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Beyond description: in search of disciplinary digital capabilities through signature pedagogies

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The development of digital capabilities has received significant attention in higher education (HE) in recent years, with various attempts made to develop digital frameworks to support curriculum design. However, few studies have articulated these generic capabilities in terms of specific disciplines. This paper addresses the gap by exploring how digital capabilities are planned in HE curricula in two professional disciplines, engineering and management, at the two UK universities. Originality of the study is achieved in part through a newly proposed conceptual framework that weaves Shulman's notion of signature pedagogies together with Joint Information Systems Committee (JISC)'s Digital Capability Framework (DigiCap). This study employed a multiple-case study methodology, drawing on documentary sources and academic, professional and student perspectives via interviews and focus groups. This study offers insight into the digital capabilities in engineering and management education, as well as the digital practices of engineers and managers. Findings report on which DigiCap elements are prioritised, and how, in the two professions, followed by a discussion of their most distinct 'signature digital capabilities'. These indicate that the development of digital capabilities is aligned with the respective discipline's signature pedagogies. This study argues that, simply just using a descriptive, typological framework is not sufficient to identify signature digital capabilities of a subject without tending to their disciplinary aspects. It is the combination of a typological DigiCap framework through the lens of signature pedagogies, which can be effective in identifying disciplinary digital capabilities. This approach is one of the major outcomes of this study.

Keywords: digital capabilities; digital literacies; disciplines; signature pedagogies; curriculum design; professional learning; engineering; management; higher education

Introduction

In this paper, digital capabilities are defined as those 'which fit someone for living, learning and working in a digital society' (JISC 2017b). This definition encompasses all areas of life, reflecting our knowledge economy. Digital information and technologies permeate all actions and interactions (Littlejohn, Beetham, and McGill 2012). Universities have a role in advancing disciplinary knowledge and educating

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tomorrow's professionals. Professionals' digital capabilities are linked to disciplinary innovation, economic competitiveness (Orlik 2018), and to social inclusion, citizenship and lifelong learning (Carretero, Vuorikari, and Punie 2018; Mihailidis 2018). Digital skills are required for jobs (Becker, Pasquini, and Zentner 2017; Djumalieva and Sleeman 2018) and for graduates to make a positive contribution to society. Universities therefore have a role in developing digital capabilities of their graduates.

So what are these capabilities? A plethora of digital capability (DigiCap) frameworks and definitions exist (Beetham, McGill, and Littlejohn 2009; Ferrari 2012), including UK/European policies (EC 2016). These focus on generic digital skills for employment and living. However, inherent in generic frameworks is a lack of specificity as to digital capabilities in a given discipline. Few studies have applied or mapped such generic skills in particular subject settings. And when the evidence points to the effectiveness of discipline-based embedded approaches as opposed to generic digital skills development (Beetham, McGill, and Littlejohn 2009), having limited examples of disciplinary digital capabilities is not conducive to curriculum design and review. If universities have a central role in developing professionals' digital capabilities (Payton 2012; Sinclair 2013), then higher education (HE) curriculum teams need to articulate what digital capabilities mean in their disciplinary contexts (Belshaw 2012; Warren 2011) to be able to design them into their course. This gap leads to the overarching research question of this paper: 'How are digital capabilities conceptualised in different disciplines?' and whether the research process designed for this investigation could be used to explore additional disciplines.

For this investigation, two disciplines, engineering and management, were selected. Prior to this study, few published mappings of digital capabilities existed, including English as a second language (John 2014), religious studies (Sinclair 2013) and sustainability education (Brown 2014). Apart from a study (Jupp and Awad 2013) on construction management, no mapping existed for engineering or management, and none offered triangulation of perceptions between academics, students and professionals (see Figure 1). In addition to these aims, this paper concentrates on finding

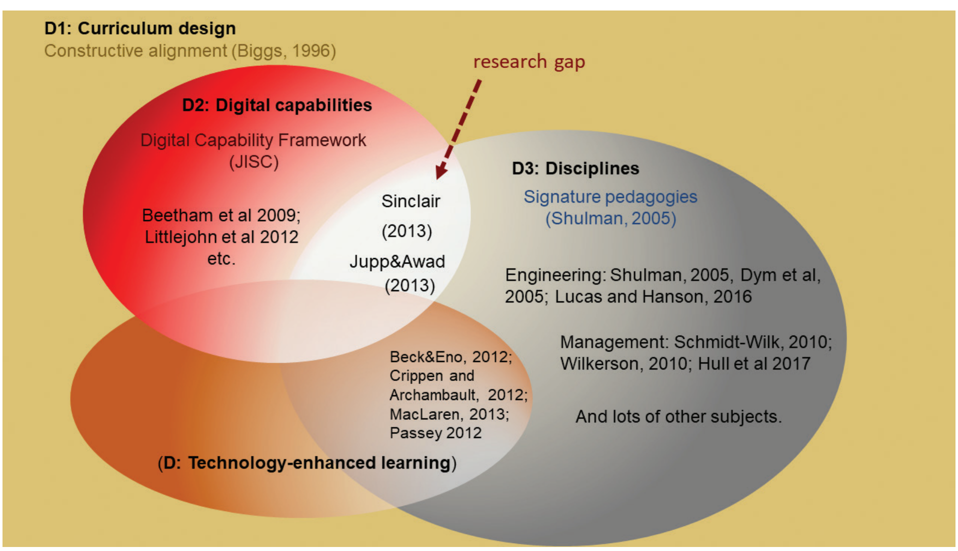

Figure 1. Gap in literature: disciplinary digital capabilities (domain: HE curriculum design).

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a suitable framework and elicitation process for capturing the digital capabilities to benefit educators, educational developers, learning technologists and professional bodies in any disciplinary context. This elicitation process logically needs to involve a conceptual framework which captures digital capabilities.

This proposed framework, detailed in the conceptual framework section, comprises Joint Information Systems Committee (JISC)'s DigiCap Framework (2017a, abbreviated as DigiCap hereafter) combined with the notion of Shulman's signature pedagogies (2005a, 2005b). The research design section presents the data collection instrument, in the form of interview questions, informed by the combined conceptual framework. This study maps the digital capabilities in engineering and management education, as well as the digital practices of engineers and managers. Findings report on which DigiCap elements are prioritised, and how, in the two professions, followed by a discussion of the most distinct 'signature digital capabilities'. This paper argues that, simply just using a descriptive, typological framework (e.g. DigiCap) is not sufficient to identify these signature digital capabilities without tending to their disciplinary aspects. It is the combination of a typological DigiCap framework through the lens of signature pedagogies, which can prove to be effective in identifying disciplinary digital capabilities. This elicitation and co-construction process is one of the main outcomes of this study, in addition to identifying disciplinary digital capabilities in engineering and management, enhancing the plethora of typological frameworks in a way that makes them applicable to any disciplinary context.

Literature review

In policy-level initiatives, there is a tendency to view digital skills as technical skills (Hinrichsen and Coombs 2013), whereas in education, they are seen as situated, social, cultural and disciplinary practices associated with higher forms of knowledge creation, creativity and innovation (Goodfellow 2011; McDougall, Readman, and Wilkinson 2018). However, this latter perception leads to a tension between striving to identify a generic set of capabilities and specific examples in local contexts (Orlik 2018). This poses a problem for studies of digital capabilities.

The scarcity of disciplinary studies of digital capabilities is due to this tension between narrow and broad conceptualisations. Authors over the last decade have established, used, evaluated and adapted generic frameworks of digital competences/capabilities (Coldwell-Neilson 2017; Handley 2018). As part of, or in addition to these, a number of studies have also produced a review of frameworks (Beetham, McGill, and Littlejohn 2009; Ferrari 2012; Janssen *et al.* 2013; Sharpe 2014). The most commonly-used frameworks in education are JISC's DigiCap (2017a) and DigComp – EU's Digital Competence Framework for Citizens (Ferrari 2012).

This study draws on DigiCap, as this framework used most extensively in UK HE (Handley 2018). DigiCap is a typological framework. It characterises different kinds of digital practices of professionals. Its six elements are visualised in an overlapping Venn-diagram: (1) information and communication technologies (ICT) proficiency; (2) information, media and data literacies; (3) digital problem-solving (creation, innovation and scholarship); (4) digital learning and development; (5) digital communication, collaboration and participation; (6) digital identity and wellbeing (JISC 2017a). DigiCap has always been intended to be generic, inviting local interpretation. This co-creation process is seen as important as the resulting definition or the framework itself (Baume 2012; Belshaw 2012; Ilomäki *et al.* 2016), an aspect to be returned to later in the conclusion.

The question remains how this local, disciplinary interpretation can be facilitated. Disciplinary articulations of digital capabilities have been produced at an institutional level (Anagnostopoulou 2013; Oxford Brookes University 2013; University of Bath and JISC 2012) and at professional level, for example adapting DigiCap for health and social care professionals (NHS Health Education England 2017). Studies argue that subject-specific disciplinary tasks using relevant technologies in the curriculum are an effective way to develop digital capabilities (Coldwell-Neilson 2017; Littlejohn, Beetham, and McGill 2012). Despite this recommendation for embedded design, the 2017 Universities and Colleges Information Systems Association (UCISA) survey indicated that only one-fifth of responding universities recognised student achievement in digital capabilities in credit-bearing modules (Fielding *et al.* 2017). Moreover, two-fifth of HE students reported that they felt unprepared for a digital workplace (Newman, Beetham, and Knight 2018). All this points to the need for more work in embedding digital capabilities in HE courses in a subject context.

As mentioned previously, few examples explore digital capabilities in specific subjects. The two most pertinent studies on digital capabilities in a specific discipline concern construction management (Jupp and Awad 2013) and religious studies (Sinclair 2013). They are pertinent because they account for the impact of changing knowledge-practices as a result of technological innovations of their respective fields, and what this means for curriculum design. This paucity of studies inspired this paper to develop a conceptual framework to support curriculum designers in being able to review their curricula from a DigiCap perspective, which is proposed in the next section.

Conceptual framework

The research domain of this paper is curriculum design (Figure 2). It is concerned with preparing HE students to transition to professional practice, drawing on the principle of constructive alignment (Biggs and Tang 2011). This means a scrutiny of

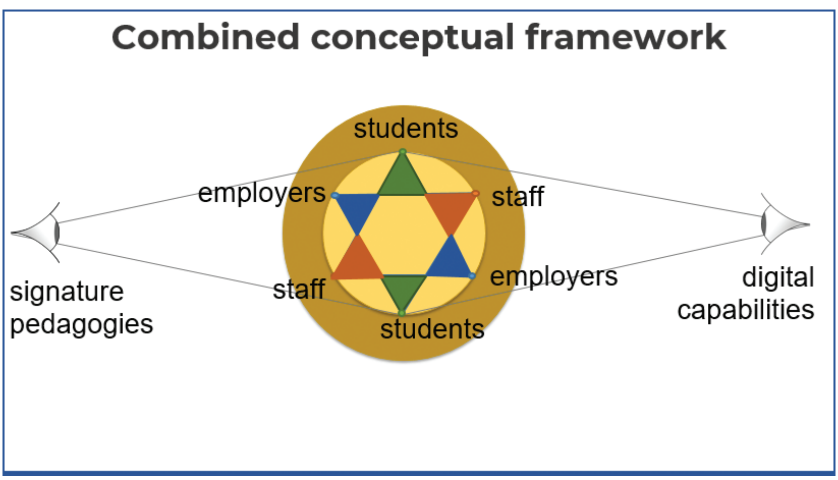

Figure 2. Combined conceptual framework.

learning outcomes, teaching activities and assessment tasks for opportunities when students are developing digital capabilities. The proposed conceptual framework is a combination of JISC's DigiCap and Shulman's (2005b) signature pedagogies. The former helps with exploring digital capabilities, whilst Shulman's notion assists with the disciplinary angle. Both offer a different perspective on curriculum design in applied disciplines. This framework is a novel contribution of this paper; no prior studies had explored digital capabilities through the lens of signature pedagogies.

This study looks for articulations of digital capabilities adopting DigiCap as one lens, in modules' learning outcomes (James and Casidy 2018). DigiCap's six elements are (1) ICT proficiency, concerned with basic digital skills; (2) data and information literacy, the capacity to find, evaluate, manage and share digital information and data; media literacy, the capacity to read critically in a range of digital media; (3) digital problem-solving, or creating, innovating, problem-solving with technologies or developing digital artefacts/materials/practices; (4) digital communication and collaboration, the capacity to communicate and collaborate effectively in a variety of digital media for different purposes and audiences; (5) digital learning/development, the capacity to identify/participate in digital learning opportunities; and (6) digital identity and wellbeing, the capacity to maintain a positive digital identity across platforms; look after one's work-life balance (JISC 2017a). The digital activities undertaken by engineering/management students/professionals were identified in the collected data sources according to these six elements. These capabilities, however, also need to be analysed with regards to disciplinary characteristics. Why are these activities foregrounded over others in engineering or management?

Thus, the other lens offers a disciplinary perspective (Becher and Trowler 2001) through the notion of Shulman's signature pedagogies, 'the types of teaching that organize the fundamental ways in which future practitioners are educated for their new professions' (2005b, p. 52). Shulman's concern with professional education has emerged from the observed gap between the HE curriculum and professional practice (Dotger, Harris, and Hansel 2008). This connection is a key rationale for this paper. Shulman is interested in defining what is distinctive in legal education that develops students' capacity to think like a lawyer. Such 'pervasive, routine, and habitual' (Shulman 2005a, p. 22) examples, for example engineering's design studio, are what he coins as 'signature pedagogies'. He distinguishes three dimensions (Shulman 2005a): *surface structures* are the concrete learning and teaching activities; *deep structures* reflect the set of assumptions on how best knowledge, know-how and skills are imparted; *implicit structures* reflect the values and beliefs of the profession.

A wide range of studies have applied Shulman's notion of signature pedagogies to subjects, including nursing, social work and political science (Chick, Haynie, and Gurung 2012); law (Hyland and Kilcommins 2009); mathematics (Passey 2012) and history (Beck and Eno 2012). The most pertinent work on engineering signature pedagogies detects six elements of 'engineering habits of the mind', including systems thinking, adapting, problem-finding, creative problem-solving, visualising and improving (Lucas and Hanson 2006). However, these do not include references to digital capabilities. Management's signature pedagogies are similarly under-explored: one journal editorial invites readers to consider signature 'habits' (hearts, minds and hands) of management education, noting that integrity (heart) is missing from their curricula (Schmidt-Wilk 2010).

Further, Shulman himself pointed out that signature pedagogies would require constant reviewing due to technological changes (2005a). And indeed, since introducing signature pedagogies, the digital landscape has significantly altered. Technologies non-existent or in their infancy in 2005, such as social media, mobile technologies and cloud computing are now widespread. Despite this, only a limited number of articles concern themselves with the intersecting domains of technology use and signature pedagogies, and none seems to deal specifically with HE students' digital capabilities. The only exception, which links digital literacy and signature pedagogies, is by Bruce and Casey (2012), who identify enquiry-based learning as a 'pedagogical sweet-spot' for developing digital capabilities. Therefore, this study addresses the aforementioned limitations with respect to researching signature pedagogies in engineering and management from a DigiCap angle, updating Shulman's concept of signature pedagogies in a digital context. In addition to the detailed findings of engineering and management's digital capabilities, this study argues that the research process (the proposed conceptual framework) is more important than the findings themselves in that it can produce (and re-produce) itself in future years, as well as being appropriate to be used with other disciplines to arrive at *their* signature digital capabilities. This research process is outlined in the next section.

Research design

Epistemologically, this study draws on pragmatist principles (Dewey 1938), concerned with what provides the best understanding of the inquiry (Creswell 2003). This paper focuses on a sub-set of research questions:

(1) How are digital capabilities conceptualised in modules of two disciplines (engineering and management)?
    (1.1) What digital capabilities are planned by academic staff in intended learning outcomes, teaching and learning activities, and assessment tasks?
    (1.2) What are the digital practices of engineers and managers?
(2) Can the signature digital capabilities of engineering and management be identified? And if yes, what are they?

These research questions, being focused on processes of 'how' and 'what', rather than on quantitative measurements of competencies, lent themselves to a qualitative case study methodology, investigating 'a contemporary phenomenon in depth and within its real-life context' (Yin 2009, p. 18), bounding a *discipline* as the case and a *module* (semester-long unit of UK HE curricula) as the unit of analysis. Two cases were chosen to allow for disciplinary comparisons between applied disciplines. This was for two reasons: first, the concept of signature pedagogies (Shulman 2005) relates to professional disciplines, such as medicine, law and engineering; second, due to the purpose of the research in establishing potential gaps between the HE curriculum and the workplace with respect to students' digital capabilities. For this, 'applied' disciplines (Tight 2015, p. 279) with typical employment trajectories seemed most suitable. Four modules were chosen to enable similarities and differences to be observed within each case. Six modules were from UniA for pragmatic reasons and two from UniB, as it required programmes to map digital capabilities as a graduate attribute. Lancaster University granted ethical approval in April 2017. Data collection took place in June-Nov 2017.

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Each unit of analysis drew on various data collection methods, including documentary analysis, interviews with module leaders (engineering/ENG = 4, management/MAN = 5, total *n* = 9) and professionals (ENGprof = 5, MANprof = 6, total *n* = 11), and student focus groups and interviews (ENGstd = 7 student focus groups; MANstd = 5 student interviews and a focus group, total *n* = 13). Documentary sources included module and programme documents, subject benchmarks (QAA 2015a, 2015b) and professional competency frameworks. Analysis comprised identifying DigiCap elements and signature pedagogies in learning outcomes in programme/module specifications, subject benchmarks and professional frameworks.

The case study's proposition was that disciplines differently prioritise, or even conceptualise, their DigiCap elements in their curricula. Mapping digital capabilities in engineering and management was based on interview questions derived from the combined conceptual framework (DigiCap and signature pedagogies):

(1) Elicit the signature pedagogies of the discipline: 'What are the characteristics of a good X (= discipline) student?' 'What do you think are distinct teaching methods in X?'
(2) Explore the way digital technologies have transformed or disrupted the discipline, for example 'Can you recall any significant digital development that has transformed or disrupted the field of X in recent years?'
(3) Elicit the features of digitally capable professionals: 'Can you describe a digitally capable professional in X?'
(4) Analyse module outcomes, skills, assessments/criteria and learning/teaching tasks using DigiCap with the associated programme outcomes and subject benchmarks, for example 'What tasks or activities have digital aspects in this module/programme?', 'Do the module's/programme's (formative, summative) assessments contain any digital aspects?', 'Any digital artefacts produced?', 'Do the module's/programme's learning outcomes contain or relate to any digital aspects, explicitly/implicitly?'… (see Varga-Atkins (2018), Appendix A for the full set of questions).
(5) Identify emerging/existing signature digital capabilities, for example 'As a result of significant digital developments that have transformed or disrupted your field of X in recent years, what emerging/new digital capabilities do you think your students need to develop?' and 'And why/how might these be important in your field?'

All data were thematically analysed via inductive and deductive coding, which meant a combination of looking for concepts and themes related to my conceptual framework (signature pedagogies and the six DigiCap elements) as well as identifying emerging themes, which were derived from the data in addition to the conceptual framework. Findings were presented of the three perspectives (academics, students and professionals) within each of the six DigiCap elements (see Varga-Atkins 2018 for full findings). Framework analysis (Ritchie 2011) was then used to identify which DigiCap element(s) were foregrounded as expressed in assessment criteria or weighting; this was visually indicated. The more prominent the element was, the darker it was shaded (see Figure 3). Due to lack of space, it is not possible to present the full findings. Rather, the next section will offer a window onto the two disciplines' digital capabilities and practices.

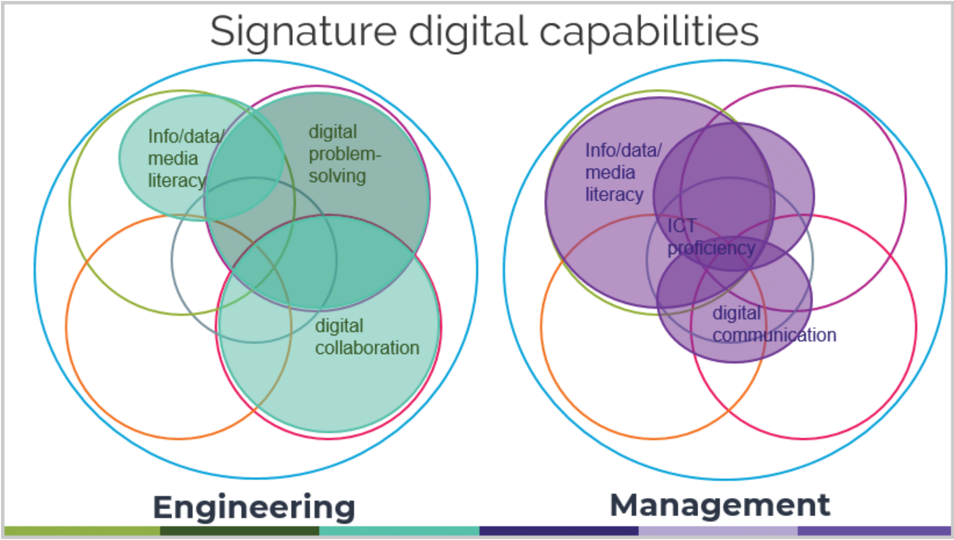

Figure 3. Digital signature capabilities in engineering (left) and management (right).

Findings: digital capabilities

This section presents findings that relate to the overall research question, that is how digital capabilities are conceptualised in curricula and practised by engineers and managers, mapped to the six DigiCap elements, many of which overlap.

Digital capabilities in engineering (Case 1)

The four units of analysis (modules) were as follows. ENGm1 is a third-year module on materials design: student teams 'reverse engineer' a manufactured artefact, for example a hedge trimmer and record their findings in a wiki. ENGm2 is a second-year module on product design: teams write a product specification for a smoothie maker and develop its 3D-CAD design and a design report. ENGm3 is a master's-level engineering management module: students develop a business plan in groups and present their ideas for peer feedback. ENGm4 is a second-year module on product visualisation and simulation techniques: students create/animate a 3D-model of a teaching room. The foregrounded digital capability elements are shown in Figure 4, which include:

(1) ICT proficiency for engineering students includes basic ICT skills, such as using Microsoft (MS) Office as well as digital applications for project and risk management. Students generally seem to lack know-how in presenting and managing data. Engineers use general ICT skills, IT development and project and risk management tools. They use MS Office tools, Adobe suite, OneDrive and SharePoint alongside cloud computing facilities and MS Project for resource allocation. An engineering consultant uses data collection devices and software, for example thermal imaging cameras, vibration sensors, drones, oscilloscopes, etc.

(2a) Data literacy – As engineers need to generate, manage and interpret large amounts of data, developing data literacy as a key capability to develop at the university. This involves tasks with generating, managing and representing data in experiments and simulations. 'I am always surprised about how little [students] have actually

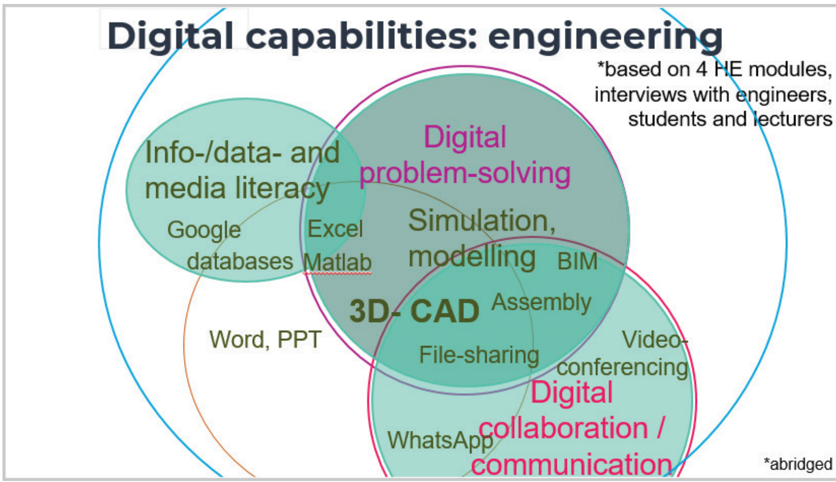

Figure 4. Engineering digital capabilities mapped according to the DigiCap framework.

used the packages, like [MS] Excel, to present data' (ENG1-Thomas). Both risk analysis and quality improvements are areas where engineers draw on large amounts of data and/or use digital tools.

(2b) Info literacy – In engineering education, information literacy comes into focus when engineers need to be aware of the legal and safety requirements as well as the relevant ethical, social, commercial and environmental factors related to the problem they are solving. Students 'have to look at legislation …can you fly a drone anywhere you like?' (ENG2-Mike). Whilst information (and data) literacy appears to be a significant capability in the curriculum, the engineers who interviewed discussed it less frequently.

(2c) Media literacy – Engineers constantly work with 2D/3D images, animations and simulations when problem-solving or collaborating, which is probably why visual literacy is not explicitly articulated in the curriculum or by engineers. Students display a range of media capabilities. Whilst in some cases students might have no 'idea how to lay a poster out to convey the information and what a good poster should look like' (ENG1-Thomas), other assessment tasks or collaborative design projects result in creative digital multimedia outputs.

(3) Digital problem-solving – Sub-disciplines use different kinds of software for problem-solving (Becker, Pasquini, and Zentner 2017), of which skills also overlap with information, data and media literacies. A structural engineer uses REVIT and AutoCAD, and an infrastructure engineer uses WaterCAD, StormCAD and Hevacomp (for simulation and energy analysis and BIM5D modelling). Engineers also use product lifecycle management tools, for example Siemens NX. The approach is to give students a sense of the breadth of industry-standard software to prepare them for professional practice. This means that instead of in-depth training in a specific tool, for example a 3D-CAD package, students are to acquire the scientific principles underpinning the software, future-proofing them against continuous software updates and institutional/company differences.

(4) Digital communication and collaboration – Engineering routinely collaborate in teams, produce and share digital product specifications, presentations, reports, designs and visual artefacts. Digital collaboration capabilities are facilitated by staff, for example setting up institutional tools, whilst allowing collaboration to emerge organically according to the teams' preferences. Students use 'high street-tech, communication software, and it is just so second nature, we don't even deal with it' (ENG2-Mike). Staff feel that what students need guidance on is group working, intercultural skills and professional communication/collaboration practices. Engineers consider various factors when choosing communication methods between teams and customers (face to face, telephone or digital). These include the size and location of the given company and its sites, the perceived formality of the conversation, client and team preferences and intercultural norms. For such synchronous collaborations, Skype, Lync and other platforms, for example See-and-Share, a remote image-sharing software, are used.

(5) Digital learning/development – Students use digital resources (e.g. online resources in the virtual learning environment, YouTube videos, lecture capture, in-class polls, online submission, peer evaluation and note-taking tools). Engineers also use Virtual Learning Environments (VLEs), such as Blackboard, Moodle or Canvas, and online resources for continuing professional development.

(6) Digital identity – Engineering students are more likely to develop a positive professional digital identity in social media via co-/extra-curricular activities. Students may arrive as 'savvy' social media users, but when it comes to professional use, they need academic guidance (Jones *et al.* 2010). Automotive engineering was one exception, due to sponsors being central to engineering development. Most engineers' approach to social media is cautious and critical. LinkedIn was seen as the only professionally acceptable platform: 'if you said you want to meet on Facebook, a senior strategist will probably… no longer take you seriously as they did before' (ENG6prof-Paul).

Digital capabilities in management (Case 2)

The four units of analysis (modules) were as follows. MANm1 is a third-year module on e-business: students develop an e-business strategy for a real client. MANm2 is a masters-level risk management module: students complete an online simulation game, arranging a relief effort for a hurricane-hit village applying risk theories learnt. MANm3 is a first-year market research module: groups produce a market research report and present to their real client. MANm4 is a third-year corporate communications module: students evaluate the communications of a public-sector or non-profit-making organisation and deliver their findings (Figure 5).

(1) ICT proficiency for management students involves mainly on MS Office packages. Students are influenced by academics (Beetham, McGill, and Littlejohn 2009; Jones *et al.* 2010) in their technology adoption: one student on placement used Slack to keep in touch, as prompted by their lecturer. Managers use chiefly MS Office tools, with some variation of using additional tools. Office365 for collaborative working was not yet widespread at the time of interviews. Organisational practices are the main influencers of managers' technology choice.

(2a) Data literacy involves collecting and critically analysing data for problem-solving and interpretation. Whether it is analysing market research data, organisational budgets or calculating risk probability, students need to draw on qualitative and quantitative data methods. Both students and academics perceive students to lack the ability of using spreadsheets. Managers work with data and information similarly, for example with business intelligence tools or data mining software to identify

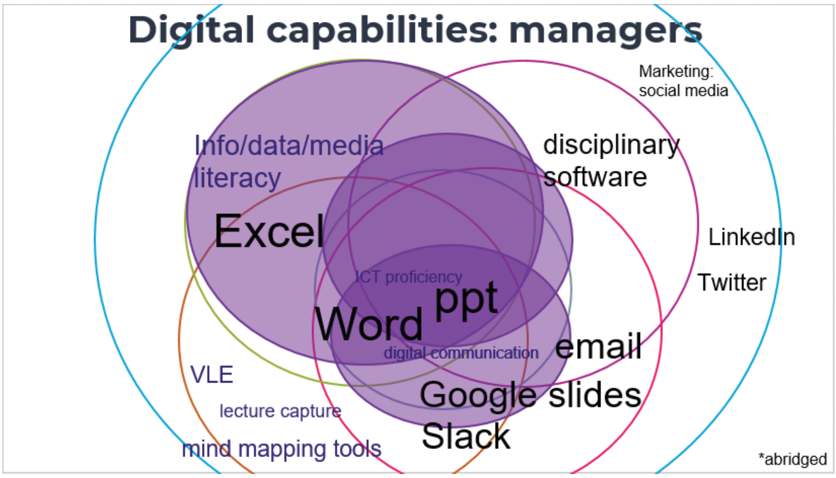

Figure 5. Management digital capabilities mapped according to the DigiCap framework.

customer behaviour trends. One manager's company generates their own market research, which is faster, better than buying off-the-shelf market intelligence: 'If we're looking at a medical product, we will go and talk to the clinicians who are leaders in their field'.

(2b) Information literacy in management involves the resourceful collection of primary or secondary data from a wide range of sources (academic, case based or online). It includes critical analysis and interpretation for the purpose of decision-making to relevant stakeholders. This features in a number of UniA' graduate attributes for management students under the labels of 'self-guided research', critical 'analytical skills', 'commercial awareness' and 'international awareness'. Academics and librarians play a large part in educating students: 'If the university hadn't told us "Oh, go use Mintel," I probably would have just gone on Google' (MANstd-Lidia).

(2c) Media literacy in management overlaps with digital communication and information/data literacy insofar as this element refers to students' ability to communicate content effectively, verbally or in writing. Management students' media literacy tends to be limited to creating presentations or documents with diagrams and charts. This is confirmed by a similar finding that 63% of students have minimal/no training in multimedia production (Becker, Pasquini, and Zentner 2017). The critical evaluation aspect of media literacy seems well covered in disciplinary tasks.

(3) Digital problem-solving in management tends to involve working with information and data in digital form, for example whether students are given a real-life challenge to find out about a particular market or if invent business solutions for an organisation. Their problem-solving skills equate with their ability to source requisite, reliable information. As for managers' digital problem-solving practices: (1) the higher they are on the managerial ladder, the less likely they are to use subject-specific software; (2) their disciplinary background and their company's practices appear to be the two main factors of technology choice; (3) the degree of digitisation changes from company to company, and, in turn, this impacts managers' digital practices too.

(4) Digital collaboration/communication is less prominent in management than engineering. Even in group tasks, marks tend to be moderated to reflect individual achievement, although ‘working productively as part of a team’ is clearly important. Some academics recommend institutional communication tools. Most module leaders let students make their own choices, with groups opting for WhatsApp, DropBox, Google Docs, etc. Students consider speed, visibility, reaction time, platform dependency and access when it comes to choosing communication tools. Managers typically use email, web-conferencing systems (e.g. Skype, WebEx, etc.) or other tools (e.g. Lync or Yammer) to connect with clients and colleagues. Employees in larger companies collaborate via institutional tools, for example SharePoint and OneDrive. Rebecca, a self-employed co-owner of a marketing company, communicates with clients via social media, such as Facebook, Instagram, Twitter and LinkedIn. When choosing collaborative tools, managers are influenced by client preferences and skills, company size, software availability/price and intercultural considerations. University education, therefore, needs to prepare students, so they can carefully consider their technology choices in different contexts (Remneland-Wikhamn 2017).

(5) Digital learning/development of management students is similar: they use digital resources (VLE and captured lectures) and digital tools for reading, annotating, note taking, etc. Digital tools enable reflection. UniB’s smartphone SkillsApp, for instance, is aimed at supporting their management students’ confidence. Reflection strengthens the relationship between their DigiCap, confidence and self-efficacy (Becker, Pasquini, and Zentner 2017). Managers similarly partake in online tutorials and courses run by their organisation.

(6) Digital identity in management education is addressed from an employability angle. Academics and career advisors educate students about how companies look at their digital footprint, or how students can develop a positive online identity on LinkedIn, the most significant professional platform for management students and managers. Broadly speaking, management students are present on digital platforms, for example Facebook, Instagram and Snapchat, though on the whole, they also seem to be cautious social-media users. They tend to separate their social media profiles and keep to private spaces for learning (Beetham, McGill, and Littlejohn 2009). Students are aware that being able to positively manage their online identity can ‘make you more employable’ (MANstd-Reem). Managers make careful decisions regarding the digital platforms they use as an individual or a company, which depend on their company type and their disciplinary area. Using social media can be inappropriate due to client confidentiality or fear of losing competitive edge if broadcasting innovations in progress.

In summary, aforementioned findings so far explored three perspectives, curricular, student and professional, of DigiCap practices in engineering and management. In engineering, digital problem-solving and collaboration, followed by data/information literacy, appear to be the most important capabilities. In management, data/information literacy, overlapping with problem-solving, and digital communication form this discipline’s most characteristic capabilities. Next, the discussion demonstrates that these digital capabilities are not accidental but strongly align with the discipline’s signature pedagogies.

Discussion: signature digital capabilities (Cases 1 and 2)

This section focuses on the detected patterns and associations (Ritchie 2011) between the discipline’s signature pedagogies and its prioritised digital capabilities, referred to

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as 'signature digital capabilities'. In this sense, the signature digital capabilities identified later also evidence that the concept of signature pedagogies needs to be constantly updated in response to an ever-changing digital context, as Shulman himself suggested (2005b).

Based on this study's findings, engineers' values and attributes are summarised as collaborative problem-solvers who are resilient, creative and act with integrity (Figure 6). Engineers, working in teams, apply science and mathematics to real-world and to open-ended problems, whether economic, social, environmental, and at global or local level. Dym *et al.* (2005) identify design thinking and project-based learning as two signature pedagogies in engineering. Another signature pedagogy is that students are 'thrown into teamwork from day 1' (ENG1-Thomas). Although some of these feature in other disciplines, the combination of long-term, team-based, open-ended projects is a 'mode of teaching …that I don't think you see anywhere else in the university' (ENG2-Mike). Engineering's overarching signature pedagogy is Conceive–Design–Implement–Operate (CDIO); it is a worldwide educational framework which sets engineering fundamentals in the context of real-world systems and products (Crawley *et al.* 2014).

Management's signature pedagogies are summarised starting with the implicit values and attributes of a good manager (Figure 6). These are adaptability, resilience, dynamism, cultural/commercial awareness and good networking, with the focus being on individual achievement. The deep structure of management seems to be a combination of three aspects: developing students' understanding of the link between management theory and application, their commercial and strategic awareness and a mix of subject-specific and generic/transferable skills. Despite the fact that management is an umbrella term for distinct sub-disciplines, Collect–Analyse–Interpret–Communicate (CAIC) emerged as one of its overarching signature pedagogy (discussed later).

This study set out to explore how the six DigiCap elements are conceptualised in two subjects, with the expectation that certain elements might be more prominent than others, and in different ways. Findings suggest that disciplinary digital practices

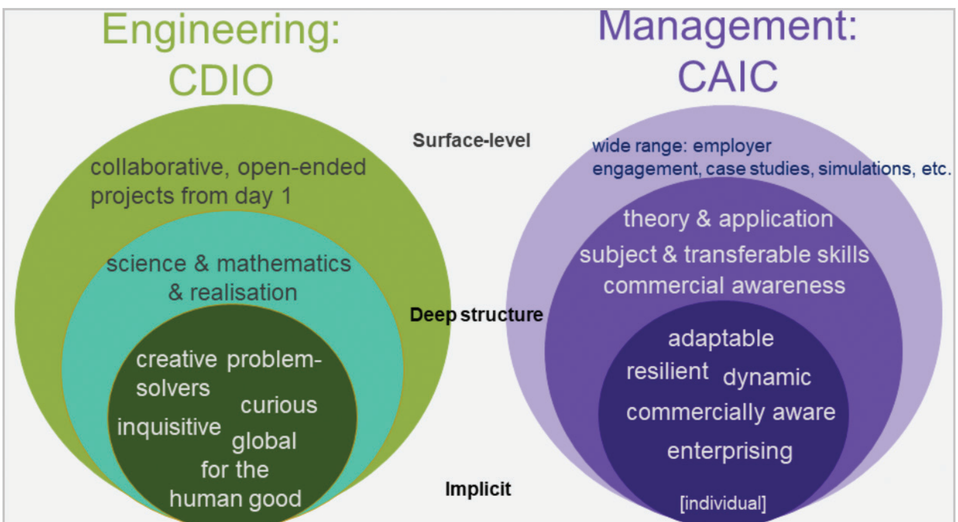

Figure 6. Signature pedagogies of engineering and management.

align with their signature pedagogies. Engineers are collaborative problem-solvers, drawing on scientific and mathematical knowledge (Figure 6). Accordingly, collaboration, problem-solving and information/data literacy are its most typical capability elements. In contrast, managers analyse/interpret information/data for communication and decision-making; this tends to be an individual endeavour. Digitally capable managers concentrate on information/data literacy, digital problem-solving and communication (Figure 6).

Four of these distinct digital practices, or 'signature digital capabilities', are discussed in the next section: in engineering, simulation and modelling (1) and open-ended collaborative design projects (2), and in management, digitally mediated Collect-Analyse-Interpret-Communicate (CAIC) (3) and using technologies to connect theory to practice (4).

Engineering

(1) Simulation and modelling have emerged as digital signature pedagogies in engineering, demonstrating the transformative impact of technology on disciplinary practices (Warren 2011). Participants emphasised the shifting skill-set from hand-sketching and physical manufacturing to 3D-CAD modelling, simulation as transformational. Engineers used to build physical prototypes in laboratories to test them under real conditions. Today's engineering students are not 'in a workshop using machinery' (ENG1-Thomas), but sitting at computers using highly specialised industry-standard simulation software, applying forces to things to 'predict what's going to happen in the real world when you get components' (ENG8prof-Jack). Students learn how to model and test in 3D, use virtual reality, visualisation and simulation tools, for example Photoshop, CorelDraw Fluent, Pro/Mechanica, Dyna3D, Cobra, Moldflow and 3DS Max. At the same time, they also acquire the underpinning scientific principles, materials and operations. Epistemologically, the virtual 3D-model becomes the 'master-model', from which all the analyses derive: 'If you looked at the 3D-model of our car, you probably would be quite stunned at the level of detail on it. They have wires, nuts, bolts, everything' (ENG4-Dylan). Although the 'engineering habits of the mind', systems thinking, adapting, problem-finding, creative problem-solving, visualising and improving (Lucas and Hanson 2006), are still valid labels for the type of work that engineers do, the nature of this work as a result of these technological possibilities does require quite different digital capabilities than Lucas' and Hanson's engineers in 2006. In fact, much of the mind-work happens in a digital flow.

(2) Open-ended collaborative design projects from day 1 are signatures to engineering, for example from designing slot cars to humanitarian drones. Relating this to DigiCap, HE needs to prepare students to be self-reliant and confident when using unfamiliar technologies. 'Collaborative' refers to the fact that many of these complex, open challenges are the result of a team effort. Aforementioned findings have shown the many ways digital collaboration is intrinsic to engineering practice. Academics facilitate the development of such collaborative skills in a digital context either by providing institutional technologies for collaboration, modelling ways of collaboration or letting the student groups choose collaboration tools according to their preferences. A typical 'signature' picture would show a team of engineering students huddled around a screen discussing their design components. Both of the

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aforementioned identified signature digital capabilities offer a vivid picture of current engineering practice, which would not have been gained by with just one of the lenses (signature pedagogies and digital capabilities) before.

Management

(3) Digitally mediated Collect-Analyse-Interpret-Communicate (CAIC), emerged as management's overarching signature DigiCap, suggested by MAN1-Sam. Identifying this is one contribution of this study. This pedagogical approach is succinctly illustrated by one programme learning outcome, to 'use IT tools and digital media effectively, efficiently and flexibly for the purposes of information gathering, collation and analysis, with appropriate adaptation for the nature of the problem-solving task under consideration'. Digital skills are required in all its stages. In the module explored, in the Collect stage, students work on searching academic and other literature related to companies' e-business strategies (using numeric/textual data, information, diagrams, etc.). In the Analysis phase, students critically analyse their data, developing their information, data and media literacy. In the Interpret phase, students identify solutions related to an e-business strategy by deploying their critical analysis. In the Communication phase, students report their business strategy, integrating diagrams and charts. The digital capabilities inherent in CAIC are also characteristics in inquiry-based learning. Indeed, Bruce and Casey (2012) describe critical inquiry as a 'pedagogical sweet-spot' for developing digital literacy (p. 192). They also confirm this study's finding that extending students' skills to creative production using multimedia would enhance and expand their practice of inquiry and critical analysis (Bruce and Casey 2012). Whilst information and data literacy are pervasive in any discipline in terms of digital capabilities, what the concept of signature pedagogies lens has augmented here is to illustrate how management practice uses evidence-based decision making, and so, how these processes are underpinned by digital tools and techniques. The DigiCap framework on its own would be descriptive, devoid of capabilities situated in disciplinary practices.

(4) Connecting theory to practice has been identified as another 'habit of the mind' (Shulman 2005a) that supports students' development into management. Computerised simulation games are being used as signature pedagogies to help students connect management theory with practice. In MANm2's assessed online simulation game, each student manages a relief effort for a village hit by a hurricane within a limited budget and a finite amount of time by working with the village chief and other stakeholders. Whilst Remneland-Wikhamn critiques university management education in relation to the limited opportunities it offers students to enact management practice (2017), virtual simulation appears to be a perfect vehicle for addressing this critique.

Summary

The aforementioned digital signature capabilities are completely new as compared with education practice at the time when Shulman coined 'signature pedagogies' (Shulman 2005b). Their identification within the level of discipline, in engineering and management, is one achievement of this study. This study does have limitations with respect to the restricted range of sub-disciplines, university programmes, sectors and work contexts explored, since digital resources and infrastructure vary, even from one organisation to another. Zooming out to a theoretical level, these findings also confirm the view that the concept of signature pedagogies needs to be revisited regularly (Lucas and Hanson 2016) by taking into account disciplinary innovations and technological changes.

Conclusion: the research process as outcome

This study's overarching research question was 'How are digital capabilities conceptualised in two different disciplines, in engineering and management?' Findings through detailed mapping and analysis of interviews, documentary sources and focus groups highlighted the distinct ways in which the six DigiCap elements manifest in engineering and management, in alignment with the professions' signature pedagogies. Digital signature capabilities were also presented for engineering and management, including a number of implications for curriculum designers (Varga-Atkins 2018). This study appears to be the first to identify an overarching signature pedagogy for management, CAIC, which has not been achieved before, apart from accounting (Wilkerson 2010).

The research process, namely the conceptual framework combining DigiCap with the notion of signature pedagogies (Shulman 2005b), is an another, novel outcome of this study, as presented in the research design section. Using just a generic DigiCap framework would have yielded a mere descriptive account of disciplinary practices. However, the proposed interview process, eliciting signature pedagogies, enabled to demonstrate why and how certain digital capabilities were foregrounded in professional practice in two subjects. This approach can also then transgress this case study being limited to selected modules, sub-disciplines and two university environments, by offering an insightful and effective process of co-construction to any disciplinary experts to articulate the distinctness of *their* digital capabilities in *their* context. Finally, given that many innovations are interdisciplinary arising from collaborations between different fields (Shulman 2005b; Tsatsou 2017), further research could explore signature digital capabilities in interdisciplinary contexts.

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