Playing Games with Technology: Fictions of Science in the *Civilization* Series

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Introduction

Videogames might be thought to be too recent, and to concerned with entertainment, to reveal appropriately historicised attitudes to technology. However, as this essay will demonstrate, there is value in considering how one type of game, the "4X strategy" game, encodes particular assumptions about technology and its development. Although closely affiliated to the "God game" (a videogame in which the player is given absolute, and often supernatural power over a civilization or tribe's development), "4X strategy" games are defined by the phrase "EXplore, EXpand, EXploit and EXterminate". That is, such games encourage players to "explore" the in-game environment, "expand" their civilizations, "exploit" the resources of their civilization's territory, and "exterminate" rival civilizations. Whilst this phrasing is loaded, it provides a sense of the kind of activities within the game, although it does not foreground the importance of technological research. Using the *Civilization* series of videogames (six games and various "expansions" over the period 1991-2016) as an exemplar, this article asserts that "technology trees", as the underpinning structural element of such many 4X strategy games, reveal not only a specific cultural attitude to technology, but also towards the history of technology. Whilst this essay will describe and examine "technology trees" later, it is important to realise at the outset that these are the ways in which the games structure gameplay: they serve as a timeline of a civilization's development and facilitate effective play.

For those unfamiliar with the games, in the *Civilization* series the player takes control of a civilization and guides its development over a period of time, from its earliest origins (the virtual equivalent of a few tribespeople and huts) in 4000 BCE, through various ages until it achieves dominance over the other civilizations—usually controlled by the game—via victory conditions set in advance, or until the default of about 2000 CE. Players control broad civilizational elements, such as model of government, a civilization's economy, and what buildings are built in its cities, and also guide units around the map to expand a civilization's territory (see Figure 1).

Figure 1. Screenshot from *Civilization IV*, showing cities and units on the game map (Zak 2016)

Depending upon the specific *Civilization* game played and how the player sets up the game, victory conditions vary to include the construction of a spacecraft or military, cultural, or economic dominance. Issues of "winning" *Civilization* aside, the game is, at least in some respects, quite sophisticated in its modelling of cultures—considering factors such as happiness of population, food and resource production, and political structures and policies—but most importantly, the series emphasises the technological development of a society.

A fair amount of research has been published in relation to the *Civilization* games, specifically in relation to its use to the study of history, or its cultural biases.[1] However, no work has hitherto linked such studies with the games' fundamental aspect: a model of the "history of technology" that uses scientific "progress" to define the advancement of a culture. That is, there is a built-in "history of technology" within these games and, more importantly, one cannot have such a game without such a model in place. To that end, this piece offers a speculative interpretation of the *Civilization* games in which that model of

[1] For the use of selected *Civilization* games in history education, see, for example, Ford 2016, Fogu 2009, Wainwright 2014, and Weir and Baranowski 2011. For cultural critiques and ideological analyses of selected *Civilization* games, including the games' attitudes to technology, see, for example, Douglas 2002, Friedman 1999, Kapell 2002, and Poblocki 2002. Carr's work takes issue with such ideological readings, however, and would equally take issue with much herein, as "criticizing a simulation for being reductive is nonsensical" and because merely revealing that "fantasies [of Western chauvinism] are persistent" (2007, 234) is not the same as revealing that players' attitudes are somehow informed by games. However, implicitly reinforcing such fantasies is clearly a problem, especially as using such games for educational purposes means that the *framework* of the games must also be critiqued. That is, if they are to be used to simulate counterfactual histories for educational purposes (as they often are), it is surely as important to query the assumptions behind the simulation itself, else they merely reinforce such assumptions.

"the history of technology" is itself revealed to reflect particular historical biases over the relatively short lifespan of the series.[2] Thus, the purpose of this article is twofold. It examines the intrinsic biases of the *Civilization* series as its relates to the practices and assumptions of the associated histories of science and technology: in effect, using a technological artefact (a computer game), across its various versions, to explore a broader sense of the history of technology. Thus, this article could be said to sit in the tradition of George Basalla's work on *The Evolution of Technology*, were it not for the fact that in that seminal piece he dismissed the "the home computer boom" as a fad, stating that "playing electronic games [on home computers…] was an activity that soon lost its novelty, pleasure and excitement" (1999, 185). A problem of hindsight familiar to anyone trying to be up-to-date when talking about the history of technology, the future caught Basalla out. In contrast, this piece will show that, as a vector of cultural transmission for ideas about history, technology, and the history of technology, games such as *Civilization* have significant influence in determining common perceptions of the relationship between technology and culture. Most importantly, and worryingly for historians, such influence can be seen to reinforce overly simplistic and deterministic models of the history of technology: since its first electronic edition, the *Civilization* series has sold over 33 million copies, 8 million of which were for *Civilization V* alone (Nunneley 2016), which clearly attests to the popularity of the series, and to the numbers of players who will have to a degree internalised the logic of its model of history.

Modelling the History of Technology

Since the first iteration of *Civilization* as a videogame, one of the key elements to a civilization's success has been the "technology tree", a list of skills and knowledges possessed by the civilization that determines what possible governments it can have, what buildings can be constructed, and what kinds of units can be fielded. Indeed, the original board game of *Civilization* (produced in 1980) is often credited as being the first game to incorporate a "technology tree". Technology trees have proved to be influential within the genre of strategy games and computer games more broadly. They facilitate coding by setting parameters on the availability of units, resources, or even character traits based on a programmable hierarchy, and allow coders to balance the game to enable different styles and types of solution to problems; in short, they usefully simplify a larger-scale problem such as "model global technological development" into a discrete set of steps. Thus, the easiest way to conceive of a "technology tree" is to imagine a genealogical tree of technologies, in which earlier experiences provide the basis for a civilization to discover

[2] There are dangers inherent to this latter point, given that this piece approaches a large conceptual field through merely twenty-five years, and which little reference to other cultural touchstones. Yet, as Mahoney notes, much of the emphasis in the history of computing has been hardware: "The emphasis," he writes, "has lain on what the computer could do rather than on how the computer was made to do it" (2008, 12). This article extends this awareness to consider how particular things the computer was made to do (play games) have been constructed in the way that they have been: software encodes the structural and cultural biases of its creators, and the *Civilization* games are no different.

more advanced technologies (for example, to research "Compass" in *Civilization IV*, a civilization must have learned "Sailing" and "Iron Working" first).

In the *Civilization* games, each player assigns a proportion of their civilization's "work" to research, which determines how quickly an "advance" (as research is called in the games) is discovered, and selects a given technology on which to focus. Once that technology is 'discovered', others become available, and players then select another, with some not becoming available until still further prerequisites have been met.[3] Ever since the second *Civilization* game, in 1996, the series has also utilised the notion of Eras, in which particular technologies are mapped into a distinct historical epoch. Only once all the requisite technologies are discovered can a civilization proceed to the next Era (say, from ancient to classical, or industrial to modern). These Eras model something akin to a Kuhnian paradigm shift, where a civilization's view of the world and its ability to interact with it ostensibly changes as the result of a specific discovery, invention, or technology. In this way, technologies within the technology tree are classified by their respective Eras. It is worth noting, however, that this "paradigm shift" is primarily cosmetic, rather than affecting gameplay.

Another important element of the technology tree is the intertwined notions of prerequisites and obsolescence. Each technology after the initial few has a set of prerequisites which determine how and when it might be researched. The notion of a technological prerequisite is not that difficult to fathom; it is difficult to conceive of an automobile without the conception of a wheel, and also the various advances in science and technology that facilitate the construction of a combustion engine. However, as Basalla notes, the gasoline engine versus steam- or electric-engine might be said to the product of specific cultural factors (1999, 197ff), and *Civilization* elides these factors. As a result, the teleological structure of the technology tree means that particular "prerequisites" can seem idiosyncratic, especially as the player "knows" the outcome of the technology before it is researched. In *Civilization V*, for instance, the Refrigeration advance requires a player to have researched Biology and Electricity, and Refrigeration in turn allows players to then research Penicillin, which in turn is required for a player to later research Ecology, which in turn allows Telecommunications. The causal chain—Refrigeration is necessary before a civilization "understands" the potential of Ecology, and in turn Ecology is necessary for Telecommunications—seems unusual, but it is intended to facilitate a clear line of technological advancement that enables players to build units and enhance cities

[3] For an example technology tree, see https://www.civfanatics.com/civ2/downloads/reference/posters/, which provides links to scans of the technology tree from *Civilization II*. Within the field of history, the notion of an implicit technology tree is perhaps most obvious in the work of James Burke, who in *Connections*, based upon the television programme of the same name, and to a lesser extent *The Day The Universe Changed*, demonstrated the inter-dependence and -reliance of technological developments and the ways in which they impact on how a society perceives the world (see Burke 1985, Burke 2007). One might also consider Pitt-Rivers's approach to cultural evolution via technological artefacts being arranged in "order" of complexity as another instance of an historical technology tree, albeit specific to one technology (see Basalla 1999, 17ff).

(technology is instrumental in strategy games, and particularly in the *Civilization* series).[4] Similarly, the use of technological advances to make other advances or units obsolete is intended as a game mechanic to promote gameplay balance (so the effects of certain structures or units are weakened over time, and players can use advances to overcome deficiencies in military power, therefore). However, this in-game mechanic presents a linear model of technological development rather than a more complicated network or repertoire of available technologies and techniques that might function in different ways in different contexts.

The assumptions behind the concept of *Civilization*'s "technology trees" are thus worth noting. Firstly, the game designers have encoded a simplified history of Western civilization, ideological, political, and technological, into a world simulator, along with all the concomitant baggage that that implies.[5] It is, as has been examined, a fundamentally deterministic model of technological development and thereby of civilization. For example, Ghys's work examines the implications of the technological determinism at work in four strategy games, one of which is *Civilization IV* (2012). However, defending the genre's focus on technology, Watrall notes that "Of all the variables wrapped up in the process of culture change, technology is arguably one of the easiest to quantify and track. Technology leaves a lot of stuff behind for archaeologists like myself to find and study" (2000a, 1). Watrall remains unconvinced by technology trees as they are currently conceived, however, and as he later asserts in the article, "designers desperately need to realize that for in-game technological innovation to happen, some of the direct control must be taken out of the hands of players" (2000b, 6); as of 2018, this has yet to really occur, despite the verisimilitude that would promote. Determinism is also evident in the fact that the more technologies a civilization possesses, the more "advanced" it is, thereby positing a technocentric view of "civilization" that is measured in progress along a predefined tree. (As *Civilization*'s creator Sid Meier stated, "The tech tree represents a certain kind of optimism, the idea that we are constantly progressing […] It's true, we don't represent the Dark Ages in the game. It's an optimist, progress-based view" (quoted in Tharoor 2016); *Civilization* is very much rooted in a "progressive" model of the history of technology.) A civilization that does not develop certain technologies therefore would find it almost impossible to "win" the game, as they would not survive their neighbour's advantages, however "advanced"

[4] Ghys notes that, in relation to *Civilization IV*, it is impossible for a player to research Robotics without having researched Mysticism first (2012, "Three sides of technological determinism exposed"), and it is possible to find similar examples in other *Civilization* games.

[5] The games become more culturally-aware over the series, in many respects, in terms of bringing in less Western-centred perspectives on world history, such as through the inclusion of non-Classical Wonders from non-Western cultures. Responding to the criticism that the more technologically-advanced a civilization is, the more it begins to "resemble contemporary America", Sid Meier (the lead designer on many of the *Civilization* games) responded that "I can also blame the internet now. The world has become flat, we are more aware and sensitive to the globalness of the world. The early 1990s world was reflective of our thinking. China was still this mysterious hidden kingdom, Russia was the evil empire" (quoted in Tharoor 2016).

they might be in other ways, such as in agriculture.[6] Moreover, the technologies that can be researched are, to all extents and purposes, assumed to be "researchable"; in the case of something like Rocketry and Computers, both technologies that have existed since the first iteration of the game, this is eminently justifiable even if the extent to which they are technologies *per se* is debatable. However, in the cases of Mass Production, Communism, Philosophy, or Religion, it is debatable as to whether these are "discoverable", let alone technologies, and are done so only to simplify the act of modelling. Ghys observes that, in technology trees, "We find machines (steam engine), techniques (sailing), sciences and bodies of knowledge (physics), abstract and religious ideas and rituals (polytheism, philosophy) and forms of social organisation (guilds, feudalism). The latter examples can be called 'social technologies' (no relation with recent network technology)" (2012, "The functioning of technology trees"). This corresponds to Arthur's view, whereby perceiving technology as any "purposed system" means that "musical structures, money, legal codes, institutions, and organizations" (2009, 56) can all be viewed as technologies.

The technology trees of the *Civilization* games are thus constructed from a series of fundamental axioms. Some of these are obviously real-world knowledge constraints (the games cannot include "unknown" technologies) whereas others are due to coding constraints (the need to streamline the history of technology to a simplified model). Some, however, are also implicitly based upon a particular set of assumptions about the history of technology:

1. All possible fundamental technologies (such as using fire) have been discovered already. All fundamental technologies are known to any sufficiently advanced civilization.
2. A civilization is conceived as one homogenous society working towards one goal. (A civilization can only research one advance at a time; they research a specific advance, such as Electronics, rather than an advance within a broad area, such as agriculture or the military. The player controls the outcome of the research in advance.)
3. The path through the technology tree is unidirectional, and applies to the whole civilization. (Once a technology has been discovered a civilization cannot forget it, even if that civilization is reduced to a small population in one city, and inequalities in technological distribution do not appear within the games, unless one counts which buildings exist in which cities.)
4. Technologies have applications, whether militaristic or civil, and contribute to the civilization in some manner, even if that is just to open more options on the technology tree. (There is no sense of discovery "for its own sake" or that might be a

[6] As Douglas summarises, "A civilization further up what is termed in the strategy game genre the 'technology tree' has a competitive edge—economic, social, military—over its rivals" (2002, para 12). Douglas' phrasings of "further up" and "competitive edge" also reveal the extent to which technologies facilitate one civilization being "better" than another.

dead end, and there is no associated "risk" with a programme of research (see Watrell 2000a, 3).)

5. There is no possible technology outside of the technology tree, and its associated applications. (A player cannot use the Computers advance to create Artificial Intelligence or Genetics to create transspecies hybrids. In general, all non-fundamental technologies have specific prerequisites and do not merely "appear" in a particular age (see note 9, below.)
6. The technology tree might appear "evolutionary", as technologies are discovered based upon prerequisites, but the tree itself is static, as are the technologies themselves. (The tree can only be "modded" from outside of the game, and the technologies do not fundamentally change the game environment, or within the game, even if understandings of "chemistry" or "physics" can change in the real world.)[7]

As a result of such axioms, whilst it is of interest to consider what is called a technology and what is not (that is, what appears in the game as a technology), it is more important to observe that all social "advances" or "technologies", through the act of naming them as such, reconfigure society as a system in the process of ongoing refinement. That is, the *Civilization* series, through its very encoding of a technologically-determined society through a (technological) algorithm, posits that human societies are in some ways "codable" or "systemic" in nature. To reframe the postcolonial critique that has often been levelled at the series—that it reveals a fundamentally Western, often US-centric view of civilization at the expense of other cultural values and norms—this implies that the technological discourse that surrounds computer games and the act of recreating technological innovation as a "tree" has itself colonised the view of civilization that the series uses.

What Do You Need to Make Computers? "Comparative Science" & *Civilization*

Given this backdrop of a "technology tree", various changes have taken place that refine or amend the ideas behind what constitutes a technology across the technology trees of the *Civilization* games. *Civilization IV*, for example, allowed players to research technologies which enabled them to enact civics, or rules that govern their civilizations, rather than suggest a direct corollary between researching "Democracy" and then enacting it as a government (which occurred in the first few games in the series). One such civic is "bureaucracy", which one can utilise once the "Civil Service" advance has been discovered, but to what extent is "Civil Service" really a "technology" and to what extent does re-casting such civil advances as technologies re-constitute how we understand their social functions? Similarly, corresponding loosely to Jared Diamond's work on the environmental features of technological development, *Civilization VI* incorporates research bonuses for technologies related to an environment that the player controls, such as quarries; in earlier versions of

[7] For a discussion of the role of players' "modding" activities—that is, amending the game's code to change how the game is played—in relation to *Civilization*, see Owens 2011.

the game, environment has little bearing on technological progress, despite simulating different environments and variable sizes of land mass.[8]

It is precisely because of the consistency of the design of technology trees in the *Civilization* series that we can move beyond the game-specific examples mentioned so far. Despite the analysis of ideological assumptions behind the *Civilization* games (Douglas 2002, Poblocki 2002), or of the ways in which technology trees might function in *Civilization* and other strategy games (Ghys 2012, Watrell 2000a, Watrell 2000b), the very act of creating different trees in different versions of the game facilitates a broader comparative analysis of the specific decisions made within each game. MacNeil begins to approach this when she observes:

> Sequels often advance the timeline/chronology of a particular plot or set of characters and contain massive updates to the engine and mechanics of the game. Spoliated games, in contrast, actually mine the older game, often using the older game's engine, mechanics, and digital assets. *Civilization* is an iterative franchise, meaning that it continues to develop a central conceit (rule a [sic] important civilization from the dawn of time onwards) all while updating and changing its approach to core mechanics, visual style, and gaming engine. (2016, "Practical Spoliation")

One of the spolia that remains throughout the *Civilization* games is the concept of the technology tree itself and thus whilst "Each new *Civilization* game starts with the desire to model history thorough [sic] this god-king lenses, but attempts to differentiate itself from the one that came before by modifying rule sets, and adding new forms of interaction" (MacNeil 2016, "Practical Spoliation") the technology tree itself remains broadly static.[9]

Because of this static model, looking at how one particular advance changes across the series facilitates an examination of the ways it has been re-conceptualised as a technology, and as a precursor to or extension of other technologies. The Computers advance is obviously something close to *Civilization*'s heart; it is a longstanding game that relies upon computers to exist, let alone function, and its complexity (in comparison to the relatively simple boardgame incarnation) is only possible precisely because of computing

[8] See Diamond 1999. Diamond's work is mentioned in both Douglas 2002 and Wainwright 2014, regarding their chosen *Civilization* games.

[9] The *Beyond Earth* game, to which MacNeil refers, utilises a "technology web" rather than "technology tree", although the basic axioms of the technology tree nevertheless remain in effect. That said, MacNeil rather optimistically believes that technology in *Beyond Earth* is viewed through a "postmodern vantage point" and that "Once a player has interacted with the Technology Web, the lock-step nature of *Civilization V*'s Technology Tree becomes apparent, along with its implicit Enlightenment biases" (2016, "Technology Trees and Technology Webs"); using the Web to view the Tree facilitates critique, in essence. It rather seems that its changes are relatively minor, despite the interesting inclusion of Affinities deriving from the types of research a player's civilization undertakes, and do little to ameliorate the "colonisation" of human society by technocentric discourse.

advances. Yet is "Computers" a technology in and of itself?[10] Figure 2 outlines the relevant conceptions of the advance across the series:

	Era	Prerequisites	Units / Buildings Available	Acts as Prerequisite For	Obsoletes
Civ I (1991)	n/a	Mathematics, Electronics	SETI Program	Robotics, Space Flight	
Civ II (1996)	Modern	Mass Production, Miniturization	SETI Program, Research Lab	Robotics, Space Flight	
Civ III (2001)	Modern	[Be in Modern Times]	SETI Program, Research Lab, Mechanized Infantry	Laser, Miniaturization	
Civ IV (2005)	Modern	Radio [& Plastics added in expansion]	Modern Armor, Laboratory, The Internet	Genetics, Fiber Optics, Robotics	Angkor Wat, Spiral Minaret, University of Sankore
Civ V (2010)	Modern	Electronics, Mass Media	Nuclear Submarine, Mobile SAM	Robotics	
Civ VI (2016)	Atomic	Electricity, Radio		Telecommunications, Robotics	

Figure 2: Table summarising the Computers Advance across the *Civilization* series

The fact that Computers are features of different "ages" is revealing. In *Civilization II* to *IV* it is a feature of the "contemporary" era, that is, the last era that the game utilises and which brings the player's civilization into the present-day (Western) technological milieu; however, in relation to *Civilization V* and *VI* it is conceptualised as an "historical" technology (that is, its "era" is earlier than the final era of the game's technology tree). Moreover, in *Civilization* I, mathematics and a working knowledge of electronics was required to gain the Computers advance, whereas from *Civilization IV* onwards it is fundamentally linked to mass media. There is also a tension about whether a society requires Computers to consider the possibility of Miniaturization or Miniaturization to consider the possibility of Computers. Similarly, although the Computers advance is assumed to lead to Robotics throughout most of the series, it is only explicitly linked with space exploration in the earlier versions.

[10] In an article on evolutionary paradigms in relation to technology, and in one of the earliest uses of a technology tree to model technological change, De Bresson sketches a technology tree for "Micro-Computers" (thereby dating the piece technologically) in which he links the necessity of combining "semi-conductor effects" (transistor, rectifier, amplifier) into an "integrated circuit" and then linking this into a conceivable "functions" of computing (input, output, operations (ROM), and memory (RAM)) in order to consider how it becomes possible as a technology, and thereby demonstrating how any given technology operates through a "*synthesis* of many different types of technologies" (1987, 755). Although De Bresson does not include a conceptual history of computing in his piece (it is a deliberately limited diagram), it nonetheless demonstrates the inter-reliance of many different fields of endeavour to any one technological advance. This might today be updated to include touchscreen technologies as well as different types of motherboard and microprocessor manufacture to factor in the emergence of the tablet computer and smart phones, demonstrating the further synthesis of available technological advances, without even considering the sociological effects of a given technological advance. Moreover, none of this takes into account the sociological effects emerging from the manufacture, distribution, and use of such technologies.

Although the later games do feature a space component, primarily through their continuation of the "Space Race" victory condition, the SETI program does not get featured in later versions of the game than *Civilization III*, and this seemingly corresponds with the more overt links to telecommunication and mass media, making computing for calculation and computing for network capabilities almost mutually exclusive as the series progresses.

In this manner, what is historical contingency (or perhaps more accurately, fashionable perceptions of particular technologies), in this case whether computers are used in space exploration or mass / social media, becomes reified within the series as the only outlet for that technology when the "technology tree" is created, and this is generally retrospectively predicated upon "what actually happened". As MacNeil states, in relation to the *Civilization V* technology tree requiring Atomic Theory to develop both The Manhattan Project and the Ecology technology:

> It makes such historical facts feel necessary and unavoidable. It reinforces the descriptive trajectory of our technological advancements, and argues for that path being the only way things could have happened. We did research nuclear technologies before we really concerned ourselves with our conservationist technologies, and permuted through the logic of *Civilization V*, we *ought* to have done so. (2016, "Technology Trees and Technology Webs")

For many of the technologies in the games, what is meant by the signifying name of the technology is assumed to be the limits of that as a technology, its culmination or *raison d'être*. In relation to Computers, the long view (whereby we might incorporate Lovelace and Babbage through to modern conceptions of Artificial Intelligence and algorithms) is elided by its virtual incarnation as that which facilitates the next technology, which has itself shifted from data management and analysis, and the ability to model dynamic situations in real time, towards communications and (social) networking. In this case, "what actually happened" has shifted over the duration in which the *Civilization* games have been in existence (as a general trend, computers popularly used for media rather than calculation / exploration) and the technology tree has been amended to reflect the very contingency denied within the determinism of the tree itself. Clearly, the games do not refine their technology trees to promote accuracy or increase coverage, as the number of technologies in the technology trees remains roughly the same across the series and it is other aspects of the games that increase in complexity.[11] By looking at the ways in which specific technologies have changed across the technology trees, it becomes apparent that these technology trees respond to and reflect paradigms of the current uses and applications of specific technologies.

[11] Each game has approximately 70-90 technologies, although this depends upon expansion packs. *Civilization* and *Civilization VI* have the fewest (approx. 70) whereas *Civilization II* and *IV* have the most (approx. 90). In this sense, the technology tree itself is spoliated throughout *Civilization*, as although the technology tree could have been made less rigid (particularly in terms of how its structures the game), it has remained in a form relatively static form, with a comparable number of technologies, across the series.

Technological Contingency & *Civilization*

If this is how the *Civilization* series structures historical technologies, then a similar structural bias is built into its imaginings of contemporary society. A. Martin Wainwright has used historically-focused strategy games to consider the "counterfactuals" of history with students, as such games are—however artificially—simulating the emergence of civilizations, and thereby allow players to manipulate variables and outcomes (see Wainwright 2014, 591-593). This can also be true, in a more limited sense, within the *Civilization* series as the outcomes of particular technological developments, and technological interactions can also be simulated: "what if," we might ask, "a culture had focused on agrarian and pacifistic technologies at the expense of military or economic expansion?" Indeed, this simulation of a set of historical givens (say, for example, the development of a particular technology as leading to another) marks the *Civilization* games as being useful for asking questions about technological determinism versus technological contingency.[12] But, importantly, the *Civilization* series demonstrates a series of iterations of the act of modelling technological development itself. As mentioned above, this is not a refinement of the accuracy of the modelling (as simulations are generally assumed to be), but one that responds to enhancements in computer technologies themselves (such as the game's user interface shifting from top-down coloured squares to an isometric and animated maps), consumer markets (what sells and what does not in computer games), and in what is indeed considered "technological" at a given historical juncture. That is, the *Civilization* series is—via its very acts of technological modelling—a set of historically-contingent models about technological development: it not illustrates a particular view of technological and scientific development, but also reveals, to a limited extent, historical shifts in the perceptions of particular technologies.

To provide a clear indication of this, one only needs to consider the ways in which technologies have been included or removed from the franchise over its various incarnations. Figure 3, below, presents a simplified view of the lists the various advances that can be researched across the *Civilization* series, in the final era(s) of the game, "Modern" in *Civilization II* and *III*, "Future" in *Civilization IV*, and the "Information" Eras in *Civilization V* and *VI*.

[12] For example, taking into account Francis Bacon's assertions that printing, gunpowder, and the magnetic compass are key Western technologies, it is worthwhile noting that they "were the products of Chinese, not European, civilization" (Basalla 1999, 169), although China did not develop them in the same directions as Renaissance Europe because of specific cultural values (169ff). To this list we might add optics and glass technology, which might be construed as key to Western developments of the microscope and the telescope, but were also not developed in the societies that first discovered them because of the relative cultural value of ceramics "over" glass. Such generalisations also behove us to consider the extent to which technologies that might today be perceived as "primitive" might someday appear to be the first steps to a far more advanced technology, but that we cannot yet draw a lineage because the technology is not yet invented.

	Civilization II (1996) [Modern Era]	*Civilization III* (2001) [Modern Era]	*Civilization IV* (2005) [Future Era]	*Civilization V* (2010) [Information Era]	*Civilization VI* (2016) [Information Era]
Advanced Ballistics				✓	[Atomic Era]
[Advanced] Flight	✓	[Industrial Age]	[Modern Era]	[Modern Era]	[Atomic Era]
Amphibious Warfare	✓				
Automobile	✓				
Combined Arms	✓			[Atomic Era]	[Atomic Era]
Composites			[Modern Era]		✓
Computers	✓	✓	[Modern Era]	[Atomic Era]	[Atomic Era]
Ecology		✓	[Modern Era]	[Atomic Era]	
Electronics	✓	[Industrial Age]		[Modern Era]	
Environmentalism	✓				
Espionage	✓	[Industrial Age]			
Fiber Optics			[Modern Era]		
[Nuclear] Fission	✓	✓	[Industrial Era]	[Atomic Era]	[Atomic Era]
Future Technology	✓		✓	✓	✓
Genetic [s] [Engineering]	✓	✓	[Modern Era]		
Globalization				✓	
Guerrilla Warfare	✓				
Guidance Systems					✓
Integrated Defense		✓			
Labor Union	✓				
[The] Laser[s]	✓	✓	[Modern Era] [in "Beyond the Sword" expansion]	✓	✓
Mass Media			[Modern Era]		
Mass Production	✓	[Industrial Age]			
Miniaturization	✓	✓			
Mobile Tactics / Warfare	✓	[Industrial Age]		✓	
Nanotechnology				✓	✓
[Nuclear] Fusion [Power]	✓		✓	✓	✓
Nuclear Power	✓	✓			
Particle Physics				✓	
Plastics	✓		[Modern Era]	[Modern Era]	[Atomic Era]
Radio	✓	[Industrial Age]	[Modern Era]	[Modern Era]	[Modern Era]

Recycling	✓	✓			
Refrigeration	✓	✓	[Modern Era]	[Modern Era]	
Robotics	✓	✓	[Modern Era]	✓	✓
Rocketry	✓	✓	[Modern Era]	[Atomic Era]	[Atomic Era]
Satellites		✓	[Modern Era]	✓	✓
Smart Weapons		✓			
Space Flight	✓	✓			
Stealth [Technology]	✓	✓	✓ [in "Beyond the Sword" expansion]	✓	✓
Superconductor[s]	✓	✓	[Modern Era]		
Synthetic Fibers / Materials		✓			[Atomic Era]
Telecommunications				✓	✓
The Internet				✓	

Figure 3: Table summarising "Final Era" advances in the *Civilization* series[13]

[13] The original *Civilization* did not use the Era system and so is omitted from this table.

Although comparing the games is difficult because they utilise slightly different technology trees, variant prerequisites for units or buildings, and the like, there are clear changes here. Perhaps the most obvious difference is the way in which the Era system developed over the course of the franchise. Whereas *Civilization II* and *III* end with "Modern" technologies, *Civilization IV* suggests technologies for the "Future" era, at least one of which (stealth technologies, such as those utilised by the F-117 Nighthawk or the B2 Spirit) exists, and the latest two versions, *Civilization V* and *VI*, divide this into the "Modern", "Atomic", and "Information" Eras. The "Modern Era", thus conceived, has become something of a historical epoch that laid the ground for subsequent Eras, and the two named—"Atomic" and "Information"—have only relatively recently gained some traction as terms for distinct historical epochs.[14]

Similarly, the contexts in which technologies are situated can change over the series. Whereas Plastics was situated as a "modern" technology until *Civilization V*, in *Civilization VI* it became an "Atomic Era" advance, as the boundaries on what constituted a particular level of technology changed, and it comes to be perceived as more "historical" in the light of more recent innovations. The same is also true of the "[Nuclear] Fission" advance, which has shifted between Industrial and Atomic Era over the franchise as what that advance enables has been altered. That is, the "knowledge" encapsulated by the "Atomic Theory", "Fission" and "Fusion" advances varies according to what it considers to be the "threshold" of a particular technology (usually in its realisation via a real-world application). Atomic Theory, for example, can signify a Classical conception of the notion of the "atom" as well as how that understanding plays out via applications of the underlying scientific principles, depending upon which edition of *Civilization* is played.

Alongside this, the appearance (and disappearance) of technologies as the series develops is also worth noting. "Space Flight" disappears as a discrete technology relatively early in the series, for example, phased out alongside the introduction of others such as "Satellites" (from *Civilization III*). Then there are some advances that only occur once (such as "The Internet" or "Particle Physics" in *Civilization V*, "Smart Weapons" in *Civilization III*, or "Guidance Systems" in *Civilization VI*), whereas others (such as "The Laser") recur across the series. This feature of the series is useful to interrogate what constitutes a "technological advance" for the game designers. Perceiving "the internet" as a technology, rather than a set of implementations of technologies, for example, reconstitutes its importance and how it might be situated in a social context. It first appeared in *Civilization IV* as a "world project" (like a Wonder of the Modern World), but then became a technology in *Civilization V*, before leaving only a vestige in *Civilization VI* via the "Social Media" civic, which one can imagine also disappearing in later versions of the game. As much as these shifts are due to the

[14] For instance, in terms of the linear model of technological eras, Wikipedia—itself arguably an indicator of the Information Age—suggests that after the (Second) Industrial Revolution that there are: the Atomic Age, the Jet Age, the Space Age, the Digital Revolution, and the Information Age. (https://en.wikipedia.org/wiki/Information_Age "History of Technology [by technological eras]" sidebar)

mechanics of the game, as the series developed and gained in popularity "the internet" was emerging as a term with cultural valency, meaning that it was only an interesting "talking point" in the development period around *Civilization IV* and *V*, between the launch of *Civilization III* in 2001 and *Civilization V* in 2010, when it became less of a "wonder" and more of a technological norm, and after which point it became something so accepted—and further built upon—that ceased to be sufficiently conceptualised as a technological "advance" in its own right.[15]

Further, larger scale technological shifts across the series include those concerned with genetics and genetic engineering (disappearing from *Civilization IV* and subsequent games), superconductors (also disappearing from *Civilization IV*), and nanotechnology (only appearing in *Civilization V* and *VI*). The removal of genetic engineering and inclusion of nanotechnology arguably reveal the ways in which the *Civilization* series reflects the socio-cultural conditions within which technological "advances" operates. Genetics, as an advance, could lead to effects and wonders such as "Cure for Cancer" (in Civilization *II* and *III*) and "Longevity" (in *Civilization III*), or with increased population health (in *Civilization IV*).[16] The removal of these from later games, incorporating politically "safer" technologies such as Penicillin—an Atomic Era technology in *Civilization V*—or removing health technologies as viable advances in *Civilization VI*, speaks to a broader cultural concern about these technologies, or at least as viable technologies to be explored.[17] Thus, the inclusion of nanotechnology in later games (post-2010)—as a more "technological" technology with more potentially interesting applications within the game mechanics—is arguably present not only because it might be seen as less politically charged than genetics, but also because it has matured—at least as a hypothetical technology—to the extent that it can be conceived as a viable technological advance.

Whilst we cannot take one game series as anything but a general indicator of social trends and patterns, these changes suggest that, in its very attempts to be technologically aware and "model" technological developments, the *Civilization* series acts as a limited barometer of a wider, public awareness of scientific and technological fashions. In relation to nuclear warfare, for instance, the *Civilization* franchise demonstrates a particular view of so-called scientific progress. In the earlier games, the nuclear option is available for destroying enemy cities, and whilst this exists throughout the series, the type of weapons,

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[15] For instance, although limited in terms of evidence value, looking at Google Trends for the term "internet" (and as a topic) decline as a search term since 2010, and which is even more evident from the "United States" search origins (where the game designers are based), rather than "Worldwide" (see https://trends.google.co.uk/trends/explore?date=all&q=internet). One might also point to the use of "internet" as an adjective amending existing activities itemised by the *Oxford English Dictionary*, many of which are listed as appearing primarily in the early 2000s.

[16] Interestingly, this application of "genetics" operates in both present and futuristic contexts; that is, we have "discovered" genetics already, but the promise of the technology, at least according to the *Civilization* games, has yet to be fulfilled.

[17] However, with the advent of "CRISPR", the use of CRISPR-cas9 techniques to edit gene sequences, we might hypothesise that a future *Civilization VII* or *VIII* that may end up re-vivifying genetics as a legitimate technology (see, for example, https://www.broadinstitute.org/what-broad/areas-focus/project-spotlight/questions-and-answers-about-crispr).

their deployment, and how players might defend against them changes significantly. In *Civilization II*, the "SDI Defense" is a possible building for the player's cities (available through the "Laser" advance), built in each of the player's cities to protect them and their immediate environs from nuclear weaponry. Similarly, in *Civilization III*, the "Integrated Defense" advance allows players to construct the "Strategic Missile Defense" wonder (a special type of building which is built only once by a civilization), which affords a 75% chance of intercepting an enemy's ICBM. Both of these clearly reference the Strategic Defense Initiative—the so-called Star Wars programme developed by the United States, especially during the Reagan administration. Yet although the Laser advance enables construction of the SDI Defense in *Civilization II*, it shifts position in *Civilization III* as it is a prerequisite for "Smart Weapons", which is itself the direct prerequisite for "Integrated Defense". In *Civilization IV* this element is replicated through the SDI national project, which produces the same results as in *Civilization III*, however *Civilization IV* also introduces the "Tactical Nuke" unit, distinct from the ICBM unit, which can avoid interception. In *Civilization V*, however, a player can only build a "Bomb Shelter" within each of their cities to ameliorate the population loss and contamination caused by a nuclear strike. By *Civilization VI*, players can develop nuclear and thermonuclear devices with the right advances, but only the "Mobile SAM" unit can help defend against them. Thus, over the franchise, there is a clear movement away from the "fantastic" technologies promised by the SDI programme, of national shields and lasers shooting down nuclear weapons from within cities, to merely surviving the attack, alongside a concomitant development in the range and type of nuclear weapons (from Nuclear Missile, to ICBM, to Tactical Nuke, and so forth). In so doing, the series reveals itself to be responding to particular trends in contemporary technological developments, and perceptions of those technologies, whilst not significantly changing the axioms upon which those technologies are developed.

Conclusion

What emerges from the ways in which the *Civilization* games "play with" technology and write fictions of (the history of) science is that the ideological nature of the games so often observed in the ways in which they treat civilizations—and indeed the very notion of civilization—is equally replicated through, and perhaps even emerges from, their deterministic views of technology and technological progress. Their power, as models of the "history of technology", is that they clearly demonstrate the potential for games to engage with questions of technological development, and at least imply historical contingency being divorced from "what actually happened": a player might industrialise their society in the 1200s, for instance, or develop Lasers in the 1600s, or not learn Horse Riding until the 1400s.

But for all its superficial "play" with technology, which nonetheless encourages players to consider technology to be unidirectional, the series' model of the history of technology thereby serves to limit its potential to consider cultural technological relativism in favour of reifying (contemporary) ideological concerns. It is entertainment, not history,

but the series demonstrates which models of technological development and fictions of scientific progress become perpetuated (and which become hidden or ignored). Thus the legitimacy of the technology tree as a model of technological progress remains in question, filtered as these incarnations are through a US-centred, capitalist worldview. Whilst they purport to be generalisable histories of human technological progress they in fact reinforce a capitalist and deterministic view of technology despite the moves that the series has made towards being more "inclusive" of other cultures and norms. Whilst they are computer games, and so limited in terms of what they can do both technologically and in terms of market demands on such types of game, the basic assumptions of technological progress limits the series' ability to conceive of the very futures it gestures towards in their more utopian moments. Most damaging of all, at least from the perspective of this article, is one of the most pervasive fictions within the games—its instrumental approach to science and technology ignores the human agency and cultural decisions at work within their respective histories.

As Mahoney observes, "the history of computing, especially of software, should strive to preserve human agency by structuring its narratives around people facing choices and making decisions instead of impersonal forces pushing people in a predetermined direction" (2008, 10). The decisions and choices made by the creators of *Civilization*—what Mahoney calls in relation to software "an operative representation of that portion of the world that captures what we take to be its essential features"—clearly make a virtue of modelling technology (understood in both senses) as being central to human endeavour and ascribe to technology an almost inexorable, inevitable ability to shape human society. The assumptions behind *Civilization*, all too often shared by those who work within "technology" itself, will only serve to reinforce a culturally damaging, and overly jingoistic view of humanity, at the expense of the "history of technology" itself, and to the detriment of those students who will might be embarking on the study of technology for the first time. The Civilization games can provide an effect means into "history of technology" education, but primarily through asking students to interrogate their models of the technology trees, and to question their own assumptions based on what prior experience they may have of playing such games.

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