ways of being human from a non-human.

10 About cognition

10.1 Observation: the technological connectome is both what makes us smart and is itself part of that smartness

There is a technological connectome that vastly extends our neural connectomes' capacity. Metcalfe (1995) demonstrates that the value of a network can be expressed using the formula N(N-1)/2, where N is the number of nodes. The formula expresses the fact that, because it can form multiple connections, every additional node adds significantly greater value to the network than the node itself and, in a human brain, there are billions of neurons, with trillions of connections. However, Reed (1999) shows that, in a network with clusters, and in which each cluster itself can be treated as a node, the potential value is far higher - $2^N - N - 1$ - so each additional node adds exponential value. This is the dynamic of the intracranial technological connectome. Every technique can become part of a very large and unprestatable number of others, and so it repeats and recurses. Words, say, cluster in sentences which can cluster into concepts, theories, models, stories that in turn can recombine, almost limitlessly. Some are pedagogical methods that provide tools that increase our capacity to form these clusters faster and further.

The expansion of the adjacent possible that feeds the growth of this network is vast, but our minds are not just intrasomatic. We enlist extrasomatic technologies, delegating and offloading parts of it for our own and others' use, and benefitting from others doing the same. You, the reader, and I, the writer are, at this moment, parts of a technology of writing that directly participates in our cognition. We are not of one mind, but parts of our minds are shared. The technologies that surround us, be they words used in conversations or doorknobs (Gibson, 1977) become participants in our cognition in much the same if not at least sometimes functionally identical ways to those enacted intracranially (Clark, 2008). As Mcluhan (1994, p.3) puts it, "Each of man's artefacts is in fact a kind of word". This includes the products of not only living humans, but also of the innumerable ancestors who did the same and have done so since long, long before homo sapiens evolved, and all that has been assembled from them.

Evolving through assembly, woven into a vast tapestry that is rich in both designed and emergent structure, all technologies are intricately connected in complex webs. There is cognition woven into the fabric of our technological systems, at all scales, that not only supports and enables our intracranial thinking but embodies parts of it in ways that extend far beyond what any one human mind can apprehend. There are at least millions of co-participants in any cognitive act. Any one individual is at a unique intersection of a planet-wide, epoch-spanning network, from which their own cognition, and their own means and capacity to extend that cognition through learning, is formed. Our technological connectome is not just what makes us smart: it is part of that smartness.

10.2 Illustrative implications for teaching

- Designated teachers may have greater influence but can never control all the many teachers who play roles in student learning, and it is demotivating to try. The effects of specific interventions on specific learners are, for the most part, impossible to accurately predict in advance or to comprehend in detail, unless the goal of learning is very hard, which is rarely useful.
- Short-term local predictions of learning are more accurate. The technologies we use for learning should be sufficiently rich in adjacent possibles to allow timely adaptation to what we discover.
- Physical institutions, not just the people they employ, teach, whether through processes, such as clubs, societies, and social events, or structures like common rooms, corridors, and libraries that bring them together. Online learning sites and systems should similarly be populated, and designed to foster similarly diverse kinds of communication, including serendipitous encounters. Dialogue and opportunities for sharing should occur everywhere: a static web page is a lost opportunity for learning.
- Online teachers should create opportunities for learners to engage in and make use of their own social, physical and virtual contexts.
- Inequalities are almost inevitable because every human on the planet participates in the technology connectome from a unique spatio-temporal perspective and its distribution

is very uneven. Public educational systems help to reduce such inequalities by enabling access to more than most students could achieve alone, even more so when they are relatively open. However, none can fully overcome the uniqueness of every human context, and nor should they try, for it is that uniqueness that creates new adjacent possibles.

- We should celebrate the diversity, and design learning experiences that make use of it. The implications for assessment, in particular, are profound. While there is great value in helping students to achieve intended learning outcomes, every student will also achieve other learning outcomes, explicit and tacit, that may be at least as important. There is, arguably, even greater value to be gained from harvesting such outcomes (Wilson-Grau & Britt, 2012) and, if possible, sharing them with other learners. The process of learning, not just its products, should also be harvested and used to support adaptation. it should be as visible as possible, whether through observation, reflection, discussion, or automated logging.
- Not all that is shared is useful. For beings of limited attention, a glut of technologies to choose from may be as bad as or worse than a limited range (Page, 2011; Schwartz, 2004); the blind may lead the blind; network effects may privilege what receives attention over what supports effective learning; and there may be concerns about privacy and ownership. Counter-technologies, from deliberate training or feedback, to techniques that support critical thinking, to automated approaches to filtering that dampen mob effects may be needed. This, again, speaks to the need for teachers to seek to understand the whole: to see how it fits together and, should things not fit or be harmful, to adjust the assembly to counteract the problem.

11 Conclusion

To understand the nature of technology is, in part, to understand the nature of learning, because technologies do not just enable but embody learning, and they form many of its goals. The model I have presented in this paper can be boiled down to 10 simple statements about technology, none of which is directly concerned with learning or teaching but each of which carries profound implications for how it can or should occur:

1. Technologies are the organization of stuff to do stuff.
2. Technologies are assembled of and form parts of other technologies, joined in a largely unbroken global technological connectome.
3. The use of a technology is also a technology – a technique – and forms part of its assembly.
4. Through technique, we are participants in technological assemblies, and they are participants in us.
5. Technique may be soft (malleable, creative) or hard (rigid, consistent), and is nearly always a mix of the two.
6. Hard influences soft more than vice versa but, through assembly and technique, all technologies can be hardened or softened.
7. The technology that matters is only the whole, including the techniques of all participants in its instantiation.
8. Soft technique – the way something is done -matters at least as much as hard technique, in all technologies.
9. Human capacities and propensities are inseparable parts of the orchestration of technologies in which we participate.

10. Technologies enable and form significant parts of both our collective and our individual intelligence.

I have so far avoided much consideration of cognified (Kumar et al., 2022) technologies, which may seem odd for a paper about the role of technologies in cognition, but it should now be clear that the smartness of a technology cannot be separated from its instantiation, including its connections with all the other technologies in its web and above all the humans who participate in it. All human intelligence is at least partly artificial. That said, any paper written in 2024 would be incomplete without some mention of generative AI.

Generative AIs pose novel challenges because they are the first technologies we have ever created that are capable of soft technique that, at least superficially, resembles our own, and that embody and connect our collective intelligence at a hitherto unseen scale. Globally, the technological connectome and the consequent adjacent possibles for learning and teaching have therefore expanded exponentially. However, when a generative AI teaches, like a human teacher, it does not only teach ways of doing or knowing, but it also teaches values, ways of being, ways of engaging, and ways of seeing (Dron, 2023b; Gallagher & Breines, 2023). Being largely composed of the collective outputs of actual humans, these resemble our own, but they are not the same. They are not the product of a person with skin in the game; there is no "I" there, no identity, no purpose. They embed the biases of their trainers and maintainers. They are designed to be inhumanly tireless and endlessly patient. They are not human. Whatever we become as these technologies become ubiquitous and we ubiquitously learn from them, it will be different from what we are now.

The challenges of teaching in a post-generative AI era are therefore different in emphasis, if not in kind, from those faced in the past. In the past, learning of values, attitudes, relationships, and ways of being has been innate in our educational systems as we learn the techniques that learning outcomes define, within structures that strongly affect what and how they are learned (Sarikhani et al., 2020) as well as with people who model them (Rossouw & Frick, 2023). We have seldom if ever had to pay much attention to the hidden/tacit curriculum, nor have we needed to assess it, because it came for free because of learning from other humans. Now, if we are to retain this vital role, we must seek active ways to bring humans back: to create space for community, relationships, and engagement with others, and to make this explicit in the design of educational structures and processes. The relentless trend towards creating and assessing explicit learning outcomes to the exclusion of all else is antagonistic to this goal and is already groaning under the weight of counter technologies, from cheating to tactical satisficing, that undermine it. It also fails to acknowledge the connectome, the extended mind in which we are all inextricably implicated (Hug, 2023). The model of technology proposed in this paper reveals the problem, and some of the implications of it may hint at some of the solutions: to focus on the whole – especially the soft human technique - not the parts; to develop teachers, not methods of teaching; to harvest, not assess compliance with, learning outcomes; to make learning itself visible; to build social engagement into every nook and cranny of a system. This speaks to the most important message that springs from understanding cognition in technological terms: that people and technologies are inextricably intertwingled. Technologies make us who we are, for better or for worse. Understanding how they work is therefore to understand how we work, and that is the start of what makes teaching possible.

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