On Intelligence in Technology Education: Towards Redefining Technological Capability

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The Technology subject in general post-primary education is unique based on its conception and treatment of knowledge. The task specific utility of knowledge is emphasised and at the same time, in reflection of the breadth of technology in society, the variance in the context of learning tasks can be quite large. The subject is considered to have a fluid epistemology which directly affects how capability is contextually defined. The concept of technological capability has been ascribed multiple definitions however the more commonly aligned with model suggests it refers to a synthesis of knowledge, skills, values and problem solving in a technological context. However the combination of knowledge, skills, values and problem solving neglects to acknowledge intelligence in the form of domain general abilities which have been observed to have a significant effect on student performance. Therefore this paper argues for the integration of contextually relevant domain general abilities with current conceptions of technological capability.

Key Words: Learning, Knowledge, Intelligence, Capability.

1. INTRODUCTION

A laudable goal of technology education is its aspiration to develop technological capability in students (Davies & Rogers, 2000; Kimbell, 1994; Liou, 2015; Norman, 1998; Rauscher, 2011; Shaw, 2002; Tairab, 2001). However, there is an inherent difficulty in achieving this aim due to the ambiguity in what it means to be technologically capable (Black & Harrison, 1985; Gagel, 2004; Gibson, 2008). This is clearly evidenced through work examining constructs and qualities of capability in technology education (Canty, Seery, & Phelan, 2012; Kimbell, 2009; Kimbell, Stables, Wheeler, Wosniak, & Kelly, 1991). This is not to say that the subject does not make a unique and meaningful contribution to general education, but it does create the potential for a lack of consistency in the provision of the subject (Atkinson, 2017). The often subscribed to model of technological capability offered by Gibson (2008) suggests that it refers to a synthesis of knowledge, skills, values and problem solving in a technological context. But there is a lack of utility in this model as it does not qualify an explicit epistemological boundary for the included components. However, such specificity may not be appropriate as will be discussed later. The inevitable result of the agenda to espouse technological capability is a relatively large degree of variance in the provision of the Technology subject (Atkinson, 2017). This variance results in uncertainty concerning practice. This is not necessarily negative as, for example, it arguably elevates Technology teachers' professional status by providing them with the autonomy to make decisions about the usefulness of knowledge for their students. However, this uncertainty does create a scenario whereby students may receive varying standards of technology education. Furthermore, qualifying the effect that engaging with technology education has on students generally is impossible, as even if it the effect is determined for one cohort, another is not guaranteed to be guided under the same interpretation of a

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technologically capable person. This paper argues that what is described as technological capability in existing models offers a definition which is too narrow. In accordance with this, it is argued that the construct of human intelligence should be integrated with existing definitions of technological capability to provide a more comprehensive description of capability which, despite its increased scope, offers more precision and hence, utility.

2. SITUATING THE ARGUMENT

The concepts of learning, knowledge, intelligence and capability are central to this paper. They are all distinct but interconnected. However, they can be interpreted in several ways and explored through the lens of multiple paradigms. Therefore, before proceeding to contextualise each concept within technology education, the position taken regarding each of these needs qualification.

Becoming more capable in any context requires learning. Learning cannot be explained independent of memory systems and there are two core components in the human memory system; the working memory and the long-term memory. The working memory is associated with actively maintaining attention on information (Engle, 2018), or in other words, consciously thinking about something(s). The long-term memory describes stores of accumulated knowledge (Kirschner, Sweller, Kirschner, & Zambrano R., 2018) which can be recalled. Learning is defined as "a change in long-term memory" (Kirschner, Sweller, & Clark, 2006, p.75). As the long-term memory describes stores of knowledge, learning therefore "involves the acquisition of knowledge" (Mayer, 2002, p.226).

Since learning is associated with acquiring knowledge, what is meant by knowledge needs further clarification. Many taxonomies describing the nature of knowledge types exist (Alavi & Leidner, 2001; de Jong & Ferguson-Hessler, 1996; Huang & Yang, 2009). Gorman (2002) provides a taxonomy of four knowledge types which reflect those commonly found in other taxonomies. It is particularly useful for technology education as the knowledge types are associated with technology transfer. These knowledge types include declarative knowledge (knowing what), procedural knowledge (knowing how), judgment (knowing when), and wisdom (knowing why). Furthermore, there is a division between explicit knowledge and tacit knowledge (Collins, 2010; Polanyi, 1969) which is overarching and applies to each of Gorman's (2002) types of knowledge. Tacit knowledge describes that which cannot be explicated and explicit knowledge refers to that which can. This distinction reflects the nature of a piece of knowledge itself rather than the communication capacity of a person to explicate the knowledge. Therefore, the term knowledge is considered holistically to describe the multiple types of knowledge inclusive of both their explicit and tacit elements.

Like knowledge, the concept of intelligence can be defined in many ways and consists of multiple elements. One definition of intelligence relates to accumulated knowledge whereby a person's level of intelligence is considered as a product of what they know (Ackerman, 1996). However intelligence as a concept is much broader. The most comprehensive framework of intelligence, the Cattell-Horn-Carroll (CHC) theory (Schneider & McGrew, 2012), describes intelligence as consisting of a number of cognitive factors, arranged hierarchically into three strata. The first layer contains narrow or specific first-order factors. The second layer contains broad second-order factors whereby each second-order factor describes a group of related first-order factors. Finally, the third layer contains one third-order factor, general cognitive ability or general intelligence, which describes the commonality or positive manifold which emerges from the combination of second-order factors. The CHC theory does include factors associated with acquired knowledge, but it also includes sensory abilities, motor abilities, and domain general abilities associated with reasoning, speed and memory. The most important characteristic of CHC theory for this argument is this separation between acquired knowledge and domain general abilities.

3. CAPABILITY AS THE INTERACTION BETWEEN INTELLIGENCE AND KNOWLEDGE

To define technological capability, it is first necessary to clearly establish what it means to be capable and as such, how to see evidence of capability. In any context, capability is observable through action. In the context of technology education this action refers to performance, both in terms of the process and product, in a task or problem. Hambrick et al. (2012) conducted a study examining performance in a geological bedrock mapping task examining performance relative to between visuospatial ability, a domain general ability, and pertinent knowledge. They found that both visuospatial ability and knowledge could predict performance, but an interaction between visuospatial ability and knowledge predicted performance above and beyond the effects of the two variables individually. This suggests that capability can be described as the relationship between domain general abilities and knowledge. This result is supported by similar findings in Chemistry (Stieff, 2007) and in Physics (Kozhevnikov & Thornton, 2006). Based on this, capability in a given context can be described as the relationship between contextually relevant domain general abilities and contextually relevant knowledge. For technological capability, current definitions (Black & Harrison, 1985; Gibson, 2008) do not take contextually relevant domain general abilities into account.

4. TECHNOLOGICAL CAPABILITY CURRENTLY DESCRIBES KNOWLEDGE

Before discussing the introduction of domain general abilities into a definition of technological capability, the current conception needs to be examined to identify how they should be positioned. Gibson's (2008) model, as the most widely adopted model (e.g. Gibson, 2013; Sahin & Ekli, 2013; Seery, Canty, & Phelan, 2012), serves as an example in this case. Gibson's (2008) model is widely acknowledged to describe technological knowledge (Pool, Reitsma, & Mentz, 2013; Rauscher, 2011; Underwood & Stiller, 2014). Buckley, Seery, Power, & Phelan (2018) note why the components of Gibson's (2008) model describe knowledge by aligning them with the types of knowledge put forward by Gorman (2002). They argue that what Gibson (2008) describes as knowledge is synonymous with declarative or conceptual knowledge and that skills correspond with procedural knowledge. Buckley et al. (2018) note how Gibson (2008) conflates values with ethics, further arguing that being ethical aligns with capability while holding values does not, and that ethics has similarities with wisdom as both involve knowledge of why something should or should not be done. Finally, Buckley et al. (2018) argue that problem solving describes an action making it categorically different to knowledge, skills and values, as these are constructs which a person can have. Due to the temporal dimension of problem solving, it is similar to judgment, or knowing when to do something. However, if problem solving is considered as meaning the ability to solve problems, this is either disciplinary in which case requires wisdom, declarative and procedural knowledge to denote capability, or is domain general, in which case it is better considered as biologically primary knowledge (Geary, 2007, 2008) and not as being associated with capability.

If the current depiction of technological capability describes knowledge, or more accurately technological knowledge, the remit of this must be established. De Vries (2016) suggests that technological knowledge can be considered as being similar to applied scientific knowledge. He also characterises technological knowledge relative to its normativity, collective acceptance, non-propositionality and context-specificity. These defining characteristics make it impossible to explicate a strict epistemological boundary for technological knowledge. Furthermore, McCormick (1997) suggests that explicit technological knowledge will be relative to specific tasks and circumstances and Kimbell (2011) argues that technological knowledge is inherently different to scientific knowledge whereby scientific knowledge is concerned with literal truths and technological knowledge is more aptly associated with usefulness. Kimbell (2011) advocates for knowledge to be viewed as provisional in technology education, noting that learners reside in an “indeterminate zone of activity where hunch, half-knowledge and intuition are essential ingredients” (p.7). Finally, Williams (2009, pp. 248-249) argues that “the domain of knowledge as a separate entity is irrelevant; the relevance of knowledge is determined by its application to the technological issue at hand. So the skill does not lie in the recall and application of knowledge, but in the decisions about, and sourcing of, what knowledge is relevant”.

5. INTELLIGENCE RESEARCH IN TECHNOLOGY EDUCATION

Considering capability as the interaction between domain general intellectual abilities and knowledge, it is clear that the concept of technological capability as it currently stands is missing an intelligence related dimension. The inclusion of domain general abilities, or general intelligence, is important as it is positively associated with a number of different constructs such as creativity, leadership, conscientiousness, happiness, mental health and longevity (Ritchie, 2015). From an educational perspective, it is positively associated with educational outcomes (O’Connell, 2018; Smith-woolley et al., 2018) with 50 years of research illustrating that it accounts for approximately 80% of the variance in student performance (Detterman, 2016; Wiliam, 2010). The concept of intelligence is especially important for technology education when considering the nature of learning with respect to technological knowledge. Based on how technological knowledge is described (de Vries, 2016; Kimbell, 2011; McCormick, 1997; Williams, 2009), the transferability of knowledge between tasks is likely to be less than in other subjects. For example, in one problem students may be designing a form of technology for a specific person, such as a prosthetic limb for an adult, and in the next they may be designing for general use such as a toy for children. This means that the accumulation of knowledge in technology education that is pertinent and transferable between tasks can be relatively uncertain. Another finding from Hambrick et al.'s (2012) study was that the importance of domain general abilities in predicting performance was higher when pertinent knowledge was lower. Due to the varying contexts of problems in technology, there is less likelihood of students having high levels of associated knowledge when posed with a learning activity relative to other subjects. As such, general intelligence or domain general abilities are likely to have significant effects on performance in technology education, meaning the magnitude of influence these abilities have on capability in the subject is likely to be high and they should therefore be considered in models of technological capability.

6. TOWARDS A NEW DEFINITION OF TECHNOLOGICAL CAPABILITY

The concept of intelligence is broad. The CHC theory (Schneider & McGrew, 2012) describes 84 specific first-order factors and the integration of all of these factors would likely hinder the development of technological capability more than assist it. However, as discussed the theory contains factors associated with acquired knowledge, sensory abilities, motor abilities and domain general abilities. Currently, technological capability describes knowledge, and sensory and motor abilities are important in technology education but only to the extent of enabling students to engage in the cognitive activity of modelling or the physical activity of making. Integrating intelligence into the meaning of technological capability essentially means integrating the contextually necessary domain general abilities. Buckley, Seery, Canty, & Gumaelius (2018) hypothesised that one second-order factor of intelligence, fluid intelligence, which describes “the use of deliberate mental operations to solve novel problems” (Primi, Ferrão, & Almeida, 2010, p.446) aligned appropriately with technology education due to the prevailing conceptions of technological knowledge. By examining 16 domain general first-order factors relative to fluid intelligence, they observed that a combination of visualization, inductive reasoning and memory span could statistically account for between 28% and 43% of the variance in technology education students fluid intelligence. They also argue that the importance of these factors is theoretically sound as memory span affords the capacity to retrieve and hold chunks of information in the working memory while engaging with a problem or task, visualization builds on this capacity by allowing for information to be generated, represented and manipulated and inductive reasoning (I) allows for inferences to be made based on the available information. By allowing for information to be retrieved, stored, generated, represented, manipulated and inferred, these factors, both empirically and theoretically, can account for all of the necessary mental operations presented in established problem solving frameworks (M. Carlson & Bloom, 2005; Gigerenzer, 2001; Gigerenzer & Todd, 1999; Novick & Bassok, 2005; Schraw, Dunkle, & Bendixen, 1995; Wang & Chiew, 2010). Therefore, while there are many factors of intelligence, it is argued that integrating fluid intelligence with a focus on visualization, inductive reasoning and memory span, with the conception of technological knowledge would better describe what enables and constitutes as technological capability. Finally it is important to consider how these factors can be integrated in the context of technology education. While this research is still emerging, preliminary results show that visualization does relate to educational performance in technology education but has a complex relationship with external modelling (Buckley, Seery, & Canty, 2018) and importantly that it can be developed through targeted interventions (Sorby, 1999, 2009; Stieff & Uttal, 2015; Uttal et al., 2013). Furthermore, inductive reasoning has also been shown to be malleable and can be developed through interventions (Klauer & Phye, 2008) but it has not been considered relative to technology education. Research concerning memory span indicates that it is fixed (Cowan, 2001; Miller, 1956) and cannot be meaningfully impacted through interventions (Harrison et al., 2013; Redick et al., 2013; Thompson et al., 2013). Similarly research concerning fluid intelligence also suggests that interventions other than engaging with general education do not have a meaningful effect on its development (Au et al., 2015; Ritchie, 2015). However while they may not be able to be developed through interventions, this does not restrict their consideration in terms of practice and pedagogical approaches can be underpinned by cognitive frameworks.

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