Victims of Outcomes: Towards an Enactivist Model of Technological Literacy

Cyclical models are often used to describe how students learn and develop. These models usually focus on the cognitive domain and describe how knowledge and skills are learned within a course or classroom. By providing insights into how students learn and thus how an instructor can support learning, these models and the schemas drawn from them also influence beliefs about learning and thus how educational programs are designed and developed. In this paper the authors present an alternative cyclical model of learning that is drawn from a philosophy of enactivism rather than rational dualism. In comparison with the dualism inherent in viewpoints derived from Descartes where learners construct internal mental representation from inputs received from the external world, in enactivism development occurs through continual dynamic interactions between an agent and their environment. Enactivism thus emphasizes the role environments play in learning and development.

The model developed in this paper hypothesizes that the environment in which learning typically occurs can be represented by three elements: the learner's identity and culture which informs personally significant goals and values; the affordances a degree program offers in areas of knowledge, identity, and context which informs the capabilities of the environment; and the implicit and explicit goals of education as they are negotiated and understood by learners and teachers. These three elements are strongly coupled and together define the ever-changing learning environment.

The paper explores how changing technologies and cultures affect each of these three elements in regards to students' ability to become technologically literate. While rational or dualist views of education see such environmental changes as peripheral to developing accurate representations of truth, enactivism posits that environment significantly affects the process of education. Because each student or faculty member is a participant in a learning organization changes within the organization—whether externally or internally driven—change the learning process. If education is deemed successful when students can transfer learning to new contexts, dualist models assume transfer is weakly coupled to educational environments while the enactivist viewpoint posits that environments strongly affect transfer.

The enactivist model can inform efforts to encourage technological literacy. Like many areas in STEM, education technological literacy has sought to identify and support learning outcomes that specify effective teaching or content interventions which enable learners to become more technologically literate. From the enactivist perspective, however, technological literacy is achieved by placing individuals into an environment in which they must navigate technology-induced challenges, with success defined as learning processes that allow learners to manage tensions inherent in their environment. Because most students already live in such environments teaching definable or enumerable outcomes makes less sense than helping student to be metacognitive and reflective how they manage and relate with technology.

Introduction

This paper uses technological literacy as a foil, to reflect back a vision of technology and engineering education that can lay claim to be better than what currently exists. Making a claim to be better sets up several conditions on the claimant – to identify what needs to be improved and why; to craft a credible plan explaining why the situation will be improved in some specific way; and that any change will not have unpredicted negative consequences, particularly for groups who lack the resources, power, or position to engage in decision making processes. In brief this paper argues that as engineering education broadly has engaged deeply with the process of achieving defined education outcomes, it has unintentionally skipped over issues fundamentally related to becoming a person. Reconsidering the person and the larger environment in which they exist offer opportunities for better defining educational outcomes and processes. This paper is not concerned with specific processes, content, or outcomes of technological literacy; rather using technological literacy as foil lets us cover familiar ground from a different perspective. This is analogous to walking a familiar path after an unusual weather event in which the familiar landmarks remain unchanged, but are seen in a new light and with new possibilities for beauty or meaning.

Technological literacy makes a valuable foil for discussions because of its purpose, evolution, and definition. Pragmatically technological literacy is one of many literacies—scientific, information, media, civic, etc.—that are being promoted as necessary to live in today's world. Each literacy can lay claim to a set of overlapping skills that are hypothesized as needed to navigate a world of increasing complexity and interconnection. As the natural world has historically changed on scales long compared to the human lifespan, most adaptation to change is technological in origin. Technological literacy as a framework arose in education in the US from shifting focus from traditional shop class to other areas of technology and thereby sought to influence educational policies. Since technology changes rapidly, what counts as technological literacy and what doesn't is fluid; definitions are subject to change over time. There are multiple definitions of technological literacy that are adopted by various groups who impinge upon the broad space that is being defined here (for a review see [1]), but in terms of education and student learning the most common is being able to use, manage, evaluate, and understand technology in one's day-to-day activities or one's life. The definition is both intersectional—all domains where technology impinges upon human activity—as well as teleological in that it focuses on technological literacy in terms of the purpose it serves rather than the causes by which technology arose as a force in a person's life.

It is the above definition—which broadly connects technology (the systematic treatment of craft) with life—which makes technological literacy an interesting foil for education more broadly. The definition implies that we must weave ours and others' craft into our lives in a way that benefits both us and the society in which we live. Given the crafts which are driving societal and individual changes today such as computing and communication technologies, technology necessarily impacts education through science, technology, engineering, and mathematics –

broadly known as STEM disciplines. The STEM-predominant focus of technological literacy introduces an interesting tension. Education in STEM mostly focuses on necessary knowledge, those things which are true always. However the application of technology to one's life deals with contingency or things whose truth depends on context. That is what may be right for one person in their life may not be right for another. This tension between necessity and contingency is one that is becoming central to engineering education whether it is framed as achieving a proper balance between engineering science and engineering design or discussions over where and the extent to which transferable skills should be taught in a curriculum.

Additionally, it is implied in the above definition of technological literacy that a technologically literate person should not only should be proficient in managing technology in their own life, but it should be done in a way that is beneficial to oneself and society at large. This way of being, or mindset, is eloquently captured in the Wiradjuri (an Aboriginal group in New South Wales) phrase that Charles Sturt University has adopted: *yindyamarra winhanganha* which means "*the wisdom of respectfully knowing how to live well in a world worth living in*" [2]. A related word coming into common use at universities is 'thriving'.

Of course the alignment of education and life is not strictly limited to the domain of technological literacy or how such literacy is defined; it can be broadly claimed that this has been a goal of all education for some time [3]. What is relevant and special for technology, and its crucible engineering, is that since technology seeks to change the world then becoming technologically literate implies the necessity of either as adapting to changes or oneself architecting such changes. Dias [4] frames this as the difference between *homo sapiens*, man the wise who uses philosophy to understand their life, and *homo faber*, man the maker who uses technology to change their life and the world around them.

All of this sounds quite inspiring, but for educators it is not at all clear what exactly is to be done differently than what we are doing now. What specifically suggests a path to a better in which *homo faber* lives well in a world worth living in? There are broadly two issues. The first is to learn at all; if learning is to be guided it must be supported and implemented by reference to some valid theory or model. Second is to transfer what one learns; from the perspective of education, the issue of technological literacy can be framed, over-simplistically, as taking what one learns or should learn in school and using it productively in the space outside of school.

The Process and Goals of Learning – Models and Outcomes

First we look at models of learning of which the literature is quite extensive. There are numerous books on how to promote learning which offer sets of heuristics to try in the classroom (for example see [5]–[7]). As mentioned previously here we are not concerned with techniques that those who teach can adopt as much as we are teachers' disposition. Disposition is the way we habitually approach life and here it is assumed that with regards to teaching or promoting learning an individual's disposition in the classroom is based both on what they value in education [8] as well as the mental models they hold about how others learn. Values affect what is taught and the mental model(s) a professor holds affects how they teach.

As mentioned above there are a very large numbers of models of learning which are based on theories of how people learn. These models may be explicitly developed by reading research studies and learning from the experiences of others, or they may be more implicit, developed through individual practice and one's own experiences of being taught. Often they are both.

One of the simplest mental models or schemas of how people learn, which dates back at least to Aristotle, is the learner as a *tabula rasa*, or blank slate upon which perception and experience imprint knowledge which then becomes useful through a process of abstraction. The mind as a blank slate contrasts with the Platonic view of the mind (or soul) as existing before birth and coming into this world with some knowledge. The *tabula rasa* view has a long history including St. Thomas of Aquinas introducing it into Church doctrine and its adoption in Locke's empiricism which has a strong influence in engineering [9]. Those who hold this model of learning view students as learning what we teach them, so the process of education is to clearly define important and achievable learning goals and teach or offer experiences in a way that best leads students to the desired knowledge [10]. This view is represented simplistically in Figure 1, below with the instructor (orange) sitting above to guide the paths of learners to defined goals.

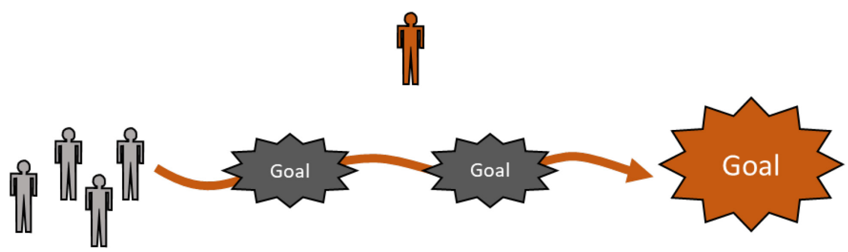

Figure 1: The tabula rasa view of education where an instructor (orange) leads students (grey) through progressive learning goals by teaching them.

Another broad class of models takes the abilities and agency of the learner into account and assume the learner has a role in developing their cognition. Here knowledge is not simply impressed upon students, but to learn students themselves must take part in the construction of knowledge. Unlike the implied linearity of the tabula rasa view, such models are commonly circular and iterative to capture that understanding is developed through a series of actions that help develop understanding and abstract knowledge so it is more useful. Figure 2 shows the Kolb cycle [11] which is an example of models which build on the *tabula rasa* framework by saying it is not enough simply to have experiences, but one must actively seek to make sense of the experience either cognitively or through some sort of active experimentation. Different individuals may make sense of their experience in different ways, but some form of active participation is necessary. It can be argued that such activity does occur in the *tabula rasa* model, but the model does not explicitly specify what these activities are or how they support learning.

Active and cyclical models put the instructor at the center of the activities required to learn, Figure 2, as a designer, coach, and even participant rather than above them. Clearly the two models are not exclusive, as in if a teacher adopts one they must reject the other, rather they suggest different valuations of where one puts one's effort into the classroom. By focusing on the role of agency and action in learning such models imply that learning occurs in some environment and among other students, but these factors are usually not addressed explicitly.

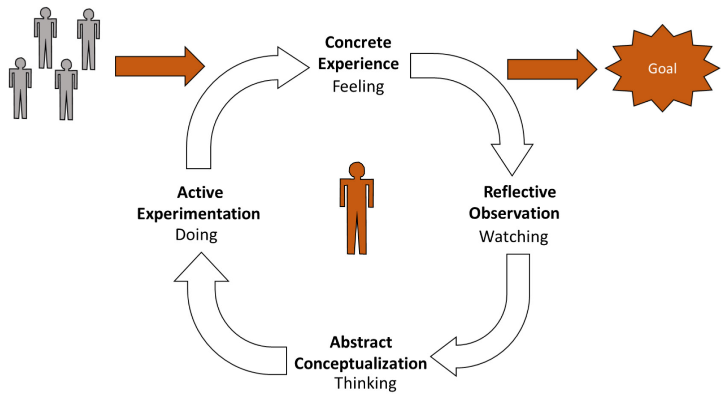

Figure 2: The Kolb cycle as an example of a model of learning where the instructor leads students through a series of activities to develop knowledge.

A third type of model expands upon the cyclical models of cognitive development and explicitly acknowledges that learning is both a mental and social activity. While the Kolb cycle of Figure 2 discusses the steps that an individual learner goes through, models such as Harre's Vygotsky cycle [12], Figure 3, integrate social aspects of learning. Here learners are explicitly assumed to be interacting with other learners and the teacher as they go through various stages of learning. It is the social interaction and acceptance of others through which a learner comes to recognize themselves as possessing knowledge which they can then pass on to others in turn.

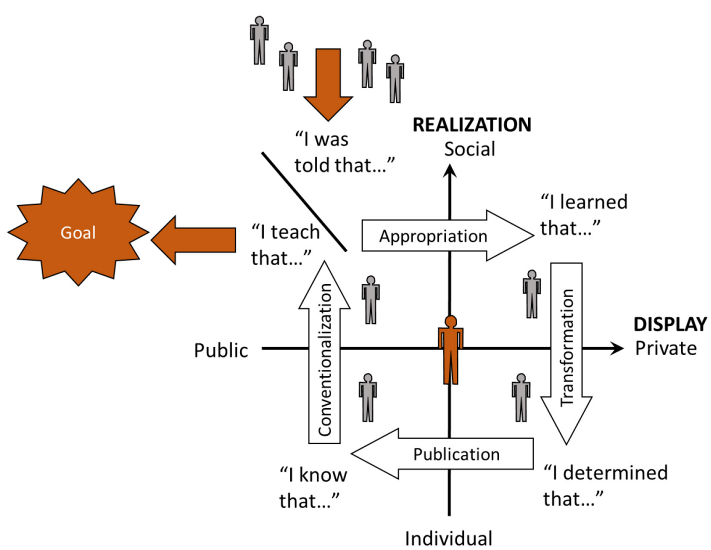

Figure 3: In the socio-constructivist Vygotsky Cycle students go through a process of interacting with the teacher and peers to obtain personal ownership of knowledge.

Again, such models are not antithetical to each other, rather each tries to capture certain assumptions and hypotheses about learning. Holding such models—either implicitly or explicitly—informs a teacher about the types of activities and environment they should promote in the classroom. The *tabula rasa* model emphasizes preparation and goal setting, the cyclical models of active and social learning steer attention to how the goals are achieved, placing the instructor more centrally in learning and in creating an effective milieu. The cyclical nature of iterative models implies that learning is imperfect and needs to be built and reinforced over time by multiple experiences rather than imprinted once.

Regardless of the model used there is an assumption that the student learns some defined content, and it is the job of the instructor or curriculum to set what that content is. While a strict interpretation of the *tabula rasa* model assumes that what is taught is learned, even in this model teachers know that learning is imperfect and what is taught is learned with varying degrees of fidelity. The more active and constructivist models imply how this fidelity can be improved but retain the idea that typically some entity external to the students is defining learning goals. These of course are not the only models that can be adopted, other views derive from other philosophical bases and have been discussed in detail by Davis [9].

Beyond how people learn there is the question of how students are to use the knowledge they acquire. Such use is both in the present and presumably in the future. In more education specific terminology this is broadly known as transfer – the ability to take what is learned in one context and use it in a different context. Transfer is often discussed on a scale of near transfer on one end and far transfer on the other. Near transfer is using what was learned in one domain and applying it in the same or very similar domains. The definition of a domain is not exact and can include spacing in time, location, framing or context of a task, etc. Far transfer is using what was learned in significantly different contexts. While there are ways of teaching that support transfer—a focus on understanding of concepts, having learners practice skills in various settings, emphasizing abstraction, the use of metaphors and analogy—transfer becomes harder the farther it is [13]. While clearly near and far transfer occurs on a spectrum, it has been claimed for a long time that the farther the transfer the rarer it is [14]. While some question this conclusion, recent studies generally support the fact that far transfer generally does not occur [15]. In other words, becoming smart in one domain does not necessarily make you smarter in other domains. If we want learning in school to broadly apply to life we must account for the fact that learning is situated [16], [17] and context matters greatly. We still have much to learn about how learning in one context transfers to different contexts [18].

Where has this discursive exploration of learning taken us in terms of the purpose of this paper, which is to use technological literacy as a foil for better education more generally? First, most models of education are goal oriented; that is they assume some set of content that students are supposed to learn. Second, they recognize that learning is not an automated process but that its effectiveness depends a great deal on who is learning, the methods used, the social environment in which learning occurs, and characteristics of the learner themselves. Thus learning is seen as an outcome of teaching that is met to a greater or lesser degree depending on multiple factors, many outside of the instructor's control. Third, even if something is learned in one context it is not automatically transferred so it becomes usable in a different context. Since this is true for both necessary and contingent knowledge it implies that the outcomes of learning should be measured at some point later in time, perhaps in a different context.

To respond to the issue of how much students actually learn and retain, many organizations and policy makers who concern themselves with the quality or rigor of education have gravitated to defining outcomes or standards as a way both to measure learning achievement and, in the case of policies like 'No Child Left Behind', assign resources to schools even though the notion of quality can be highly problematic. As a result outcomes-based education has become almost *de rigueur* in the United States, particularly in engineering education after ABET adopted standards of outcomes-based education several decades ago [19]. Although outcomes can help provide accountability and serve to help educators define what should be taught, the discussion above makes clear the use of outcomes is not a panacea and their use can raise a significant number of tensions for educators.

Let use return to technological literacy and look at it through the lens of outcomes. At first glance it would seem to make sense to develop a set of standards or outcomes for technological literacy to ensure that there is some consistency both in how technological literacy is defined and what students are taught. In the K-12 space a comprehensive set of standards have been developed for technological literacy [20], but here we will avoid getting down into the details and look at our high level definition of technological literacy: being able to use, manage, evaluate, and understand technology in one's day-to-day activities or one's life. While it is certainly possible to develop outcomes, there are several areas that are problematic if we want those outcomes to be meaningful.

The first problematic area is that if technological literacy involves utilizing technology in daily activities and life more generally we first have to determine what activities are meaningful to students and have some idea of what it means to have a good life. This is difficult enough in the case of our own children, but the more diverse classrooms become the harder the task for the educator. A second challenge is that technology by its nature can change much more rapidly than educational programs can, particularly today in rapidly moving areas of technology such as software and mobile communications. The leads to a situation where learning outcomes need to be dynamic. A third challenge to developing outcomes is that the models of learning that outcomes are based on do not fully describe the complexity of learning and it is worth asking what the models leave out. Certainly the models are more useful when the goals of learning are carefully prescribed, but for a question as big as helping individuals to deal gracefully with inevitable and rapid change in their environments (for that is the effect of technology), it seems unlikely that attempts to develop standards or outcomes will be very useful. For example, the models only peripherally take the larger environment of learning into account even though studies show that this is a critical factor in student success [21]. Finally, if the goal of technological literacy is to use the learning outcomes in one's life then transfer is critically important. But we know far transfer doesn't happen much so learning has to take place in similar contexts which creates new challenges. Generally the intersection between environment or context and transfer is not well understood [18] and may offer some affordances not yet taken into account in common models of learning.

A Critique of Outcomes-Based Education

The above offers several possible critiques of outcomes-based education. In the spirit of Habermas' discourse ethics, the point is not to assert outcomes are bad *per se*, but rather to recognize that the limitations of a system that has become extremely prevalent in education are often ignored. For example, when ABET adopted outcomes-based evaluation with EC-2000 the focus become on continual quality improvement. This framework was well understood by engineers and thus readily accessible to engineering educators. In this case the quality that is being improved in the ABET process are the defined student learning outcomes that each program is responsible for assessing and evaluating. Thus the entire ABET accreditation system rotating through cycles of continual improvement—along with its inherent power dynamics and influence on what students learn—is held together by the lynch-pin of learning outcomes. Because outcomes and what can (and cannot) be assessed depends on the learning models that support outcome development, it is important to focus on applicability – i.e. when they are useful and when they may not be.

Previously three broad areas were identified where outcomes-based education faces challenges in achieving the broader and holistic goal of technological literacy; that is helping someone deal with technology in a way that improves their life. The first of these is broadly the difficulty of meaningfully interpreting what outcomes will improve others' lives. Depending on the life we have lived, and envision ourselves living in the future, some technologies or lessons may be more relevant and meaningful than others. In the case that students are not diverse—that is they do not come from too different cultural backgrounds, economic strata, or family value systems—making assumptions on what they value may be warranted to a degree. Alternatively, if within a discipline there is broad agreement on topics are vital to student development these can define outcomes. However, within technological literacy it is unlikely these conditions apply, so to teach how to manage technology in one's own life students themselves need to be given agency in their own education [17]. Such agency is not addressed in most models of learning, perhaps because doing so raises significant challenges related to the resources required.

This challenge, and it is a large one, has been considered by several authors one of whom, the economist Amartya Sen, has created the *Development as Freedom* framework that defines a good life by a person's capabilities and functionings [22]. In this framework, the freedom to pursue the life an individual values is both the means and end of intellectual and moral development so the goal of education is to enhance an individual's capacity for freedom. Such capacity would include the individual's relationship with technology. To make the framework actionable freedom is defined by two characteristics: capabilities and functionings. An individual's freedom to act will not let them lead a life they value unless they possess the capability to dynamically change their situation for the better. Relevant knowledge and skills, economic resources, political freedoms, etc. that enable an individual to choose a life they value are their capabilities. Under Sen's framework a goal of education is to provide students capabilities they do not currently possess. As discussed above an education which assumes a common set of capabilities are needed by all students may fail to enhance an individual's capabilities unless the student themselves intrinsically values the capability that is taught. While curriculum design driven by learning outcomes must assume some ends which are of value to the student, discipline, or society, the achievement of the outcomes is determined by individual valuation. Sen's framework also accounts for what a person values being or doing. These valuations are described by the person's set of functionings. Each individual has a unique "functionings vector" based on what they personally value. In a broad sense the degree of alignment of an individual's functioning vector with the vector determined by the set of institutional outcomes will impact motivation and thus learning. In terms of education, capabilities then are the functionings that are currently achievable to a student based on their education and life experiences to date. The fact an individual has developed a capacity to accomplish something they do not value is not considered a capability.

For a student developing technological literacy there are two important outcomes of education. The first is to build capabilities to achieve existing functionings, basically enabling them to better realize things they value in their current life. However education also has a role in opening up new possibilities for students, helping them find new things they value thus adding to their functionings vector. As Jerome Bruner said, "*Education must, be not only a transmission of culture but also a provider of alternative views of the world and a strengthener of the will to explore them*" [23]. Thus beyond developing capabilities, education should open up students to identify and develop new functionings.

In terms of the broader goals of technological literacy, Sen's *Development as Freedom* framework fundamentally shifts goals of education from utilitarian concerns—i.e. economic utility or workforce preparation—towards supporting a student's future freedom by increasing their capabilities (what they can do) in a way that is both aligned with, and substantially expands, their own functionings vector (the things they value, or want to do). While a critique is that such a shift could have significant negative consequences for society, Sen has shown that individual freedom serves as a necessary means to a wide range of societal ends [22].

The second challenge for driving technological literacy through outcomes is that the dynamic nature of technology means it often changes faster than education can keep up. While one solution is to improve educational technologies, this likely only shifts the burden of change to different individuals and groups, and may exacerbate the challenges technological literacy is supposed to address. Perhaps a better solution is to reconsider how learning outcomes are defined. Currently outcomes and standards are relatively static given the effort required to convene experts and negotiate a mutually acceptable set of outcomes. Part of the challenge may be definitional, in that outcomes are seen to define end goals of education while pedagogy broadly speaking is the method through which those goals are achieved. As the previous discussion on models of education showed, how we think about the process of education is closely related to the goals we can envision for that education. Thus there is the potential by adopting new models to develop outcomes that are better aligned to an individual managing technology in a way they can better thrive.

One way this might occur is by shifting away from expert-defined outcomes to co-identifying outcomes with students. Such outcomes need not be solely content or skills, but integrate more closely with pedagogy, or the way content or skills are developed. In fact education which helps students develop and reflect upon their own processes for learning would seem important if a goal of technological literacy is transfer of what is learned into later stages of students' lives. This too need not undermine the utility of engineering education. To share a personal anecdote, several years ago the author attended a workshop and one evening ended up in a dive bar with a vice president of human resources from Microsoft. They articulated that in some areas in software development the half life of useful knowledge was measured in months rather than years, and software companies faced a real challenge in hiring students who could continue to learn since most metrics they had access to related to what students had learned, not their potential to learn.

The third challenge is that of the relationship between environment or context and knowledge and skills transfer. Any models of learning which give rise to outcomes ideally should address the effect of context in terms of how belief systems affect experience (intersubjective reality) as well as the physical environments and affordances available to students (interobjective reality). Technology is key to the relationship between environment and learning since it has greatly increased connectivity, enabling new forms of extended range networks to form. In this space many current models of learning which presuppose students in isolation (often based on Descartes' view of an isolated, rational mind [24]) cannot well inform educational goals or processes. Put more simply, the models assume learning is separate from living when in fact the two are highly interconnected.

The importance of the environment is well captured by a philosophy known as enactivism [25] which arose from work in complexity science and developmental biology showing that not all behaviors are intrinsic to an individual organism, but also can emerge from collective interactions between individuals. Biologists such as Maturana [26] frame cognition not as originating in an isolated rational mind but as the internal and external processes by which an organism adapts to the environment. Enactivism [27] asserts that our behaviors, language, and thoughts are mediated by strong coupling to the physical and social worlds. From the enactivist perspective we ourselves are simultaneously both an individual and a set of relationships to others and our environment. Education thus exists within a complex and highly coupled system to develop a form of distributed cognition that couples thought, affect, relationships, and our environment. Given that complex systems are distributed and have the characteristic of autopoiesis, the moral and ethical dimensions of enactivism [28], [29] include the relationship between autonomy and socially distributed responsibility. Although arising from biology and complexity, personalist philosophers such as John Macmurray have captured elements of enactivism in developing philosophies designed to explain how an individual's actions and relationships are central to their development as a person.

Expanding the Models

To briefly recap, technological literacy makes an interesting foil for questions about engineering education more generally since it seeks to connect technology (the product of engineering) with individuals' lives. To create a technologically literate society we must hold some model—whether intrinsic or extrinsic—of how people become technologically literate, i.e. how they learn. There are many such models from the simple *tabula rasa* to more complicated models of cognitive to socio-constructivist development. Such models inform not just how one teaches (pedagogy) but also what one can teach, and thus what educational outcomes can be. It is in connecting what students *should* learn to *how* they learn it that such models have value. Learning outcomes, and the models they are derived from, are useful in education but are not a panacea if one's goal is to connect learning about technology to thriving in life. Put simply the challenges with outcomes are that: 1) because they must be both defined and finite they can't fully capture the richness and diversity of students' lives; 2) technology always outpaces education; and 3) using the outcomes in one's life relies on transfer which is highly context dependent.

The challenge then is to develop new models or frameworks that address these challenges and which can also inform outcome development. Here we start from the perspective that in terms of learning individuals are not isolated minds, but rather strongly coupled to their environment (enactivism), and that environment necessarily includes other people. Additionally interactions with others and the environment are absolutely necessary to an individual's development in order for the individual and others in their community to live a life with substantial freedom (personalism).

In terms of learning, strong coupling to the environment and other persons serves to provide continual feedback to individuals on the effects and effectiveness of their actions. Unlike the models of learning shown earlier which assume effort converges to knowledge, the environment and other persons act together as divergent forces on an individual's actions. Shifting from an internally focused model to one in which the student is coupled to outside influences perturbs learning, potentially allowing a broader range of results or outcomes. At first glance allowing external perturbations to well-defined and carefully articulated outcomes seems counter-intuitive. Isn't learning improved by managing and controlling the process so that each person has the opportunity to learn the content without distractions? This is true when learning is focused on what students should know and under the condition that learning outcomes should be as uniform as possible across a group of different individuals. Uniformity, however, is certainly not the case in practice where different disciplines learn very different things; even within a degree program students customize their learning based on their interests. As far as management and control of the learning process, if the goal of technological literacy is to help students live a more fulfilling life then knowledge is only part of the issue; capability for action matters as well.

As Varela summarizes in a treatise on enactivism, a person who is broadly educated is "*one who knows what is good and spontaneously does it*" [25]. This is of course very similar to the Wiradjuri phrase mentioned earlier. The shift from acquiring knowledge to developing a capability for spontaneous right action means that the models for learning presented earlier need to be reconsidered in several ways. First, knowing and acting are strongly coupled. We must learn what appropriate actions are, but such learning matters only if it enables an individual to take action at need. Second, acting always occurs in some context and cannot be separated from it. What may be a correct action is some context often turns out to be incorrect in a different one. This is the basis of much comedy. Third, the results of our actions always affect others and our environment. Even though the impact may seem small, coupling between the actor and others and the environment cannot be ignored since we are unable to comprehend all the results our actions cause. Fourth, spontaneity in action is important. If you have to carefully and laboriously think through the consequences of an action before you take it you have likely missed the opportunity to act. Fifth, the methods used to perform an action and the results of that action are interdependent. While this statement seems obvious, put into educational terms it means that pedagogy and learning outcomes are tightly coupled.

Beyond these factors any model that makes a claim to be "better" about informing improvement of learning should further suggest to educators specific actions they may take to support student development. For example, a model with a cyclical path informs actions an instructor could take to support an individual's development over time. Furthermore models of learning should support development of both of schema and heuristics, or valid mental models and suggestions for action. This applies both to students and to faculty if the model is to suggest changes to how they teach. Given the strong coupling to the larger environment the model needs to explicitly account for environment and suggest ways teachers can configure environments for better learning. Finally, the model should account for how students develop both new capabilities and new functionings since education fails unless it provides new perspectives on what should be valued in life.

Figure 4 presents one such model adapted from the authors' previous work examining the intersection between the philosophy of John Macmurray and engineering education [30]. In brief, the model shows an individual learner in blue going through a cycle of learning that involves both action and reflection. The learner on the left side of the figure interacts through their actions with the larger environment, including others, which is represented on the right side of the figure. In the upper action part of the cycle the learner initiates an action with the intent to achieve some goal. The goal may be self-defined or suggested by the instructor, represented in orange. When the student acts the environment reacts, generating a result which the student observes based on their capability for attention. The act itself and the environment's response takes the student to the lower reflection part of the cycle where they gain knowledge that informs their future actions. This cycle of acting then reflecting to develop knowledge takes place continuously and sequentially in time. In other words the cycle does not describe just a learning outcome intended by the instructor, although it could, rather it more generally describes a continuous series of actions and reflection through which individuals learn in their day-to-day lives.

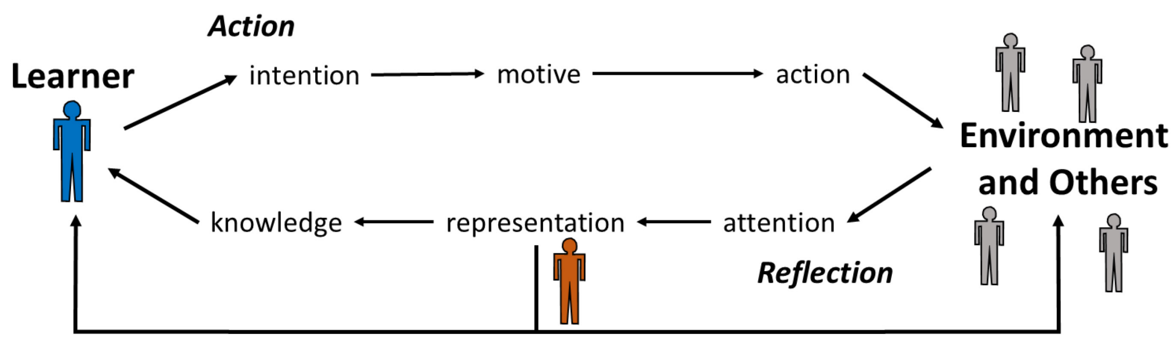

Figure 4: The action-reflection cycle described by the philosopher John Macmurray which describes how human personal development occurs [31], [32].

Each part of the action-reflection cycle of Figure 4 is explained more fully below:

Intention: Action begins when the student has an intention to act achieve some desired outcome for themselves or perhaps one set by the teacher. The student's intention is to change some aspect of the environment, and thus the future, in a desirable way even if it is just to earn a good grade. The student is conscious of their intention based on their knowledge of the larger environment. Intention is causal, that is it is forward looking into the future, and the action the student plans to take is intended to cause a change in the future state, modifying their context. Intention serves as more than simply intent and fundamentally affects the way we perceive the world [33].

Motive: The student's intention is affected by what they anticipate the results of their action will be. While the student may wish for a particular outcome, the result depends to some degree on the effectiveness of the student's action. Anticipation necessarily involves emotion, so the student's intention is modified by their motive which describes the underlying emotions that affect the intended action. Motive acts as an (usually) unconscious emotional filter to conscious intention. Because the student focuses their attention outwardly on the goal rather than inwardly on their emotions they are typically unaware of motive. Furthermore, others help to determine our emotional state so motive is affected by environment. If a student has performed an action many times, habit can also serve as a mostly unconscious motive.

Action: The student then chooses a course of action to change their environment. What choice the student makes depends intention, motive, the anticipated outcomes, and what knowledge they have of ways to act. While there is a choice of possible actions, the student must commit to one and then actually act. Acting inevitably affects their environment and other people.

Following the moment of action the student begins the next part of the cycle, withdrawing into the self and starting the reflective phase of the cycle. It is on the reflective phase where the teacher's role becomes most important.

> Attention: The intent of the student and what outcome they anticipate determines how the student pays attention to the effects of their action. The student must choose what to pay attention to since human beings are not omniscient. Furthermore the student's actions will have effects that are effectively invisible to them because that is not where their attention was focused. If student acted a second time with different intention or based on different knowledge their attention might be focused in another direction and they would view the results of our action in a different light. The student's focus of attention at the moment following action thus serves as a pivot point in the turn from action to reflection. One role of a teacher is to serve as a second or third set of eyes, letting students know results of their actions they might themselves not be aware of.

> Representation: By focusing attention on some results of the action the student constructs a mental representation—i.e. schema [34] or mental model—of the relation between the intention and results of the action. The process of constructing a representation or reflecting on the act is what enables the student to translate the results of experience to knowledge. The instructor again has an important role here in helping to guide the student to construct representations that will suggest more effective, caring, ethical, or nurturing actions. The representations developed need to inform both future actions but also how the student affects their immediate environment. It is through constructing representations of actions that the student slowly and painstakingly develops expertise and values and changes their mindset.

> Knowledge: Regardless of the approach used, the student's creation or refinement of a representation leads to knowledge. Knowledge modifies the student's understanding of themselves and their environment and enables them to conceive of new courses of action or modify their intention. Once further knowledge is gained the student shifts back to the action part of the cycle.

Unlike the Cartesian view of an isolated, rational mind the cycle of action and reflection in Figure 4 encompasses both thinking and feeling. Both the start and end of an action are defined through the student's feelings since action is initiated by a feeling of dissatisfaction and the anticipation that their situation improves. For humans, however, anticipation is selective so the choice to act eliminates, at least at a given time, other avenues of action. Emotion also affects the end of the action since the student will feel some level of satisfaction or dissatisfaction depending on the degree to which their action accomplished the anticipated outcomes. How the agent acts upon their feeling determines the form of the mode of reflection which is why the presence of a teacher in the stages of reflection can play a large role.

Does the model shown in Figure 4 satisfy the general requirements posed earlier that were hypothesized to inform the true challenge of technological literacy which is how to live with change? Overall the various criteria seem to be met to some degree:

- knowing and acting are coupled,
- acting occurs inseparably from context,
- the results of action affects others and the environment thus affecting future action,
- spontaneity is supported through the explicit role of emotion and habituation, and
- methods and results are coupled through experience.

Furthermore the model meets the criteria that is can guide practice in education:

- The model suggest faculty can have the largest influence by focusing on student attention following action and guiding representation (reflection).
- The model like many other portrays learning as cyclical development over time, but such development is dependent on the degree to which students are provided opportunities for both action and reflection [35].
- By focusing on development of representations and tying such development to the results of actions, it encompasses both schema and heuristics.
- The model explicitly accounts for environment and suggests that faculty emphasize ways to 1) steer students' attention in the moment and 2) create spaces in which reflection leads to representation.
- In terms of developing capabilities and functionings, the action part of the cycle develops capabilities as students apply knowledge in context while guided reflection supported by the instructor allows for new functionings.

Brief Conclusion

In this paper the authors used technological literacy—defined as living well in a world that technology is rapidly changing—as a foil to look at larger issues in education, particularly the current focus on learning outcomes. Through some common models it was seen that methods (pedagogy) and outcomes are strongly coupled. Focusing too much on outcomes, however, can leave education programs either locked into the past or focusing on the mechanistic or trivial. This is not to say that outcomes are bad, per se, but rather demands recognition that outcomes do have limitations. It was hypothesized that perhaps outcomes-based education is not in itself the challenge, but rather the fact that while outcomes-based education implicitly relies on models of learning it rarely explicitly accounts for limitations of the learning models the outcomes are based on. The paper then explored an alternative model based on the expansive philosophical system of John Macmurray, a personalist philosopher. This model, drawing on enactivist frameworks, met various criteria for better informing how to make members of society more technologically literate.

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Citations

[1] R. A. Cheville and J. Heywood, “The Philosophical Foundations of Technological and Engineering Literacy,” in *American Society for Engineering Education*, 2017, p. 19530.
[2] “Charles Sturt University - Our Ethos.” [Online]. Available: Our ethos.
[3] J. H. Newman, *The Idea of a University Defined and Illustrated: In Nine Discourses Delivered to the Catholics of Dublin*. Project Gutenberg, 1852.
[4] P. Dias, “The Engineer’s Identity Crisis: Homo Faber or Homo Sapiens?,” in *Philosophy and Engineering: Re ections on Practice, Principles and Process*, D. P. Michelfelder, N. McCarthy, and D. E. Goldberg, Eds. Dordrecht: Springer, 2013.
[5] N. R. Council, *How People Learn: Brain, Mind, Experience, and School*. Washginton, DC: National Academy Press, 2000.
[6] S. A. Ambrose, M. W. Bridges, M. DiPietro, and M. C. Lovett, *How Learning Works: Seven Research-Based Principles for Smart Teaching*. San Francisco: Jossey-Bass, 2010.
[7] D. L. Schwartz, J. M. Tsang, and K. P. Blair, *The ABC’s of How we Learn*. New York: W. W. Norton & Co., 2016.
[8] M. S. Schiro, *Curriculum Theory: Conflicting Visions and Enduring Concerns*. Thousand Oaks, CA: Sage, 2012.
[9] B. Davis, *Inventions of Teaching: A Genealogy*. New York: Routledge, 2009.
[10] D. W. Johnson, R. T. Johnson, and K. Smith, *Active Learning: Cooperation in the College Classroom*. Edina, MN: Interaction Book Co., 1991.
[11] D. A. Kolb, *Experiential Learning: Experience as The Source of Learning and Development*. Upper Saddle River, New Jersey: FT Press, 1984.
[12] R. Harre, *Personal Being*. Cambridge, MA: Harvard University Press, 1984.
[13] J. G. Greeno, D. R. Smith, and J. L. Moore, “Transfer of situated learning.,” in *Transfer on trial: intelligence, cognition, and instruction*, D. K. Detterman and R. J. Sternberg, Eds. Norwood , N.J.: Ablex Publishing, 1993.
[14] E. Thorndike and R. Woodworth, “The influence of improvement in one mental function upon the efficiency of other functions (I),” *Psychol. Rev.*, vol. 8, pp. 247–261, 1901.
[15] G. Sala and F. Gobet, “Does Far Transfer Exist? Negative Evidence From Chess, Music, and Working Memory Training,” *Curr. Dir. Psychol. Sci.*, vol. 26, no. 6, p. 515, Dec. 2017.
[16] J. Lave and E. Wenger, *Situated learning: Legitimate peripheral participation*. Cambridge University Press, 1991.
[17] J. P. Gee, *Situated Language and Learning*. New York: Routledge, 2004.
[18] J. Bransford *et al.*, “Learning Theories and Education: Towards a Decade of Synergy,” in *Handbook of Educational Psychology*, 2nd ed., P. A. Alexander and P. H. Winne, Eds. Mahwah, NL: Lawrence Erlbaum, 2006, pp. 209–244.
[19] J. F. Volkwein, L. R. Lattuca, P. T. Terenzini, L. C. Strauss, and J. Sukhbaatar, “Engineering Change: A Study of the Impact of EC2000,” *Int. J. Eng. Educ.*, vol. 20, no. 3, pp. 318–328, 2004.

[20] International Technology Education Association, “Standards for Technological Literacy,” Reston, VA, 2007.
[21] D. F. Chambliss and C. G. Takacs, *How College Works*. Cambridge, MA: Harvard University Press, 2014.
[22] A. Sen, *Development as Freedom*. New York: First Anchor, 1999.
[23] J. Bruner, *Actual Minds, Possible Worlds*. Cambridge, MA: Harvard University Press, 1987.
[24] R. Descartes, *A Discourse On The Method*. Oxford: Oxford University Press, 2006.
[25] F. J. Varela, *Ethical know-how: action, wisdom, and cognition*. Stanford, CA: Stanford University Press, 1999.
[26] H. R. Maturana, “Biology of Cognition,” in *Autopoiesis and Cognition: The Realization of the Living*, Dordrecht: D. Reidel Publishing Company, 1980.
[27] F. J. Varela, E. Thompson, and E. Rosch, *The Embodied Mind: Cognitive Science and Human Experience*. Cambridge, MA: MIT Press, 2016.
[28] T. Heijmeskamp, “Ethical Know-How and the Ethical World: Towards an embodied, situated account of ethical agency,” Erasmus University Rotterdam, 2017.
[29] G. Colombetti and S. Torrance, “Emotion and ethics: An inter-(en)active approach,” *Phenomenol. Cogn. Sci.*, vol. 8, pp. 505–526, 2009.
[30] R. A. Cheville, *Becoming a Human Engineer: A Philosophical Inquiry into Engineering Education as Means or Ends?* Cambridge UK: Ethics Press Internationaal, 2022.
[31] J. MacMurray, *The Self as Agent*. London: Faber & Faber, 1957.
[32] J. MacMurray, *Persons in Relation*. London: Faber & Faber, 1961.
[33] J. Doty, *Into the Magic Shop: A Neurosurgeon’s Quest to Discover the Mysteries of the Brain and Secrets of the Heart*. New York: Avery, 2017.
[34] M. B. McVee, K. Dunsmore, and J. R. Gavelek, “Schema Theory Revisited,” *Rev. Ed. Res.*, vol. 75, no. 4, pp. 531–566, 2005.
[35] J. Cowan, *On Becoming an Innovative University Teacher. Reflection in Action*, 2nd ed. Maidenhead, UK: Open University Press, 2006.