The Teacher Bandwidth Problem: MOOCs, Connectivism and Collaborative Knowledge

Ben Kotzee (University *of* Birmingham)
S. Orestis Palermos (Cardiff University)

Abstract. Massive Open Online Courses (MOOCs) have, in recent years, become increasingly popular. An important challenge facing MOOCs is the *'teacher bandwidth problem*': In the MOOC environment, where there are potentially hundreds of thousands of students, it is impossible for a few teachers to interact with individual students—there is not enough 'teacher bandwidth'. According to Siemens and Downes's theory of 'connectivism' (Siemens, 2004) one can make up for the lack of teacher bandwidth by relying on collaboration between students; philosophically speaking, however, this theory is underdeveloped. In this paper, we consider the question of learner collaboration in online courses, and the theory of connectivism, from the perspective of social epistemology. We note the similarities between Siemens and Downes's theory and virtue reliabilist theories of epistemic collaboration more broadly. Our paper has two main aims. First, we offer an illustration of how it is possible to conceptualise learner collaboration in online settings as analogous to collaboration between scientists. Second, we attempt to expand on and clarify what Siemens and Downes had in mind when they proposed the theory of connectivism.

1. Introduction

The rise of socially imbued digital technologies—particularly Web 2.0 technologies like blogs, wikis and video sharing platforms—has transformed the potential for world-wide epistemic collaboration. Web 2.0 provides ever 'greater levels of user participation in the creation, maintenance and editing of online "content"' (Smart 2014) and makes it possible for ordinary web users to collaborate with epistemic experts as relative equals. Examples of how Web 2.0 is both increasing the scope of epistemic collaboration and erasing the boundaries between 'experts' and 'lay people' can be found in citizen science projects (e.g., Foldit, Galaxy Zoo, Planet Hunters), in which 'lay' web users actively contribute to the analysis of scientific data.

Unsurprisingly, increasing opportunities for online collaboration have come to be seen as offering educational benefits too, and a number of educational thinkers hold that collaborative learning that takes place in online settings will significantly disrupt or change education. Black, Delaney and Fitzgerald (2007) for example state that

> the increasing trend amongst industries towards collaboration is […] placing a heavier impetus upon educators to make students proficient in collaborative work and wiki application is an ideal platform to facilitate such learning.

Similarly, Noveck (2007) notes that

> the pedagogic literature is unambiguous in its recommendation of activist and engaged modes of learning. We ought to teach students, not only how to read wikis critically and check facts, but how to *write* them. [...] Let them be producers, not just consumers of knowledge!

Advocates of online and collaborative approaches to learning hold that the great reach of the web has extended learning from traditional classroom settings into the world at large; laptops, smartphones and tablets now make learning available in the home, in the workplace and on the go. More radically, it is held that Web 2.0 has also democratized learning: traditional educational institutions are being challenged by start-up education providers and teachers as sources of knowledge are (even) being challenged by new forms of teaching using technology. Some (e.g. Siemens and Downes) hold that, ultimately, this may render the teacher as guarantor and communicator of knowledge redundant as more and more learning begins to result from students collaborating with one another to construct their own knowledge.

In this paper we offer a philosophical analysis of the nature and potential of collaborative online learning.[1] We situate thinking about learner collaboration in the new world of online education as a form of a wider phenomenon receiving attention in epistemology and in the philosophy of science: i.e., the phenomenon of epistemic collaborations. We ask whether the prime exemplars of epistemic collaboration studied in epistemology and the philosophy of science – large scientific collaborations – offers a good model to make sense of online collaboration between learners. Offering a cautiously positive answer, we go on to explore the implications for the conduct of collaborative online learning.

2. MOOCs, Connectivism and the Teacher Bandwidth Problem

Since the advent of the World-Wide Web in 1991, online learning has been growing exponentially. Today, online learning is available at all educational levels from pre-school to PhD. Some online education is 'closed': study materials are only available to those who qualify, enrol and pay the accompanying fee. However, today, much online education is 'open': the Massive Open Online Course (MOOC), for instance, is built on the principles of requiring few (if any) prior qualifications, being free, and being offered at a massive scale. Some of the most attractive features of MOOCs are their (1) global reach (Yeager *et al.*, 2013), (2) low cost (Baker and Passmore, 2016) and (3) scaleability (Porter and Beale, 2015). Others criticise MOOCs for their low completion rates (Jordan, 2014) and low quality (Literat, 2015) or fear that MOOCs are a front for the harvesting of big data (Williamson, 2017). These fears aside, it is a commonplace that much traditional classroom based-learning is inevitably shifting online.[2]

[1] 'Online Collaborative Learning' (or 'OCL') is a technical term, coined by Harasim (2017). To avoid confusion with Harasim's own theory of OCL - 'collaborativism' – we avoid the phrase 'online collaborative learning' and write 'collaborative online learning' or 'collaborative learning online'.

[2] Indeed, the authors are writing this paper at a time (during the Covid-19 epidemic) when much classroom education has shifted online of necessity.

If the dream of moving learning online is going to come true and really offer a varied menu of low-cost, highly accessible learning to the masses, the big question is whether it can manage to do so while maintaining the same quality as traditional face-to-face education offered in bricks and mortar settings. In this regard, an important challenge to all online education is the *'teacher bandwidth problem'*. Wiley describes the problem as follows:

> 'The largest problem with scaling distance education up to thousands or more students is not a bandwidth problem of how much data may be served through scarce Internet connection resources, but rather a bandwidth problem of how many students may be served through scarce teacher resources' (Wiley, 2006: 2)

Put simply: in a classroom setting, characterised by a teacher/student ratio of tens of students to one teacher, it is possible for the teacher to interact with each student in order to provide more or less tailored teaching and feedback. However, in the online environment where there are potentially hundreds or thousands of students it is impossible for the teacher to interact in the same way with each individual. There is not enough 'teacher bandwidth'.[3]

As Wiley explains, advocates of open online education typically propose one of two possible solutions to this problem. The first approach is to take teachers completely out of the instructional process and to replace them with technology. For advocates of this approach, the solution to the teacher bandwidth problem is greater utilisation of reusable learning objects and of automated instructional systems (up to and including adaptive scoring of assessments). The other approach to the teacher bandwidth problem is not to *automate* instructional processes, but to rely on collaboration *between students* to make up for the lack of teacher bandwidth. Writing in 2006, Wiley already foresaw that these two approaches are 'walking down diverging paths'.

Indeed, one of the most influential theorists of online learning – George Siemens – has held that approaches to MOOC design increasingly fall into two: the (ubiquitous) 'xMOOC' approach and the (experimental and largely unrealised) 'cMOOC' approach. According to Siemens (2012) xMOOCs are characterised by a teaching model focused on the transmission of information from expert to novice via ordered content delivery; the difference between this and 'traditional' teaching is only that transactions between learners and teacher are automated and that assessment is computer-marked. xMOOCs (as Siemens describe them) seem to exemplify Wiley's first approach to the teacher bandwidth problem. By contrast, cMOOCs follow a learning model that is collaborative (and not transmissionist). The cMOOC approach dispenses with the idea that an expert (a teacher) designs a particular learning experience and then manages its transmission to learners. Instead, on the cMOOC model, learning emerges organically from networking between learners and on content contributions from the participants themselves. Clara and Barbera (2013) draw a parallel between cMOOCs and the democratic vision of cooperative self-education envisaged by Ivan Illich in *Deschooling Society* (1973). In that book, Illych attacked the organisation of education in the hierarchical school and proposed that we could replace schools by democratic cooperatives: in these cooperatives, individual learners would seek out individual teachers to be taught about topics they are interested in. Indeed, in Illych's system, the role of teacher and learner would be interchangeable as members of the cooperative would take turns to 'teach' the topics they are familiar with to others and again 'learn' topics that they are not familiar with from others.

[3] In setting up the problem thus, we do not imply that teachers are mainly or only conduits for information. In the context of this paper 'teacher bandwidth' is a foil against which to test the in principle possibility of fully collaborative, learner-driven learning. It is not a comment on real teachers. We thank an anonymous reviewer.

Indeed, moving away from transmissionist to more discovery, enquiry or project-based learning has a long history and has been advocated by figures as diverse as Dewey (1938), Bruner (1961) and Piaget (1970).

What is different about collaborative learning *online* (as opposed to project or enquiry-based learning in class) is that it is not a particularly radical educational alternative that involves much change to educational organisation and practice… it is already taking place widely on Web 2.0. Siemens and Downes highlight the following characteristics of Web 2.0.

(1) The rapid growth of knowledge makes the very state of our knowledge of any particular subject a dynamic phenomenon. This is illustrated very well in the operation of Wikipedia. Wikipedia aimed to be an authoritative source of knowledge, generated by multiple users, of the state of our knowledge about a topic. In practice, however, Wikipedia is not static, but dynamic – its content constantly changes.

(2) The new kinds of production and dissemination of knowledge on the Web has radically increased the number of perspectives on offer on any subject matter. While before Web 2.0 content was controlled by experts (like scientists, or journalists or opinion formers) now everyone can give a view and offer a view on a topic. In Web 2.0, there is little difference between 'informed' and 'un-informed' any more.

Based on these two observations, Siemens and Downes ask a very provocative question. In a world in which we are (1) not sure exactly what is known, but this constantly changes and in a world (2) where we are never sure exactly who knows and who does not know – what is it for anyone to 'learn' something from someone? In traditional pictures of learning, this is quite clear: teachers are the experts who know what there is to be known about a topic and then teach this to learners. However, in Web 2.0 where people come together on an internet forum to discuss a new topic matter and learn about it, we know neither what there is to know nor who knows it. In such fora, it is often hard to say who is the teacher, who the learner and who is simply shouting from the sidelines.

Siemens and Downes embraced this insight and held that, in thinking about learning in Web 2.0, we need to give up two traditional assumptions about knowledge: (a) that knowledge always resides in the individual; and (b) that knowledge is a thing—a representation—that people create or master. Instead, Siemens and Downes proposed a new learning theory— the theory of connectivism. As Goldie puts it, connectivism is a conceptual framework that views learning as a network phenomenon influenced by technology and socialization:

> Connectivism asserts that knowledge and learning knowledge are distributive, i.e. they are not located in any given place, but instead consists of networks of connections formed from experience and interactions between individuals, societies, organizations and the technologies that link them. Knowledge is viewed as a process, fluid and dynamic flowing through networks of humans and their artifacts. […] Knowledge resides within networks, without any individual necessarily possessing it, and it can be stored in a variety of digital formats. (Goldie 2016: 1065).

As interesting as this may sound, connectivism is still significantly underdeveloped. Siemens holds that because our learning environment has been changed quite drastically by technology in the last three decades, we are in need of a whole new theory of what learning is (2004). For Siemens, the theory of connectivism is meant to displace behaviourism, cognitivism and constructivism as our best explanatory accounts of human learning takes place. This is a big claim and deserves serious scrutiny. Indeed a number of authors (Verhagen, 2006; Kop and Hill, 2008) have held that connectivism does not supersede earlier theories of learning.

Harasim (2017) offers a particularly thorough critique of connectivism. She holds that the theory of connectivism has been derived in an *ad hoc* fashion to support Siemens and Downes's evolving pedagogical initiatives, rather than to theorise the nature of the actual practice of online learning. Because the theory continues to change in reaction to their new pedagogical initiatives, Harasim holds that

> 'Siemens and Downes have both… acknowledged [that] they are unable to define or agree on what 'connectivism' is and how to apply it…' (2017: 93)

Moreover, Harasim holds that Siemens and Downes present the theory in contradictory ways and that there is frequent conflict between the two authors; moreover, because they tend to publish their work via blogs, rather than in peer-reviewed academic publications, the theory is 'intellectually adrift.' (2017: 93)

Still connectivism's influence is indisputable. Siemens and Downes were the designers and presenters of what has been called the first MOOC in 2008 (rather self-referentially, this MOOC was on the topic of 'Connectivism and Connectivist Knowledge'.) At the time of writing, Siemens's work has been cited more than 23,000 times and his paper 'Connectivism, a learning theory for the digital age' has been cited 6,900 times (Downes's work has been cited 9,500 times.) Moreover, the thrust of Siemens and Downes's work could not be more important. As Harasim holds, the consequence of this work is 'to diminish or eliminate the role of the instructor in learning' and to envision a future for education that is 'teacherless' (2017: 93, 98). Given that the theory offers a bold and far-reaching idea, but is as yet theoretically under-developed, it is important to give connectivism serious philosophical attention.

In what follows, we first turn our focus to the teacher-bandwidth problem, which is arguably one of the main practical considerations motivating the connectivist proposal. To conceptualise this problem – and Siemens and Downes's solution to it - we turn to collaborative knowledge as it is studied in epistemology and philosophy of science. While we do not purport to offer a complete solution to the teacher bandwidth problem, we provide a principled consideration of the extent to which purely collaborative (and largely teacher-less) learning is possible. This is our first and primary objective. Next, we revisit connectivism to discuss how our approach may go some way to placing Siemens and Downes' theory on a more stable theoretical footing. Thus, a secondary objective is to work out the similarities between connectivism as a theory of learning and the theory of epistemic collaborations in the hope that our approach could clarify and expand on what Siemens and Downes may have had in mind when they were proposing connectivism.

3. Epistemic Collaboration in Science and Everyday Life

Let us return to the 'teacher bandwidth problem'. In the traditional classroom, the teacher (or perhaps a small number of authoritative sources, like textbooks) are all the evidence or all the justification that students need to ground their knowledge. In particular the teacher (and the material that the teacher selects) is the final authority who must judge what her students have learned. On the collaborative model, the teacher is no longer the sole epistemic authority, but students collaborate with each other and serve as epistemic authorities *themselves.* The main question about collaborative learning online is whether this is really possible. Can students who are novices in a field bootstrap themselves through collaboration to more knowledge of a topic without being guided at every step by an expert, the teacher?

We want to argue that the answer to this question is positive. Consider first a number of authors across a variety of disciplines who think that much knowledge in science and in broader society is best described as collaborative. Let us turn firstly to science. Sociologists, ethnographers and philosophers of science (Bloor, 1991; Latour & Woolgar, 1986; Latour, 1987; Knorr-Cetina 1999; Nersessian et al. 2003*a*, 2003*b*; Neresessian 2005; 2006 Thagard 1993; 1994; 1997; Giere & Moffatt, 2003; Giere, 1990, 2002, 2006, 2007) have long stressed the collaborative nature of the knowledge produced by scientific research teams.

Hardwig (1985) illustrates the collaborative nature of science through the example of large scientific projects. He cites research published in the journal *Pysical Review Letters* with 99 named authors.

> '…This experiment, which recorded charm events and measured the lifespan of the charmed particles, was one of a series of experiments costing perhaps $10 million. After it was funded, about 50 man/years were spent making the needed equipment and the necessary improvements in the Stanford Linear Accelerator. Then approximately 50 physicists worked perhaps 50 man/years collecting the data for the experiment. When the data were in, the experimenters divided into five geographic groups to analyze the data…Obviously, no one person could have done this experiment - in fact [one team member] reports that no one university or national laboratory could have done it-and many of the authors of an article like this will not even know how a given number in the article was arrived at.' (Hardwig, 1985: 347)

Similarly, Giere (Giere 2002*a*; 2002*b*; 2006; 2007; Giere & Moffat 2003) has proposed that collaborative experiments embody a kind of thinking that is not possible for one scientist to carry out themselves; instead, much scientific knowledge amounts to 'distributed cognition' (i.e., cognitive processing that is distributed between people) and is therefore irreducibly social.[4]

Knorr-Cetina's (1999) ethnographic study of High Energy Physics experiments backs up Hardwig's and Giere's remarks. She notes that large collaborations are not run by any individual alone and no individual is responsible for their management and organization. Such experiments are managed, instead, by *discourse*. Discourse 'channels individual knowledge in the experiment, providing it with a sort of distributed cognition […], which flows from the astonishingly intricate webs of communication pathways' (1999: 173). These ongoing interactions between participants forms a grid of discourse spaces, which 'was and is today perhaps the most important vehicle of experimental coordination and integration' (1999: 174).

Moreover, the distributedness of cognition is not confined to scientific contexts. It can occur in very ordinary contexts too. Consider the case of everyday 'Transactive Memory Systems'—

[4] In addition, Giere stresses the unmissable part that is played by scientific instruments or knowledge gathering tools that scientists use - as well as being dependent on people thinking together, it also depends on thinking with cognitive tools. As Giere puts it, to '…understand the workings of the big cognitive system one has to consider the human-machine interactions as well as the human-human interactions.' (Giere 2002*b*, 292).

i.e., groups of two or more people who collaboratively store, encode and retrieve information—as described by Wegner et al. (1985, 257):

> 'Suppose we are spending an evening with Rudy and Lulu, a couple married for several years. Lulu is in another room for the moment, and we happen to ask Rudy where they got that wonderful staffed Canadian goose on the mantle. He says "we were in British Columbia…," and then bellows, "Lulu! What was the name of that place where we got the goose?" Lulu returns to the room to say that it was near Kelowna or Penticton—somewhere along lake Okanogan. Rudy says, "Yes, in that area with all the fruit stands." Lulu finally makes the identification: Peachland.'

Wegner at al. explain that, during the discussion between Rudy and Lulu, the various ideas they exchange help them elicit their individual memories. 'In a process of interactive cueing, they move sequentially toward the retrieval of a memory trace, the existence of which is known to both of them. And it is possible that without each other, neither Rudy nor Lulu could have produced the item' (1985, 257). Accordingly, Wegner et al. claim, 'the observable interaction between individuals entails not only the transfer of knowledge, but the construction of a knowledge-acquiring, knowledge-holding and knowledge-using system that is greater than the sum of its individual member systems' (1985, 256).

These examples – from science as well as from ordinary life – show that much knowledge is not individual (gained by the individual alone due to their own cognitive effort) but is social (because it is gained in cooperation with other people and, many times, could not have been arrived at by the individual).

Social epistemologists have increasingly turned their attention to these kinds of epistemic collaboration. One currently influential account in explaining how knowledge arises out of epistemic collaboration is the theory of virtue reliabilism (Palermos 2020; Palermos 2017; Palermos 2016; Palermos and Pritchard 2013; Palermos and Pritchard 2016).[5] Virtue epistemologists generally agree that knowledge requires that the agent be both reliable and epistemically responsible in the way they form their beliefs. Reliability requires that the agent generally has true beliefs rather than false ones, and epistemic responsibility requires that the agent be, in some way, sensitive to whether the way they form their belief is appropriate. Now because of several counterexamples and the threat of an epistemic infinite regress (see Greco 1999), virtue reliabilists understand epistemic responsibility in a relatively weak manner that does not require any explicit reasons in support of the reliability of the agent's beliefs. Instead, virtue reliabilists count an epistemic process as responsible if it is responsive to epistemic errors: a process is responsible if it has some mechanism built in that is designed to detect and eliminate mistakes. With that proviso in place, virtue reliabilists then note that we can trust beliefs that are the result of a responsibly configured epistemic system *by default*. That is, we do not need separate justification for believing responsibly produced beliefs but are justified in trusting them as long as there is in place an error-correction mechanism that would (counterfactually) have detected and removed those beliefs if they were incorrect. (Palermos

[5] Analytic epistemology since Gettier (1963) has been much exercised by the question of whether epistemic justification is essentially 'external' or 'internal', that is, whether justification is the brute fact of evidentiary support (externalism) or an individual's grasp of or conviction of that support (internalism). (Alston, 1987) and Bonjour and Sosa (2003) show how this question goes together with the question whether justification is 'foundationalist' (built up in layers from simple to complex justification) or 'coherentist' (networked, inter-referential or web-like). While the literature in this area is vast and the debate is by no means settled, it is fair to say that virtue reliabilism represents a leading attempt at compromise and consolidation in the field.

2014). Think of visual perception. We never offer positive reasons in support of our visual beliefs. Unless we have reasons to mistrust our vision (for instance, we know we are in an environment that could generate illusions—e.g., visions of oasis in a desert), we take ourselves to know what we visually perceive even if we know nothing about how vision works and why it is reliable. Still, we do take ourselves to be epistemically responsible in believing what we see, because were there ever something wrong with our vision we would notice this and would not automatically accept the resulting beliefs.

The important point in this context is that virtue reliabilists (Palermos 2020; Palermos 2017; Palermos 2016; Palermos and Pritchard 2013; Palermos and Pritchard 2016) who are interested in collaborative knowledge hold that very similar principles can be applied *in respect of the reliable and epistemically responsible belief formation of epistemic groups*. Specifically, when an epistemic group is organized in such a way that group members will reliably correct one another if someone introduces an incorrect belief to the group, the group can be said to instantiate a reliable and epistemically responsible collective belief-forming process.

The main idea is that such collections of people tend to interact until they evolve to a stable configuration. Once the system has achieved a stable configuration, its component parts (i.e., its members and their equipment) have mutually adapted by restricting their interactions to those that allow them to accomplish their end.[6] This diachronic process of self-organization promotes the reliability of the group's belief-forming process. Otherwise, the collective would not have accomplished its end of reliably generating true beliefs—thereby being most likely to dissolve—or would have given rise to another internal configuration that would have been more appropriate (i.e., more reliable). Over time, the mutual interdependence of the individual members of the group explains how the group self-organizes to eventually bring about a structure that supports its epistemic reliability.

At the same time, mutual interdependence between individual members explains how the group epistemically self-regulates at the time of performance. The reciprocal and continuous interactivity between group members allows them to keep monitoring each other's performance, such that were there, at any given time, something wrong with the overall process, then it would become noticed by at least one member of the group, who would draw it to the group's attention and allow the group to respond appropriately by correcting or discarding the incorrect belief. Conversely, if there is nothing wrong with the overall process as it unfolds over time, the group will again count as responsible for its successful performance *by default.* This is because, so long as the group *can* become aware that there is something wrong, then the group can take itself to be acting responsibly, provided that no member has expressed any doubts about the group's beliefs.[7]

Now, notice that these forms of epistemic reliability and responsibility are not the product of adding together the epistemic credentials of the members of the group. Instead, they arise out of the synergetic cooperation of the members of the group. Such epistemic self-organisation and self-regulation can be found in a number of contexts. As noted above, at the scale of the dyad, Wegner and his colleagues (Wegner et al. 1985, Wegner 1986) have studied Transactive Memory Systems. At the level of large institutions, there is the example of scientific research teams (Palermos 2020). And at the international level, there are Social Machines such as Wikipedia (Palermos 2017) or Slashdot (https://slashdot.org/) (Wiley and Edwards, 2002).

[6] For more on the general process of self-organisation, see (Heylighen et al. 2004).
[7] For more on epistemic collaborations and the underlying processes of epistemic self-organisation and epistemic self-regulation, see Palermos (2020).

Finally, it is also worth noting that certain practical preconditions can be particularly conducive to the emergence of epistemic collaborations. For example, by taking a look at a variety of collaborative epistemic systems, it becomes obvious that there are two specific properties, which are usually required for group members to efficiently interact with one another and thus self-organise and self-regulate. In Wegner et al.'s (1985) terms, epistemic collaborations need to possess 'common knowledge' and 'a differentiated structure.'[8]

1. *Common knowledge* between the members of the group usually comes in the form of a common culture, language and background assumptions that allow group members to understand each other. When common knowledge is in place, communication between them may begin.

2. Subsequently, this facilitates the development of the group's *differentiated structure*. By revealing information about themselves group members acquire a sense of each other's knowledge and expertise. As members become acquainted with one another, the group's structure becomes more differentiated. Eventually, by having a good sense of who the other members are, each member knows when it is appropriate to rely on the knowledge and expertise of the others and, conversely, when it is time to take action themselves.

Unsurprisingly, common knowledge and differentiated structure often play important roles in empowering group members to efficiently interact with each other, and thereby give rise to the group's abilities to epistemically self-organise and self-regulate (which promote, respectively, the group's reliability and epistemic responsibility).

4. Epistemic Collaboration in a Connectivist Online Learning Environment

With the above in mind, we can now explore the question of how thinking about collaborative knowledge can help us conceptualise the design of collaborative online learning environments (like cMOOCs), that can allow groups to epistemically self-regulate and self-organise. We do so on the basis of a toy example that removes much of the complexity that would be involved in the design of an actual online learning environment. (In places, our discussion also assumes certain technological possibilities that are, to date, not available in any online learning environment we are familiar with.) Such idealizations notwithstanding, we provide a stage-wise sketch of how a collaborative MOOC (a cMOOC) can evolve in a way that gradually makes fewer and fewer demands on teachers and places more and more responsibility on learners themselves to self-organize in their discovery of new beliefs. Our toy example asks the reader to imagine a complicated MOOC and to imagine what organizational steps the teacher (or course manager) can take to minimize their own epistemic input and maximize the extent to which learners self-organize.

Suppose an academic institution organises a cMOOC at the intersection of Philosophy, Science and Religion. The cMOOC would explore, for instance, the dogmas of the main religions, the principles of evolutionary biology and the implications of quantum mechanics. The aim of the cMOOC would be for learners collaboratively to explore questions on the cutting edge between

[8] Wegner et al. (1985) introduce and stress the importance of the notions of 'common knowledge' and 'differentiated structure' in relation to TMSs. However, 'common knowledge' and 'differentiation' are likely to play equally important roles in the case of scientific collaborations as well as Social Machines (for more on this point, see Palermos 2017).

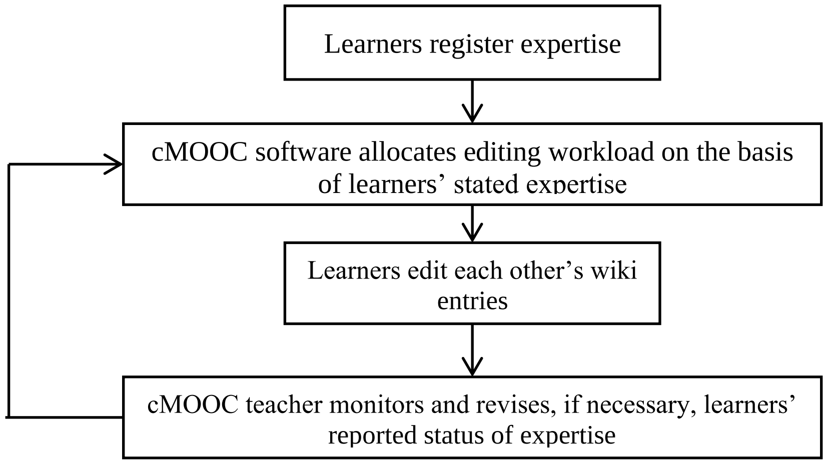
philosophy, science and religion, such as whether quantum and Newtonian mechanics are consistent, whether evolutionary biology and intelligent design are incompatible, etc. Given the state of human knowledge in the 21st century, these questions are amongst the most puzzling and rewarding intellectual questions to consider; they are also difficult and interdisciplinary… it is hard for *one person* to know enough of religion and biology and physics to answer them all.

Given MOOCs are designed and monitored by only a few academics but taken by thousands of learners, we can expect that 'teacher bandwidth' will be a problem. For one thing, the sheer number of participants would make it hard for academics to monitor every learner's collaborative contributions; for another, the subject matter of the cMOOC is such that participants are likely to have widely different levels of knowledge (and widely different opinions) about the topics discussed. How are MOOC designers to make it more likely that learners' collaborative efforts are of good quality and do not spin out of control into mere opinion? A possible solution would consist in providing learners with the means to self-organize and self-regulate so that they can collectively monitor their own discussions and overall learning process.

Current collaborative online learning design suggests that students may begin by creating wikis that map out their knowledge regarding the different subject matters in play. For example, if a certain part of the course material assumes knowledge of evolutionary biology but a learner knows little about it, then the learner could start a wiki on the topic of 'evolutionary biology' and invite contributions from other learners who are knowledgeable about evolutionary biology. Similarly, if learners are interested in the compatibility between Newtonian and quantum mechanics they could start a wiki on that topic. In this way, learners' interactions would contribute to and further their common knowledge.

However, there is a possible problem with allowing learners to answer each other's questions in the way suggested above: What would increase the likelihood that the relevant information is reliable? This is where self-organisation and self-regulation come into play. A possible strategy involves the following two steps. The first step is to ask every learner to register some areas of expertise even if they have no concrete academic credentials to offer (indeed providing and checking for such credentials would be burdensome and would suffer, once again, from the problem of 'teacher bandwidth'). Then the cMOOC software could use this information in order to allocate the workload of editing its wikis, by sending notifications of a new entry to only those learners who have reported to possess the relevant expertise.

Obviously, the weak spot of this procedure is that it does not guarantee that only competent learners are going to contribute to the relevant entries. It would be practically impossible to check all learners' credentials in a large MOOC and allowing students to self-declare expertise only goes so far: a person *could* declare themselves as knowledgeable about a matter that they are not knowledgeable about. A solution might be for the cMOOC teacher to monitor the number of changes a given learner's contributions (on any given domain of expertise) undergo over time. If the number of edits their work undergoes is high because they seem to be factually incorrect, then the teacher could recall that learner's status of expertise on the relevant problematic domain, in effect 'downgrading' a cMOOC contributor's credibility if their wiki entries have to be repeatedly corrected by other users. A workflow that explains the process is found in *workflow 1*.



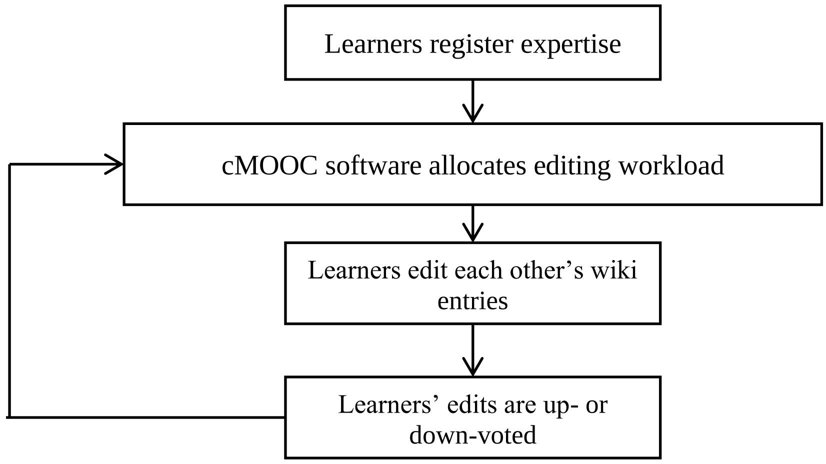
Workflow 1: A teacher-monitored system to facilitate cMOOC self-organisation and self-regulation.

Workflow 1 will solve a great deal of the teacher bandwidth problem, but it will not solve the whole problem. The teacher would still have to be involved in monitoring contributions, downgrading some contributors' editing rights and adjudicating between contributors when there are conflicts about edits. The question is: how far can we distribute the process of reliability monitoring too? Could we trust the group to monitor its own reliability without an epistemic authority figure at all?

Imagine a second version of the reliability monitoring system in which cMOOC contributors do not self-declare expertise that is then monitored by a teacher. Instead, the process of reliability monitoring would be distributed around the group. In this second, group-monitored system, MOOC contributors can edit whatever part of the wiki they like. However, each edit is put to an upvote or downvote by the whole group. For each cMOOC contributor the cMOOC software keep count of their upvotes and downvotes to establish a total 'reliability score' for that contributor. The reliability score can then be used to:

a. Give those with a higher credibility score more editing rights over the wiki
b. Appoint those with a higher credibility score to correct downvoted entries
c. Appoint those with a higher credibility score as moderators in disputes
d. Appoint those with a higher credibility score as 'mentors' for students with low credibility scores
e. Etc.

All of this can be automated and needs no teacher input. Such a system, in which the self-correcting task needed in a cMOOC is distributed away from the teacher and towards the 'students' on the cMOOC, is illustrated in workflow 2.



Workflow 2: A voting-based distributed system to facilitate cMOOC self-organisation and self-regulation

While the voting-based self-correcting mechanism is a good step forward, it is not perfect. We can imagine two kinds of problems with using upvotes and downvotes to establish a person's total epistemic credibility.

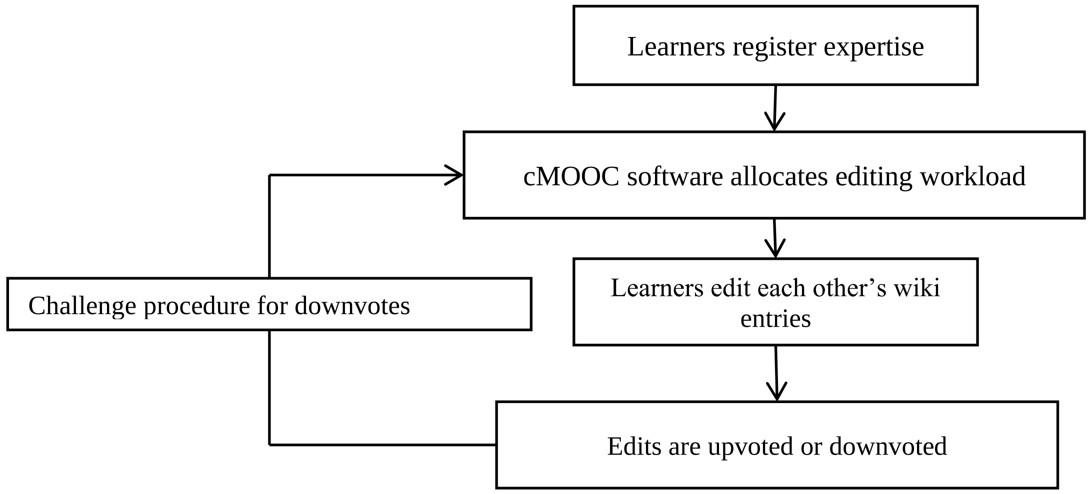
1. Someone's wiki entries can be popular (that is, attract many upvotes) without being right. Take, for instance, entries that pander to popular prejudices or entries that are entertaining, without being right.
2. Someone's wiki entries can be unpopular (that is, attract many downvotes) without being wrong. Take, for instance, entries that point out others' mistakes, or entries that clash with popular prejudices.

The upvote/downvote system therefore also needs some adjustment.

To solve problem 1 and 2, above, there could be a 'challenge' system like in tennis or in cricket. In tennis or cricket, each player receives a certain number of challenges at the start of the match. They can use these to challenge the decision of an umpire. We can use the same kind of system here. If a cMOOC participant thinks that another participant is being given upvotes for a comment that is wrong, the cMOOC participant can 'challenge' those upvotes. In such cases, the course manager or teacher may have to become involved again as an epistemic umpire, who must reach a balanced decision on who is right and who is wrong. If the umpire decides that the upvoted edit is wrong, then, the participant who makes the challenge may be awarded a certain number of upvotes and the participant who made the popular, but incorrect edit, may be penalised with a certain number of downvotes. This will disincentivize making merely popular (but wrong) edits and will incentivize challenging popular orthodoxies and so solve problem 1.

To solve problem 2, we can use the same system. A cMOOC participant can challenge their downvotes if they think their edit was right and was unfairly characterised as wrong. If the umpire decides that their edit was downvoted wrongly, then, the participant who makes the challenge can be awarded a certain number of upvotes and the participants who made the downvotes can all be penalised with a certain number of downvotes. This will incentivize making unpopular, but ultimately right edits – it will give participants the courage to speak out for what is right but unpopular. It will also disincentivize downvoting edits that are right, but merely unpopular.[9] Workflow 3 illustrates the process.

[9] Or help deal with 'bullying' downvotes. We thank an anonymous reviewer.



Workflow 3: a workflow to distribute self-correction through a combination of voting and challenges

While there are a number of additional details that would need to be spelled out in a fully functioning cMOOC with reliability checking built-in, the above indicates that cMOOCs can in principle be designed so as to epistemically self-regulate in a largely decentralised manner. Over time, self-regulation will also shape the MOOC's self-organisation. Monitoring and the 'challenge' system will have a direct effect on every contributor's status of expertise and, as a result, on their editing rights. Of course, given the above, a teacher or course manager may still be required, if only to serve as the ultimate arbiter in cases of edit wars and challenges. Even so, minimising the teacher or course manager's input to such an extent makes it obvious that the teacher bandwidth is not an insurmountable problem anymore.

The overall result will be a largely decentralised epistemic system, in which, if there are any mistakes, falsehoods or vague claims posted online, they will be spotted and removed—otherwise, entries that have been monitored but remain unchanged can be considered to amount to knowledge, by default.[10] In other words, self-organisation and self-regulation within a MOOC can in theory give rise to epistemically responsible and reliable group learning that will require minimal teacher contributions, thus alleviating and perhaps even entirely solving the teacher bandwidth problem.

What is in effect illustrated in the workflows above are three progressively more complicated forms of epistemic self-organisation. The workflows represent an 'evolution' of more complex and more self-organised forms of epistemic cooperation between learners. Indeed, in the last workflow, the learners' form of organisation comes to approximate how scientific work is organised today. Scientists do really declare what they are knowledgeable about and they do really choose what knowledge contributions to offer to the scientific community (that is, they

[10] One may worry that learners would be unaware of whether a given entry has been monitored so that it can qualify as knowledge. This is an interesting technical question. As noted in the beginning of our section, our aim here is only to *sketch* how mainstream epistemology's approach to collaborative knowledge can inform the design of cMOOCs and it goes without saying that it would be beyond the scope of this paper to attempt to provide a solution to every single problem that the design of such complex learning platforms may pose. Nevertheless, with respect to the issue of monitoring, and since the current approach to cMOOCs relies, like Wikipedia, on the "power of the many eyes" (Noveck, 2007), one possible solution could be to add on top of every wiki entry a note of the invited editors that have accessed the entry. The bigger this number, the more will the entry have been monitored and thus the more likely will it be that it is reliable.

decide what to publish). Their work is then genuinely evaluated by their peers and ‘upvoted’ (through citations) or ‘downvoted’ (through lack of citation). It may even be challenged in the form of published reactions or replies and publishing a highly successful reaction or reply can add significantly to the reputation of the one writing it. In the end, scientists’ credibility does result in something like a reputational score that determines where they publish and how widely they are read and believed. Scientific credibility and reputation is a phenomenon that emerges out of communicative interaction with peers in a process that is not too dissimilar to what we describe in Workflow 3.

The take home point is that, as long as a collaborative learning experience is set up in a way that allows students to make good judgements of other students’ contributions in more or less the same way that scientists judge each other’s contributions, there is no reason why a group of online learners cannot bootstrap themselves – even without much help from a teacher – to knowledge. Clearly, such a processing of bootstrapping will not be easy. Indeed, the group’s taking on progressively more responsibility for the learning process on themselves demands progressively greater levels of epistemic maturity on their part. How much epistemic self-organisation one can entrust to various learners at various stages will have to be carefully judged and, most likely, students will take some time to progress from working in only the more basic collaborative systems before they are ready to operate in the more complicated ones. However, as our examples show a solution to the teacher bandwidth problem can be found in epistemic collaboration. The secret to knowledge lies not in the expertise of the teacher, but in the organisation of the epistemic group.

5. Rehabilitating the Theory of Connectivism

While we do not purport to have offered a full solution to the complex design problems that will be needed to realise a connectivist MOOC in section 4, we hope that it delineates the main aspects of a principled approach to connectivism and the teacher bandwidth problem. This was our first and primary objective. Additionally, our approach, which draws on the idea of collaborative knowledge as this is understood along the lines suggested by virtue reliabilism, appears to bear certain interesting similarities with Siemens and Downes’ connectivism. In this final section, we would like to comment on these similarities in the hope that our approach could be seen as a possible way to expand on and clarify what Siemens and Downes may have had in mind when they were proposing connectivism.

There are at least two points of contact between connectivism and the way mainstream epistemology conceives of collaborative knowledge and learning. First comes the connectivists’ inspiration that cMOOCs should instantiate Illich’s democratic vision of cooperative self-education. Similarly, within mainstream epistemology, the properties of epistemic self-organisation and self-regulation are deemed central to collaborative learning. Secondly, according to Downes (2006, 2012), a successful learning environment (such as, the cMOOC is supposed to be) should have four characteristics: (1) diversity (2) autonomy of participants (3) openness and (4) connectivity. When these elements are present, Downes holds, learners can begin the process of cooperative self-learning. Our approach to collaborative knowledge also accentuates the importance of these four properties in its recognition that ‘common knowledge’ and ‘differentiated structure’ (Wegner et al. 1985) are practical prerequisites for establishing learners’ mutual interactivity, which is necessary for giving rise to the properties of epistemic self-organisation and self-regulation.

Here is how Downes (2006) conceives of the above properties in detail:

- First, diversity. Did the process involve the widest possible spectrum of points of view? Did people who interpret the matter one way, and from one set of background assumptions, interact with people who approach the matter from a different perspective?
- Second, and related, autonomy. Were the individual knowers contributing to the interaction of their own accord, according to their own knowledge, values and decisions, or were they acting at the behest of some external agency seeking to magnify a certain point of view through quantity rather than reason and reflection?
- Third, interactivity, or connectedness. Is the knowledge being produced the product of an interaction between the members, or is it a (mere) aggregation of the members' perspectives?
- Fourth, and again related, openness. Is there a mechanism that allows a given perspective to be entered into the system, to be heard and interacted with by others?

The condition of connectedness is meant to ensure that the relevant knowledge is specifically collaborative knowledge. Likewise, our approach to collaborative knowledge also takes interactivity to be a central requirement for the relevant group to qualify as an epistemic group agent that can generate collaborative knowledge. The rest of Downes's conditions of diversity, autonomy and openness jointly ensure that the relevant group will have a differentiated structure and that this structure will be put effectively in practice. A differentiated structure certainly requires *diversity* of participants, but in order for differentiation to be effective and meaningful, its participants must be able to speak their minds as and when required—that is they must be autonomous—and the structure must also be receptive to dissent—that is, it must exhibit openness.

So we see there is strong overlap between the two approaches to collaborative knowledge and a clear potential for the two views to inform each other. For example, Downes' stresses the importance of differentiation by noting the importance of diversity within a group, but he goes further by suggesting that in the absence of autonomy and openness, diversity will end up being inert. In the remainder, we would like to clarify how our mainstream epistemological approach to collaborative knowledge can help us understand the way the properties of diversity, autonomy, openness, and interconnectedness are supposed to fit together in the efficient design of epistemic group agents.

We have seen that while our approach takes the property of mutual interactivity between group members and their equipment—in Downes's terms connectedness—and the property of differentiation—in Downes's terms diversity, openness and autonomy—to be central to the generation of collaborative learning, neither is considered an end in itself. According to our mainstream epistemological approach to collaborative knowledge the final requisite is the generation of reliably produced and epistemically responsible true beliefs by the group as a whole. Section 2 stressed that, from the point of view of virtue reliabilism, this may only be achieved at the group level when the relevant network has the ability to epistemically self-organise and self-regulate. By keeping in mind that this is what the design of every collaborative epistemic network should be aiming at, we can then reverse-engineer how the above properties may contribute to it.

Self-organisation and self-regulation, as we saw in section 2, can only be instantiated by a network of mutually interacting components. Connectedness and mutual interdependence between individual users are what allows the network to achieve a stable configuration that will allow itself to maximise its collective goal of reliably generating epistemically responsible beliefs as well as adapt to changes in its environment or its own internal needs. This is what constitutes the diachronic process of self-organisation. At the same time, the mutually interconnected components of the network allow it to synchronically self-regulate by being in a position to monitor each other and respond to any signs of malfunction.

Also, we noted that mutual interdependence is not easy to come about and that it is by no means guaranteed that networks will always support their participants in engaging in efficient mutual interactions with each other. To increase the likelihood of success, interconnected networks would be good to exhibit a differentiated structure that will allow everyone to bring in their own expertise as and when required, in a way that will empower the group to reap the knowledge and talents of its participants in an effective way. Just above, we also stressed that diversity of expertise is not sufficient for providing a differentiated structure, but that the latter also needs to be open to autonomous and diversified member contributions: Even if members have a diverse expertise, their contribution won't be instrumental to the network's self-regulation and self-organisation if it is manipulated by top-down forces such as the presence of a centralised manager that controls their freedom of speech, and it will be causally inert if the network is not open (i.e., receptive) to said contributions. Moreover, we noted that the above properties that are designed to contribute to the group's differentiated structure are more likely to get off the ground if the relevant network also possesses some common knowledge that will allow its members to communicate with each other. A significant part of this common knowledge will also be information regarding each other's expertise such that everyone will know when it is time for them to rely on the knowledge and expertise of the other members and when it is time for them to take action themselves. Interestingly, as we saw in the example of the Philosophy, Science and Religion cMOOC, this common knowledge does not need to reside entirely within the individual participant's heads. Instead, it may be embodied in the technical aspects of the network (for example by having members registering their expertise), which may also be updated on the basis of participants' performance, as the network evolves over time.

The way the relevant ingredients are supposed to come together then is the following. Common knowledge promotes differentiated structure. A differentiated structure that is open to the autonomous contributions of participants allows them to efficiently interact with each other. Several cycles of this mutual interdependence between participants allows them to achieve a stable self-organised structure that is in a position to self-regulate and maximise the collective goal of reliably generating epistemically responsible true beliefs.

This is how our mainstream epistemological approach to collaborative knowledge can inform the connectivist attempt to lead the design of cMOOCs and collaborative learning networks in general. Apart from the above details, however, our approach can advance our understanding of collaborative learning in a further manner. Loosely interpreted, connectivism's focus on network structure and the nodes that give rise to it might seem as implying that knowledge is a state that can be accurately described in the form of a blueprint. While this is not what connectivists support—but instead take note that knowledge is indeed a dynamic process—tying connectionism with our approach to collaborative knowledge can further accentuate that collaborative knowledge and learning is not a state but an ongoing, evolving and highly dynamic process. It is a process of ongoing self-organisation and self-regulation between the component parts of a distributed epistemic network. While this may sound abstract, it has important ramifications for the design of such networks. Such collaborative learning networks must not be built as ready-made, pre-specified structures to be put immediately in use, but as plastic organisations that must be allowed to evolve over time and assume whatever shape might in the process prove helpful to maximise their epistemic goals.

Conclusion

We have argued that connectivism and the associated approach to MOOC design—i.e., cMOOCs—can be approached in terms of collaborative knowledge and learning. By focusing on a mainstream epistemological account of collaborative knowledge, we have offered specific suggestions for the efficient design of cMOOCs. While more details may need to be filled in, we have demonstrated that, in principle, it is possible to design bio-technologically hybrid learning structures capable to support reliable and epistemically responsible group learning in a way that may ultimately dispense with the teacher bandwidth problem.

Acknowledgements

Ideas for this project were sparked by the Templeton-funded 'Philosophy, Science and Religion Online' Eidyn Project, at the University of Edinburgh, for which Orestis Palermos worked as an RA and Ben Kotzee acted as an external collaborator. We would also like to thank two anonymous referees for *Educational Theory.*

References

Alston, 1986. Internalism and Externalism in Epistemology. *Philosophical Topics* 14, 179 – 221.

Baker, R. and Passmore, D. 2016. Value and Pricing of MOOCS. *Education Sciences* 6 (14)

Bandura A. 1986. Social foundations of thought and action: a social cognitive theory. Englewood Cliffs (NJ): Prentice-Hall.

Bell F. 2009. Connectivism: a network theory for teaching and learning in a connected world. Educational Developments, The Magazine of the Staff and Educational Development Association, 10; [cited 2015 Aug]. Available from: http://www.seda.ac.uk/index.php?p1⁄45_4_1.

Black, P., Delaney, H., & Fitzgerald, B. (2007). Legal issues for wikis: The chllenge of user-generated and peer-produced knowledge, content and culture. *eLaw J.*, *14*, 245.

Bloor, D. 1991. *Knowledge and Social Imagery*. University of Chicago Press.

Boitshwarelo B. 2011. Proposing an integrated research framework for connectivism: utilising theoretical synergies. The International Review of Research in Open and Distance Learning. 12:161–179.

Bonjour, L. and Sosa, E. 2003. *Epistemic Justification: internalism vs. externalism, foundations vs. virtues.* Oxford: Blackwell.

Bruner, J. 1961. The Act of Discovery. *Harvard Educational Review* 31, 21 – 32.

Clara M, Barbera E. 2013. Three problems with the connectivist conception of learning. J Comput Assist Learn. 30:197–206.

Dewey, J. 1938. *Experience and Education.* New York: Kappa Delta Pi.

Downes S. 2005. An introduction to connective knowledge. Stephen's Web; [cited 2015 Aug]. Available from: http://www.downes.ca/cgi- bib/page.cgi?post 1⁄433034.

Downes S. 2006. Learning networks and connective knowledge; [cited 2015 Aug]. Available from: http://itforum.coe.uga.edu/paper92/ paper92.htlm.

Downes S. 2007. An introduction to connectivist knowledge. In: Hug T, editor. Media, knowledge & education – exploring new spaces, rela- tions and dynamics in digital media ecologies. Proceedings of the International Conference, June 25–27, 2007.

Downes S. 2012. Connectivism and connective knowledge. Essays on meaning and learning networks; available at: https://oerknowledgecloud.org/sites/oerknowledgecloud.org/files/Connective_Knowledge-19May2012.pdf

Engestrom Y. 1987. Learning by expanding: an activity-theoretical approach to developmental research. Helsinki: Orienta-Konsultit.

Feyerabend, P. K. 1975. Against Method: Outline of an anarchistic theory of knowledge.

Foster T. 2007. What connectivism is. Online Connectivism Conference: University of Manitoba; [cited 2015 Aug]. Available from: http://www, umanitoba.ca/moodle/mod/forum/discuss.php?d1⁄412.

Gettier, E. 1963. Is Justified True Belief Knowledge? *Analysis.*

Giere, R. N. 2002*a*. Discussion Note: Distributed Cognition in Epistemic Cultures. *Philosophy of Science, 69*(4), 637–644.

Giere, R. N. 2002*b*. 'Scientific Cognition as Distributed Cognition'. In *Cognitive Bases of Science*, eds. Peter Carruthers, Stephen Stitch and Michael Siegal, Cambridge: Cambridge University Press.

Giere, R. N. 2006. The Role of Agency in Distributed Cognitive Systems. *Philosophy of Science*, *73*(5), 710–719.

Giere, R. N. 2007. Distributed Cognition Without Distributed Knowing. *Social Epistemology, 21*(3), 313–320.

Giere, R. N., & Moffatt, B. 2003. Distributed Cognition: Where the Cognitive and the Social Merge. *Social Studies of Science, 33*(2), 301–310. doi:10.1177/03063127030332017

Goldie, J., G., S. 2016. Connectivism: A knowledge learning theory for the digital age?, Medical Teacher, 38:10, 1064-1069, DOI: 10.3109/0142159X.2016.1173661

Halfaker, A., Geiger, R. S., Morgan, J. T., & Riedl, J. 2012. The rise and decline of an open collaboration system: How Wikipedia's reaction to popularity is causing its decline. *American Behavioral Scientist*, DOI: 0002764212469365.

Harasim, L. 2017. *Learning Theory and Online Technology*. 2nd edition. London: Routledge.

Hardwig, J. 1985. Epistemic dependence. *The Journal of philosophy*, *82*(7), 335-349.

Heylighen, F., Heath, M., & Van, F. (2004). The Emergence of Distributed Cognition: a conceptual framework. In *Proceedings of Collective Intentionality IV*.

Illich, I. 1973. *Deschooling society*. Harmondsworth, Middlesex.

Jordan, K. 2014. Initial trends in enrolment and completion of massive open online courses. *The International Review of Research in Open and Distance Learning* 15(1), 133-160.

Karsenti, T. 2013. The MOOC: what the research says *Revue Internationale des technologies en pedagogie universitaire* 10 (2), 23 – 47.

Kerr B. 2007. A challenge to connectivism. Transcript of Keynote Speech, Online Connectivism Conference: University of Manitoba; [cited 2015 Aug]. Available from: http://Itc.umanitoba.ca/wiki/index. php?tit;e1⁄4Kerr_Presentation.

Knorr, K. C. (1999). *Epistemic Cultures: How the Sciences Make Knowledge*. Cambridge, Mass: Harvard University Press.

Kop R, Hill A. 2008. Connectivism: learning theory of the future or vestige of the past? Int Rev Res Open Dis Learn. 9:1–13.

Lange M. 2012. Talk: connectivism; [cited 2015 Aug]. Available from: http://en.wikipedia.org/wiki/Talk:Connectivism.

Latour, B. (1987). *Science in Action: How to Follow Scientists and Engineers Through Society*. Harvard University Press.

Latour, B., & Woolgar, S. (1986). *Laboratory Life: The Construction of Scientific Facts*. Princeton University Press.

Lave J, Wenger E. 2002. Legitimate peripheral participation in commun- ities of practice. In: Harrison R, et al., editors. Supporting lifelong learning. Vol. 1. Perspectives on learning. London: Routledge Falmer. p. 111–126.

Literat, I. 2015. Implications of Massive Open Online Courses for Higher Education: mitigating or reifying educational inequalities? *Higher Education Research and Development* 34 (6), 1 – 14.

Nersessian, N. J., Newstetter, W. C., Kurz-Milcke, E. & Davies, J. (2003). A Mixed-method Approach to Studying Distributed Cognition in Evolving Environments. *Proceeedings of the International Conference on Learning Sciences.* pp. 307 - 314.

Nersessian, N. J., Kurz-Milcke, E., Newstetter, W. C., & Davies, J. (2003).Research laboratories as evolving distributed cognitive systems. *Proceedings of The 25th Annual Conference of the Cognitive Science Society.* pp.857-862.

Nersessian, N. J. (2005). Interpreting scientific and engineering practices: Integrating the cognitive, social, and cultural dimensions. In *Scientific and Technological Thinking*, M. Gorman, R. Tweney, D. Gooding, & A. Kincannon, eds. (Erlbaum). pp. 17-56.

Nersessian, N. J. (2006). The Cognitive-Cultural Systems of the Research Laboratory. *Organization Studies*, 27(1), pp. 125-145

Noveck, B. S. (2007). Wikipedia and the Future of Legal Education. *J. Legal Educ.*, *57*, 3.

Palermos, S. O. (2014). Knowledge and cognitive integration. *Synthese*, *191*(8), 1931-1951.

Palermos, S. O. (2015). Active externalism, virtue reliabilism and scientific knowledge. *Synthese*, 192(9), 2955-2986.

Palermos, S. O. (2017). Social machines: a philosophical engineering. *Phenomenology and the Cognitive Sciences*, *16*(5), 953-978.

Palermos, S.O. (2020). Epistemic Collaborations: Distributed Cognition and Virtue Reliabilism. *Erkenntnis*. https://doi.org/10.1007/s10670-020-00258-9

Palermos, S. O., & Pritchard, D. (2013). Extended knowledge and social epistemology. *Social Epistemology Review and Reply Collective*, 2(8), 105-120.

Palermos, S. O., & Pritchard, D. (2016). The Distribution of Epistemic Agency. In *Social Epistemology and Epistemic Agency: De-Centralizing Epistemic Agency*. (ed.) P. Reider, (Rowman & Littlefield).

Piaget, J. 1970. *Genetic Epistemology*. New York: WW Norton.

Porter, D. and Beale, R. 2015. *A Policy Brief on MOOCs*. Commonwealth of Learning. http://oasis.col.org/bitstream/handle/11599/825/Policy%20Brief%20on%20MOOCs%20May%2025%20HQ%20print.pdf?sequence=1&isAllowed=y

Ravenscroft A. 2011. Dialogue and connectivism: a new approach to understanding and promoting dialogue-rich networked learning. Int Rev Res Open Dis Learn. 12:139–160.

Siemens G. 2005. Connectivism: a learning theory for the digital age.
Int J Instr Technol Dis Learn 2:1–8; [cited 2015 Aug]. Available from:
http://www.itdl.org/Journal/Jan_05/article01.htm.

Siemens G. 2006. Connectivism. Learning theory or pastime for the selfamused?
[cited 2015 Aug]. Available from: http://www.elearnspace.
org/Articles/connectivism_self-amused.htm.

Siemens G & Downes S. 2008. Connectivism and connected knowledge;
[cited 2015 Aug]. Available from: http://ltc.umanitoba.ca/

connectivism/.

Siemens, G. 2012. MOOCs are Really a Platform *elearnspace* http://www.elearnspace.org/blog/2012/07/25/moocs-are-really-a-platform/

Smart, P. R. (2014). Embodiment, cognition and the World Wide Web. In L. Shapiro (Ed.), The Routlege handbook of embodied cognition. New York: Routlege.

Thagard, P. (1993). Societies of minds: Science as distributed computing. *Studies in History and Philosophy of Science Part A*, *24*(1), 49–67. doi:10.1016/0039-3681(93)90024-E

Thagard, P. (1994). Mind, Society, and the Growth of Knowledge. *Philosophy of Science*, *61*(4), 629–645.

Thagard, P. (1997). Collaborative Knowledge. *Noûs*, *31*(2), 242–261. doi:10.1111/0029-4624.00044

Verhagen P. 2006. Connectivism: a new learning theory? [cited 2015 Aug]. Available from: http://www.scribd.com/88324962/Connectivism- a-New-Learning-Theory.

Vygotsky LS. 1987. Thinking and speech (trans. By N.Minick). In: Reiber RW, Carton AS, editors. The collected works of L.S. Vygotsky, (Vol. 1: Problems of general psychology). New York: Plenum Press. p. 39–285.

Wegner, D., Giuliano, T., & Hertel, P. (1985). Cognitive interdependence in close relationships. In W. J. Ickes (Ed.), *Compatible and incompatible relationships* (pp. 253–276). New York: Springer-Verlag.

Wegner, D. (1986). Transactive Memory: A Contemporary Analysis of the Group Mind. *Theories of Group Behavior*. Eds. B. Mullen and G. R. Goethals. New York: Springer-Verlag.

Wiley, D., & Edwards, E. (2002). Online self-organizing social systems. *Quarterly review of distance education, 3*(1), 33.

Wiley, D. A. (2006). Learning objects in public and higher education. In *Innovations in instructional technology* (pp. 33-41). Routledge.

Williamson, B. (2017) *Big Data in Education*. London: SAGE.

Yang, S. and Wang, F. (2015) Visualizing information science: author direct citation analysis in China and around the world. *Journal of Infometrics* 9 (1)

Yeager, C., Hurley-Dasgupta, B. and Bliss, C. 2013. cMOOC's and Global Learning: an authentic alternative. *Journal of Asynchronous Learning Network* 17 (2), 133 – 47.