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Richard Edwards^a & Tara Fenwick^a

^a School of Education, University of Stirling, Stirling, UK

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Digital analytics in professional work and learning

Richard Edwards and Tara Fenwick

School of Education, University of Stirling, Stirling, UK

ABSTRACT

In a wide range of fields, professional practice is being transformed by the increasing influence of digital analytics: the massive volumes of big data, and software algorithms that are collecting, comparing and calculating that data to make predictions and even decisions. Researchers in a number of social sciences have been calling attention to the far-reaching and accelerating consequences of these forces, claiming that many professionals, researchers, policy-makers and the public are just beginning to realise the enormous potentials and challenges these analytics are producing. Yet, outside of particular areas of research and practice, such as learning analytics, there has been little discussion of this to date in the broader education literature. This article aims to set out some key issues particularly relevant to the understandings of professional practice, knowledge and learning posed by the linkages of big data and software code. It begins by outlining definitions, forms and examples of these analytics, their potentialities and some of the hidden impact, and then presents issues for researchers and educators. It seeks to contribute to and extend debates taking place in certain quarters to a broader professional education and work audience.

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Introduction

Professional practice in fields ranging from health and education to urban planning and engineering are being transformed by two interlacing technological forces: big data deluge and the software algorithms that are collecting, comparing and calculating them to make predictions and even decisions. These are part of the emerging knowledge infrastructures of daily life, the 'robust networks of people, artefacts, and institutions that generate, share and maintain specific knowledge about the human and natural worlds' (Edwards 2010, 17). The linkages of software and data, what we refer to in this article as digital analytics, are increasingly parts of professional practice, knowing and learning. While technology has always been important to professional practice, it is arguable that the speed and scope of innovation in digital analytics is at a faster pace and more pervasive than we have seen previously.

CONTACT Richard Edwards  r.g.edwards@stir.ac.uk

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Digital analytics take many forms, but are not always well understood or even visible. The material infrastructure of the Internet and its enactments of virtuality are not well understood by the majority of its users (Blum 2012). Beyond those involved explicitly in their development, the technologies are often black-boxed and naturalised as tools to be used based upon human intention and decision-making (Bowker and Star 2000). They are there and they do the work we need them to do, until they break down or do something that we do not expect. In principle, the fallible professional is displaced by the infallible technology. In practice, it is obviously more complex than that.

There is no denying of the positive effects and potentialities of these technologies and the analytics, predictions and decisions they generate. Professional practice and decision-making, informed by more efficient and effective information and analysis, are being much enhanced in many areas. There is also rapidly developing research on their effects and the issues raised by their adoption in a range of disciplines, including education (Manovich 2013). For instance, if predictive analytics become the basis of decision-making, rather than professional judgement and discretion, who (or what) is legally and ethically responsible when things go wrong?

Examining the effects of digital technologies on work organisations and practices has been a concern for many years (Orlikowski 2007, 2010), focusing on issues such as the de-skilling/professionalising and re-skilling/professionalising of the workforce, and the resultant struggles over shifting statuses and rewards. For Eriksson-Zetterquist, Lindberg, and Styhre (2009, 1151), 'professional identities and boundaries are both shaped and formed by the use of technology, but technology per se is also shaped by its use within professional communities. The two categories are to some extent mutually constitutive'. There is also interest in the changing relationships with users or clients of professional services made possible by digital technologies (Adkins and Lury 2012; Williamson 2015), as for instance, with the self-monitoring and remote sensing of data by patients and doctors in the use of digital insulin pumps to treat diabetes (Doyle 2014), which enable less face-to-face contact between the two. The professional mediation of data and use of expert knowledge in decision-making would appear to be increasingly distributed to digital analytics in such examples.

This article aims to set out some key issues particularly relevant to our understandings of professional practice, knowledge and learning posed by digital analytics. The article is in four parts. First, we overview the broader discussion of digital technologies in professional practice, drawing particularly on those employing a sociomaterial, Science and Technology Studies perspective. Second, we briefly examine big data: what it is, and examples of how it is changing professional practice. Third, we explore more fully some of the emerging research on the significance of digital analytics in professional practice. Fourth, we identify some of the issues and implications for professional practice and education. The article is exploratory, drawing on examples from published research in a range of disciplinary domains. We realise that for some educational researchers, such as those engaged in the work of learning analytics, certain of the arguments in this article may appear over-simplified. However, we, like others (Buckingham Shum 2015; Prinsloo and Slade 2015), seek to encourage a wider dialogue on the issues raised by the growing influence of algorithms and big data beyond those specialists who are already immersed within the arena.

Computer technology and professional practice

Over time, there has developed a powerful discourse, which encourages professionals and others to view digital technology use as an increasingly natural and naturalised part of their work. However, in an earlier review of theories of information technology, Orlikowski and Iacono (2001, 131) argued that:

We have a tendency to talk of (technological) artefacts as if they were of a piece—whole, uniform, and unified. For example, we talk about ‘the Technology’, ‘the Internet’, ‘the Digital Economy’, as if these are single, seamless, stable, and the same, every time and everywhere. While such simplifications make it easy to talk about technologies, they also make it difficult to see that such technologies are rarely fully integrated, flawless, and unfailing, and that they can and often do break down, wear down, and shut down.

This statement may be less the case than it was in 2001, but it is unlikely that many non-specialists have engaged with the long history of research exploring the development and deployment of such technologies, and the shaping of technologies and work practices in particular ways as they are taken up in specific contexts. In this research, the underpinning assumption is that ‘all relations should be seen as both social and technical’ (Law and Bijker 1992, 291). This has informed the moves towards understanding professional practice as sociomaterial and not simply social (Fenwick, Edwards, and Sawchuk 2011).

Orlikowski (2007) provides some enduring empirical examples of the sociomateriality of work practices and how digital analytics sometimes work independently within such assemblages, impacting upon behaviour. For example, in 2007 and continuing today, the Google PageRank algorithm that searches and sorts links to items automatically updates itself in response to the use of links by those searching, which is also in part linked to location. A Google search, unlike a dictionary, may therefore produce different results across space and time and is both emergent and contingent. This raises questions about the reliability of the sources of data identified across different locations. A second example Orlikowski outlines is the ways in which mobile technologies are reshaping behaviours and blurring the physical and status boundaries of work and home, engendering a fairly constant engagement with webs of relationships extended across space, time and absent-presences. There is a co-constitutive entanglement of the technology and work practices in these enactments. In a later article on the different ways of theorising technology in workplaces, Orlikowski (2010) outlines the example of work undertaken by geographically distributed professionals in an immersive virtual workspace through their avatars. While this example may be far from the norm for professionals, it points to aspects of simulation that are increasingly significant in practice and learning. The immersive world is not a separate background or context for those participating in it, but is co-constitutive in the enactments of practice, which also include the sociomaterial entanglements of the humans practicing at a distance as *part of*, rather than *within*, this assemblage.

A more familiar example of the entanglement of digital technologies and professional practice is provided by Eriksson-Zetterquist, Lindberg, and Styhre (2009). They studied the introduction of an American electronic purchasing system into a Swedish company to improve the purchase of goods and services to enable the more efficient production of cars. Over time, those professionals affected felt that, while the system facilitated improvements in the purchasing process by increasing standardisation, it reduced their

independence, introduced new roles and statuses as the process emerged, with different roles within the system of purchasing gaining greater visibility, and there was increasing audit of performance. Previously human professional practices became digitally automated enabling greater efficiency in the production of cars. In this example, for the professional purchasers, new assemblages introduced different bureaucracy and hierarchies. A key concern for some of the work force was the extent to which the uptakes of the new system would result in a loss of roles to be replaced by automation and information systems. As Manovich (2013) argues, these are knowledge infrastructures not simply to support decision-making but to make the decisions themselves.

The introduction or extension of digital technologies, changing professional practices and issues of de-skilling and re-skilling in the contexts of particular workplaces is obviously a key theme for empirical research. However, what has also begun to emerge as an issue is the digital analytics that enable the technologies to do the work they do. Digital analytics are working increasingly to transform the work roles, knowledge practices and labour processes of professional practice in ways which are not always explicitly planned, as the example provided by Eriksson-Zetterquist, Lindberg, and Styhre (2009) illustrates. These transformations are not only accelerating, but appear to be implemented with limited analysis or critical engagement by many professional bodies, practitioners or educators of student professionals beyond those experts in digital analytics themselves. While the specific workings of digital analytics are not widely understood, their proliferation within many areas of professional practice is mostly posited in terms of their positive potential. In the broad professional education terrain, less attention is given to the critical issues raised.

Big data and software code

Kitchin (2013) argues that the notion of big data is not straightforward in definitional terms. However, it typically refers to data that are collected in massive volume, working at high velocity, and are characterised by diverse variety, exhaustive scope, fine-grained resolution and indexical identifiers. Big data typically conjoins different data sets, and has capacities for both extension and scalability. The ever-expanding masses of data are only part of the challenge facing professionals and researchers. A further part is the integration of different kinds of data, from fine-grained tracking of individuals' behaviours and movements with environmental measures, data yielded through surveillance and dataveillance (trawlings through interconnected data sets), large administrative databases and so forth. Ruppert et al. (2015) argue that rather than focusing on big data's characteristics of volume, velocity and so forth, we should think about their social lives. Through specific and novel socio-technical practices, data are born, given meaning, then exercised in all sorts of ways (searched, cleaned, mashed, curated, staged, traced, shared, repurposed, etc.). These exercises enact data in ways that order, change, reproduce and attempt to govern social life. In their analysis of the effects of the interplay of software and data, Kitchin and Dodge (2011) present many examples of the ways in which the social is increasingly becoming 'code/space'.

Big data are collected through three main means that are interconnected with most professional activity. Directed data are produced through intentional surveillance operated by humans, such as patient record information accumulated through a range of measures,

tests, electromagnetic scans, biotechnical feedback, etc. Automated data are accumulated through embedded sensors in objects, environmental measuring instruments, clickstreams measuring people's web activity, scanners that read objects and machines that record their own uses as well as the items passing through them, such as diagnostic machines. Volunteered data emerge from content posted on the web or social media, such as teacher–student or patient–professional Facebook pages intended to share information and professional services; crowdsourcing, such as digital photos and postings that police agencies encourage the public to submit; or personal information yielded freely onto the web by people, such as through registrations for free services or software.

Algorithms in software code are the actors that process these data. Digital analytics have become a key means of performing knowledge through tagging, classification, standardisation, calculation, circulation and visualisation, and these require codes and algorithms. Data dredging techniques, data visualisation and analytics that compare and predict are now an integral part of many professional practices. In effect, digital analytics and the standardisation they require to function are integral to much of our knowledge, communication and decision-making, and are part of the enactment of new ways of working and governing work. Thus,

it is not just bits and bytes that get hustled into standard form in order for the technical infrastructure to work. People's discursive and work practices get hustled into standard form as well. Working infrastructures standardise both people and machines. (Bowker 2005, 111–112)

There are many examples that illustrate how digital analytics are transforming professional practice in a range of sectors, something we will illustrate from existing studies. Predictive analytics are used to assess conditions and prescribe remedies for students/patients/clients, to produce client and professional service records, e-learning systems and even to plan provision in health, social care, education, engineering and law (Siegel 2013). In medicine, new consumer diagnostic mobile technologies are moving rapidly from prototype to market. For instance, *Remotoscope*TM claims to offer at-home diagnosis of ear infections. These have prompted grand claims such as Khosla's (2012) that up to 80% of medical diagnosis in future will be conducted through computers. The argument is that such technology-delivered, data-driven processes are more reliable and consistent than services performed by human professionals; profession-proofing is to be achieved by enhanced decision-making by digital technologies and analysis of big data. While automation has consistently played an important role in changing work and professional practices, evaluating the positive, negative and ambiguous effects of different manifestations of digital analytics presents a significant issue for professionals and educators. In their systematic review of mobile technologies for medical diagnostics and other service delivery, Free et al. (2013) note that, while evidence does not support their efficacy to date (in fact, these technologies are more likely to have deleterious effects), health professionals as well as the public remain enthusiastic about their use.

This is not surprising, perhaps, given the claims of these technologies in their marketing. While some may dismiss such texts as 'mere' advertising, the powerful influence of such discourses on consumer and even professional behaviour is worth considering. One example is 'Ayasdi' machine learning software, now widely used in public sector

decision-making, the finance sector, life sciences and professional communications. The Ayasdi website (n.d.) boasts that it 'enable users to automatically discover and operationalise insights from complex data':

Ayasdi's award-winning platform automates the end-to-end workflow from discovery of insights to operationalising how data is used ... unifies best-of-breed machine learning approaches into a common framework without the need to write algorithms, queries of models ... empowering any user to derive operational value from complex data.

In health care, 'precision medicine' becomes possible, as Ayasdi claims it can take responsibility for a range of services including designing clinical pathways, precision medicine and patient monitoring. The notion that complex analyses and critical queries – or even insights and innovation – are no longer required from human workers, because these are now 'automated', is an interesting move to understate the analytic process. Even the pattern seeking and predictive analytics embedded in such software is deliberately obscured. Here we see also the democratic allusion to 'any user' now supposedly freed from reliance on knowledge or expertise (or knowledge workers such as professionals). Knowledge is just data that can be compelled to yield 'operational value'. However, while such claims attempt to shape the future environment, the evidence at present, perhaps unsurprisingly, is less conclusive (Jeffrey 2015). In many cases, digital analytics are used to enhance professional decision-making rather than displace it.

In law, Susskind (2013) shows how professional legal service has been proliferating into many specialised data-driven processes, with a corresponding rise of technology-driven entrepreneurs: legal technologists, legal knowledge engineers, project managers and risk managers. Online legal services such as 'Cube-Legal' (Cube n.d.) or 'Rocket Lawyer' (Rocket n.d.) have sprung up, claiming to make legal service more convenient, accessible and affordable by removing the need to meet with professional lawyers or solicitors and the associated costs. Susskind predicts a radical reconfiguration of the profession of law, delivered through such Internet-based global legal businesses, online document production and even virtual courts and online dispute resolution with many benefits for users of certain services. The nature of the reconfigurations and their impact on who has access to what legal services and with what effect has, of course, yet to be fully charted. This in itself points to an issue in researching digital analytics, as it is often the anticipated effects that have to be outlined and evaluated rather than the empirical effects.

In human resource management, Google has developed what it calls 'people analytics', using big data and algorithms for recruitment (Sullivan 2013). Digital analytics predict which employees are likely to become 'retention problems', alerting management so that pre-emptive action can be taken. Forward-looking predictive models are developed to forecast and act upon other people management issues and opportunities before they arise. A recruitment algorithm is used to predict which employees are most likely to succeed after hiring, both to shorten the total interview time and to ensure that the selection panels do not 'miss' top talent. This approach is deemed to make recruitment more 'scientific'. There is even an algorithm to solve 'diversity problems', analysing the root causes of weak diversity and presenting actions to address them. It is yet to be established if or in what ways these analytics add to existing recruitment practices, but the promise of better approaches is certainly alluring.

In the finance professions, software algorithms have already eclipsed most transactions, speeding up the process to the point where computers trade shares in thousandths of a second. In his study of high frequency trading, Lewis (2014) shows that the principal actors in well over 90% of stock market trades are computers. Software codes can 'sniff' a sale before it is completed, even detecting others' algorithms in the market, then buying the share to make a profit. Nanoseconds are crucial to making profit, such that not only the algorithms, but also access to high speed fibre optics differentiates success, not professional skill. Humans are not only mostly extraneous to the activity, but often unable to see or follow the process, let alone monitor or learn from it.

In urban planning, notions of smart cities, intelligent cities, media cities and so forth are attracting wide appeal. Typically the focus is on challenging urban planning professionals to adapt digital technologies to make cities more innovative and productive. Forlano (2013) shows how digital actors themselves are entangled in co-producing place. Working with a range of analytic technologies, Forlano tracks people's activities and meanings of place, combined with their uses of mobile technology (including mapping software and user-generated tagging capacity) in built environments, their engagements with digital networks like Wifi, and the effects of urban technologies such as large screens. What she finds is that 'place' is far more dynamic, relational and emergent than is often assumed in much professional design and planning practices.

These are the sorts of issues emanating from digital analytics in professional work that ought to provoke more scrutiny. Professional practice increasingly can draw from abundant sources of diverse real-time, fine-grained, formerly difficult-to-access data assembled with state of the art new technologies that capture, manipulate and curate this information in ever-more-accessible ways. At the same time, these examples show challenges. Everyday practice is changing in ways that may not be fully recognised. Some work is becoming tied to, and even dictated by, databases and their categories. Notions of place are being transformed. Multitudes of data require careful interfaces, transfer points and scrutiny to ensure that important nuances are not distorting or disappearing altogether. Some professional knowledge work is being delegated to digital technologies – to predict, diagnose, solve problems or even decide. What we do not see from many professional bodies, practitioners and educators, beyond the anecdotal, are critical evaluations of the ways digital analytics are affecting practices, nor significant attempts to embrace these issues within programmes of professional education. Coded objects, coded infrastructures, coded processes and coded assemblages (Kitchin and Dodge 2011) all participate in (re-)shaping professional practice, knowledge and learning, yet in ways that require much greater investigation. This raises significant practice and research challenges.

Standardisation, software algorithms and inscrutable practices

To date, exploring the work of digital has been a surprisingly small part of the research on professional practice and learning. In relation to education specifically, there is burgeoning research on learning analytics and their potential to enhance provision for students, particularly in relation to higher education (Buckingham Shum 2014; Finn 2015; Gasevic, Dawson, and Siemens 2015). Within this realm, there are significant efforts to examine issues, such as how code and algorithms reflect and relate to specific understandings of

pedagogy and assessment (Knight, Buckingham Shum, and Littleton 2014) and issues of student privacy (Prinsloo and Slade 2015). There are also attempts to develop greater transparency through the use of open source software and through participatory design approaches to the development of analytics. However, the extent to which that is influencing educational research and provision more broadly is unclear and there seems to be less links to the wider social science literature on software and big data, although this is beginning to emerge (Williamson 2014; Edwards 2015).

Drawing on some aspects of software studies, Edwards and Carmichael (2012) argue that the work of code in the uptake of digital technology in education could be examined as an aspect of the hidden curriculum. This challenges those approaches to curriculum and pedagogy wherein digital technologies are considered as simply tools by which the curriculum is 'delivered'. In particular, they argued that the effects of developing standards and algorithms on the representation of data, the forms of teaching and learning that are possible and the notion of the student assumed and enacted were part of a 'secret code' of the hidden curriculum. They provide examples of how the visualisation of data in digital education resources select what is and is not made visible in ways in which only those who have written or understand the underlying code may be able to understand. The information visualised therefore provides only a partial picture based upon the assumptions in the software and organisation of the databases.

For software to work, relevant digital databases need to be available, as 'the creation of digital archives are deeply computational in structure and content, because the computational logic is entangled with the digital representations of physical objects, texts and "born digital" artefacts' (Berry 2011, 25). Particularly significant, and yet at the same time largely unrecognised, is the role played by forms of classification and standardisation associated with the development of such databases, and the ways in which complex knowledge is represented (Lampland and Star 2009). Not least, because as Manovich (2013, 215) points out, 'standardisation of file formats is an essential condition of interoperability between applications'. In other words, for the technology to function most flexibly, data must be standardised. Classification requires developing standard forms of naming, for, as Bowker (2005, 140) argues, 'you can't store data without a classification system', and this requires naming and setting standards. Naming itself may seem a straightforward or mundane practice. Despite this, Halford, Pope, and Weal (2012, 178–179) argue that in the development of classification within such databases 'making some things "known" tends to obscure other things and, indeed, ways of knowing' and that 'ontology building is not a simple or solely technical matter'. The issue of time in relation to making certain things visible and others invisible is also an important one. With the passing of time and the incorporation of digital data into new assemblages and applications, the data, the selections and applications of standards and ontologies, and the application of rules can disappear from explicit view. Data 'once encoded ... can be resampled, transformed and filtered endlessly' (Berry 2011, 14).

Learning to code has been identified as one strategy through which to ameliorate this lack of awareness by some. However, 'turning everything into data, and using algorithms to analyse it, changes what it means to know something' (Manovich 2013, 337). Thus, as Manovich (2013) further suggests, it is possible that the reading of code is not as feasible as it is sometimes made out to be. This has profound implications for the practices and understanding of professional practice and learning, which Hoyles et al. (2010) try to

address through the development of what they term ‘techno-literacies’. Similar questions arise also from some recent research on computer algorithms.

Barocas, Hood, and Ziewitz (2013) point to the challenges with all such approaches, given, as they argue, that algorithms are neither stable, nor singular units of study or analysis. In line with the wider social scientific research on software, they argue that ‘algorithms are invoked as powerful entities that govern, judge, sort, regulate, classify, influence, or otherwise discipline the world’ (Barocas, Hood, and Ziewitz 2013, 3), but that it becomes impossible to research their precise work. Algorithms are elusive and almost mysterious; *inscrutable*. The performances of the entanglement of software and data become too complex and dynamic to be ‘read’ or fully understood. The work being done across space and time with different software and datasets can be alluded to, but is itself elusive and mysterious. There is the possibility that these entanglements bring an inherent inscrutability into professional practice, knowledge and learning, with implications, some of which we outline in the next section.

Issues and implications for professional practice and learning

The coding and the linking of data, the applications of technical standards, and the decision-making and reasoning processes articulated through digital analytics mobilise objects and information flows to perform very particular practices. However, for many, it is difficult to determine how and when they are acting, and on what basis. Their reasoning and effects may be transparent for those familiar with coding, but not necessarily for others, including those working with them. In this final section, we identify some specific areas in professional practice and learning where more research is needed and where we urge greater attention from providers of professional education.

Digital analytics often work from simplistic premises: that problems are technical, comprises knowable, measurable parameters, and can be solved through technical calculation. Complexities of ethics, purposes and values, ambiguities and tensions, culture and politics – the politics of knowledge – and even the context in which data are collected are not necessarily part of the calculation. Many warn that the growth and unexamined nature of these sorts of analytics, as they permeate professional practice, is creating a particular form of rationality, and potentially a new epistemological order (Kallinikos 2010; Kitchen 2014) and this needs explicit discussion to try to ensure beneficial effects.

An issue that Barocas, Hood, and Ziewitz (2013) point to is that algorithms ‘embody a profound deference to precedent’. They act on past data to calculate and predict the future. Predictive analytics are used extensively in professional practice, for example, in medical diagnosis, school resource allocations and individual students’ programme planning. These analytics work through identifying past patterns and cycles of anticipation. They can be self-reinforcing and reproductive, augmenting path dependency and entrenching existing practices and inequities. This deference to the past may make anticipation of different futures more challenging.

The decontextualisation of digital analytics also raises issues. In higher education, for example, student retention is being addressed through analysis of a range of predictor variables: part-time work commitments, number of classes enrolled, paper grades and available support from friends and relatives. Students are assigned a dropout prediction score, which is shared with staff who can then monitor student activity and provide

resources to keep them enrolled (Harris 2014). These predictive analytics are also being used for more educative purposes to improve student attainment by, for example, matching teachers and students, reshuffling student work groups and acting like recommender software to suggest resources and classes to individual students. These data are being cross-linked with projected labour skills demands, demographics, aptitude tests and markers of students' online engagement (for example, time spent viewing pages, content highlighted, etc.) to determine students' employment paths and suitable curricula. However, as Laurillard (2012) points out, all of these data have been generated as a decontextualised by-product from a system of past interactions and cannot be applied simplistically to a particular set of questions regarding the future. While lecturers can collaborate with learning analysts to ensure that local data are captured according to issues of most concern to them and to students to improve their own practices, the key is that professionals themselves, who understand the particular complexities of contexts and concerns within their field of expertise, need to still have professional discretion over the use of such analytics.

When the focus is research, Kitchin (2014a) argues that there are a number of challenges associated with researching algorithms: the source code is hidden and black-boxed; algorithms are woven into technical systems that are heterogeneous and embedded; they are not fixed and performative; and they are out of control. Some (Kitchin 2013; Manovich 2013) claim also that the quantitative methods currently taught to undergraduates, such as pre-service professionals and educators, are hopelessly out of date in this new era of big data. Not only are the methods unsuited for enormous, unstructured datasets with unknown properties, but students also do not develop critical awareness of emerging forms and structures of data, and of how software algorithms work in and on professional practice and knowledge. In other words, professional education is not keeping up with the work and potential of digital analytics.

The methodological problems in big data sets are worrying computer scientists partly because the errors they produce become amplified by the sheer volume of data. More importantly, these problems seem to be ignored in the hype surrounding the potential contributions of digital analytics and the political rush to employ them. Tufekci (2014, 1) identifies a series of problems with the found data, such as people's web searches, consumer records and online activity, such as Twitter, that are often used in the analytics:

- (1) Particular platforms and sources are used frequently and disproportionately (e.g. Twitter) to generate datasets without adequate consideration of their structural biases.
- (2) Dependent variables such as hashtags are often used without adequate cautions.
- (3) Big data often aggregates diverse online actions such as click, links, retweets, likes that actually bear different meanings and logics.
- (4) Big data typically captures node to node interactions, often in only one platform, and ignores the context: events affecting interactions, complex intentions and implicit inferences, and the 'wider social ecology of interaction and diffusion'.

Marcus and Davis (2014) add the problem of the 'echo chamber' effect, as the source for big data analysis is often the product of big data, feeding and amplifying error into a vicious cycle. The overriding issue is that digital analytics merge information collected at different times in different ways for different purposes, inevitably obscuring the misfits and muddy puddles that result. However, for Marcus and Davis, the biggest

concern is that, regardless of how many problems the data set embeds, or how meaningless or complex the question that is put to big data, an answer will always be produced, and this answer will always sound persuasively precise. Being able to evaluate the level of precision in digital analytics is a set of practices increasingly necessary for all professionals.

As is evident from the examples offered above, a lot of data accumulation and calculation is automated. This opens new questions about the autonomy of digital analytics and the attribution of responsibility when bad things happen. Legal issues of professional responsibility deferred to algorithms are spectres raised by Barocas, Hood, and Ziewitz (2013). In health care, as Marcus and Davis (2014) argue, new diagnostic technologies and robotics are powerful tools, but must remain supplemental to provision of care. Someone still needs to make a decision. Someone is needed to listen to patients with the nuanced understanding that attunes to complexities, understands human needs and teaches people how to cope. Digital analytics and robots do not tinker, they do not theorise or conjecture, they do not question – and so far, they are not considered conscious, responsible agents.

These questions about professional responsibility to critically and actively engage with digital analytics raise the broader issue of professionalism and accountability. Given the heightened scrutiny given to professional responsibility these days in almost all sectors (Fenwick 2014), this issue would seem to require some educational response. How should we think about professional responsibility and accountability when decisions are delegated to digital analytics? How do we understand the professional as a responsible agent when capability is distributed? What does it mean for professionals to work responsibly with potentially dirty big data sets and reductionist algorithms? We need to reimagine ways for professionals to learn strategies and principles of responsibility in these different and emerging contexts.

This is only one of a range of issues that could be addressed through professional education. Studies showing how and where predictive analytics are being used in professional work, and what benefits as well as problems are emerging could be used as examples and actively debated in professional education. More could be done to encourage new professionals to ask critical questions about powerful data visualisations and the persuasive apparent ‘precision’ of solutions produced by data analytics. What are the algorithms at work, what has been rendered invisible in the categorisations of big data? What data sets are being merged, how are they captured, what are the inherent linkage problems and what are the key ethical issues? To what extent are patterns generated from and applicable to large populations being applied inappropriately to individuals? What criteria or interests are driving the development and uptake of particular analytics? What ambiguities are being erased? What are the affordances and limitations of their uptakes? Addressing such questions is important for professionals, professional educators and researchers.

An additional response to the development of digital analytics is for students in all professions to be encouraged to learn more about coding processes. However, in much professional education, learning to code is neither feasible nor desirable given existing crowded curricula. In these circumstances, it could make more sense for professionals and student professionals to learn to collaborate more effectively with digital designers and analysts than to try to become computer scientists themselves. Most disciplines still remain separate from engaging with computational experts, for all sorts of understandable reasons, including the vast differences in language, purposes and approaches, even as their

practices are increasingly digital. Until professionals learn to collaborate effectively with computer scientists and vice versa, digital analytics may well be designed within the vacuums of technological innovation for its own sake rather than for the complex contexts of professional worlds, with sometimes unfortunate consequences. Furthermore, collaboration with coders helps professionals understand the possibilities as well as limitations of software, algorithms and big data, and perhaps even to grasp more clearly how they might work most effectively as part of the digitised workplace.

Inter-professional practices more generally can be supported through the uptakes of digital analytics. This adds to the requirements in professional education. For instance, new professionals increasingly will need to understand methods and issues of integrating data flow across professional groups and work systems. These new forms of data often require new systems for transferring data between clients, owners and operators. Professionals need to understand the potential points for error or misinterpretation at various interfaces in this data integration, as different forms of data, and different purposes for interpreting it, must be reconciled. Professionals also need to assume accountability themselves for examining these points, in order to better manage data flows and critically examine the issues in meanings, metrics and ethics that arise. In order to do this, professionals who may not ordinarily work directly with data systems need to understand more about data itself and how these systems work, and how to link with other professionals and institutions to integrate practices across professional roles.

In a range of social sciences, the increasing research on digital analytics in daily life and work raise important concerns for those researching professional world and learning that need further exploration empirically and conceptually. For us, as educators, the most critical questions are those raised about what professional knowing and capability is *becoming* through the changes in work practice being enacted through digital analytics, and how education can better support and intervene. There is no doubt that professional work is being transformed fundamentally in many sectors. As we think about the future of professional education, we perhaps need to be considering more rigorously this rather radical question: what capabilities will be needed most in the mix of digital and physical objects, languages, settings and codes that *human* professionals of the future can bring to these emerging knowledge infrastructures? Only at that point can we meaningfully reconsider what may be the most valuable forms, purposes and interventions of professional education.

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