Disciplinary digital capabilities of professionals: networked learning in engineering and management

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Abstract

This paper is concerned with the digital practices of professionals, and the ways in which educators can support higher education (HE) students with successfully transitioning into professional life by developing relevant digital capabilities according to their disciplines. Digital capabilities have received significant attention in recent years, with various attempts made to develop digital frameworks to support curriculum design in HE. However, few studies have articulated these generic capabilities in terms of specific disciplines. This paper addresses the gap of disciplinary conceptualisations of digital capabilities by exploring how they are planned in HE curricula in two professional disciplines, engineering and management. Originality of the study is achieved in part through a conceptual framework that weaves together Shulman's notion of signature pedagogies with JISC's Digital Capability Framework (DigiCap). The study employed a multiple-case study methodology with each discipline as a case, and four undergraduate/postgraduate modules as the units of analysis, drawing on documentary sources, and academic, professional and student perspectives via interviews and focus groups. The research design section presents a practical manifestation of this conceptual framework in the form interview questions, which is one main outcome of this study. The 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 digital capability 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. In engineering, digital problem-solving and collaboration/communication, followed by data and information literacy, appear to be most prominent. In management, data and information literacy overlap with problem-solving, and, together with digital content communication, form its prominent digital capabilities. The study also identifies management's overarching signature digital capability. The paper argues that simply just using a descriptive, typological framework (e.g. DigiCap) is not sufficient to identify signature digital capabilities of a subject without tending to their disciplinary aspects. It is the combination of a typological digital capability framework through the lens of signature pedagogies, which can be effective in identifying disciplinary digital capabilities.

Keywords

Digital capabilities, digital literacies, disciplines, signature pedagogies, curriculum design, professionals, engineering, management, networked learning.

Introduction

This paper is concerned with the digital practices of professionals, and the ways in which educators can support higher education students with successfully transitioning into professional life by developing relevant digital capabilities according to their disciplines. For the purpose of this paper, this transitioning process of learning is viewed as joining a particular, disciplinary, networked learning community. Current views of networked learning (Dohn et al., 2018) emphasise the different nature of connections that facilitate learning, whether it is between learners-learners, learners-tutors, or 'learners between situations and from their re-situated use of knowledge across contexts' (Dohn, 2014). All these connections are permeated with digital actions and interactions (Littlejohn et al., 2012).

Therefore, if universities have a role in advancing disciplinary knowledge and educating tomorrow's professionals, the above mentioned digital nature of professional networked learning necessitates that they pay attention to developing digital capabilities of their graduates. In turn, professionals' digital capabilities are linked to disciplinary innovation, economic competitiveness (Orlik, 2018), and to social inclusion, citizenship and lifelong learning (Carretero et al., 2018; Mihailidis, 2018). Digital skills are required for jobs (Becker, Pasquini, & Zentner, 2017) and for graduates to make a positive contribution to society.

The focus of this paper is exploring the nature of disciplinary digital capabilities which enable graduates to transition from education to networked learning communities of their profession. Digital capabilities are defined as those 'which fit someone for living, learning and working in a digital society' (JISC, 2017c). A plethora of digital capability frameworks and definitions exist (Beetham, McGill, & 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, & 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?" In particular, it focuses on digital capabilities which foreground connections between human and digitally mediated interactions.

For this investigation, two disciplines, engineering and management, were selected. Prior to this study, few 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. In addition to these aims, this paper concentrates on finding a suitable framework and process for capturing the digital capabilities to benefit educators, educational developers, learning technologists and professional bodies in any disciplinary context.

This proposed conceptual framework comprises JISC's Digital Capability Framework (2017b, abbreviated as DigiCap hereafter) combined with the notion of Shulman's signature pedagogies (2005a,b,c). As one main outcome of this study, the research design section presents this framework in the form interview questions. The study maps the digital capabilities in engineering and management education, as well as the digital practices of engineers and managers, foregrounding especially those elements of the framework, which are related to networked learning (i.e. digital problem-solving, communication/collaboration, learning and development). Findings report on and discuss which digital capability elements are prioritised, and how, in the two professions. The paper highlights that networked learning in disciplinary contexts displays different characteristics, and so, 'signature digital capabilities'. It also argues that the identification of these signature digital capabilities would not have been possible without tending to their disciplinary character through the lens of signature pedagogies.

Literature review

In policy-level initiatives there is a tendency to view digital skills as technical skills (Hinrichsen & 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 et al., 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 are 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 et al., 2009; Ferrari, 2012; Janssen et al., 2013; Sharpe, 2014). The most commonly-used frameworks are JISC’s Digital Capability Framework (DigiCap) (2017b) and DigComp, EU's Digital Competence Framework for Citizens (Ferrari, 2012).

This study draws on DigiCap, a framework used most extensively in UK HE (Handley, 2018). DigiCap is a typological framework, which groups the kinds of digital practices of professionals into six overlapping elements: 1) 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; and 6) digital identity and wellbeing (JISC, 2017b). All these elements relate to networked learning in emphasising connections, whether between human or non-human 'actants' (such as digital resources or technologies) (Dohn et al., 2018). For instance, digital collaboration (5) refers to professionals/students collaborating with each other in digitally mediated ways, or digital problem-solving (6) refers to connections between contexts and 're-situated use of knowledge across contexts' (Dohn, 2014) , e.g. professionals using digital technologies to problem-solve. Similarly, professionals exercising their information/data/media literacy (2) are making connections between digital resources and their own understanding to support their decision-making. Whilst other professionals undertake digital learning and development activities (5) are drawing on their network of other people and other (de Laat & Dohn, 2019).

Returning back to DigiCap as a framework, it has always been intended to be generic, invite local interpretation, with this co-creation process being seen as important as the resulting definition or the framework itself (Baume, 2012; Belshaw, 2012; Ilomäki et al., 2016). Disciplinary articulations of digital capabilities have been produced at institutional (Oxford Brookes University, 2013; Anagnostopoulou, 2013) and at professional levels, e.g. adapting DigiCap for health & social care professionals (NHS Health 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 et al., 2012). Despite this recommendation for embedded design, the 2017 UCISA survey indicated that only a 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, & Knight, 2018).

All this points to the need for more work in HE in embedding digital capabilities into subject contexts. That said, few examples explore disciplinary digital capabilities apart from construction management (Jupp & Awad, 2013) and religious studies (Sinclair, 2013). These studies are pertinent because they account for the impact of changing knowledge-practices of their respective fields as a result of technological innovations, 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 digital capability perspective.

Conceptual framework

This study is concerned with preparing HE students to transition to professional practice, making comparisons between the digital practices of professionals with those being developed within the curricula of students of the same discipline. The proposed conceptual framework is a combination of JISC's Digital Capabilities Framework (DigiCap) and Shulman's (2005b) signature pedagogies. The former helps with exploring digital capabilities (and so networked learning), whilst Shulman's notion assists with the disciplinary angle. Both offer a different perspective on curriculum design in applied disciplines. This framework is novel in that no prior studies had explored digital capabilities through the lens of signature pedagogies.

My study looks for articulations of digital capabilities adopting DigiCap as one lens, in modules' learning outcomes (James & 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; and look after one's work-life balance (JISC, 2017b).

The other lens offers a disciplinary perspective (Becher & 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" (2005, p.52). Shulman's concern with professional education has emerged from the observed gap between the HE curriculum and professional practice (Dotger, Harris, & 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, e.g. engineering's design studio are what he coins '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; while implicit structures reflect the values and beliefs underpinning the profession.

A wide range of studies have applied Shulman's notion of signature pedagogies to subjects including nursing, social work, political science (Chick et al., 2012); law (Hyland & Kilcommins, 2009); mathematics (Passey, 2012); history (Beck & 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). Management's signature pedagogies are 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 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 students' digital capabilities. The only study, 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. Thus, beyond the findings of engineering and management's capabilities, this paper argues that the emerging research process based on the conceptual framework is appropriate to be used with other disciplines.

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 signature digital capabilities of engineering and management be identified? And if yes, what are they?

These research questions 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. 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 requires programmes to map digital literacy as a graduate attribute. The criteria for choosing these modules were that they should include some digital activity and also preferably some employer engagement, although this latter one was not possible in each case. Lancaster University granted ethical approval for the study in April 2017.

Each unit of analysis drew on various data collection methods, including documentary analysis, interviews with module leaders (engineering/ENG=4, management/MAN=5) and professionals (ENGprof=5, MANprof=6), student focus groups & interviews (ENGstd: 7 student focus groups; MANstd: 5 student interviews +1 focus group). Documentary sources included module and programme documents, subject benchmarks (QAA, 2015b, 2015a); and professional competency frameworks. Analysis comprised identifying DigiCap elements in learning outcomes, teaching activities, assessment tasks, subject benchmarks and professional frameworks.

The case study's proposition was that disciplines differently prioritise, or even conceptualise, their digital capability 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, e.g. 'Can you recall any significant digital development that has transformed or disrupted the field of X in recent years?'
3 Elicit 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, e.g. '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 for the full set of questions]
5 Identify emerging/existing signature digital capabilities, e.g. '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 why/how might these be important in your field?

Data were thematically analysed via inductive and deductive coding. Findings were presented of the three perspectives (academics/students/professionals) within each of the six DigiCap elements. Framework analysis (Ritchie, 2011) was used to identify which digital capability element(s) were foregrounded, e.g. expressed in assessment criteria or weighting. Lacking space to present the full findings (see Varga-Atkins, 2018), the next section offers a window onto networked learning in two disciplinary contexts, in work and in education.

Findings

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

Case 1: Engineering

The four units of analysis (modules) were: ENGm1, a third-year module on materials design: student teams 'reverse engineer' a manufactured artefact, e.g. 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, 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.

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 and Adobe suite, OneDrive and SharePoint alongside cloud computing facilities and MS Project for resource allocation. An engineering consultant uses data collection devices and software, e.g. thermal imaging cameras, vibration sensors, drones, oscilloscopes, etc.

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

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 relating 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 interviewed discussed it less frequently.

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 et al., 2017). A structural engineer, uses REVIT and AutoCAD, an infrastructure engineer uses WaterCAD, StormCAD, Hevacomp (for simuation and energy analysis) and BIM 5D (for modelling). Engineers also use product lifecycle management tools, e.g. SiemensNX. 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, e.g. 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, e.g. 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, e.g. See-and-Share, a remote image-sharing software is 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 VLEs and online resources for continuing professional development.

6. Digital identity - Engineering students may arrive as 'savvy' social media users, but when it comes to professional use, they need academic guidance (Jones et al., 2010). Most engineers' approach to social media is cautious and critical. LinkedIn was seen as the only 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).

These findings offer a glimpse into engineers' networked learning practices, mirrored in formal HE settings.

Case 2: Management

The four units of analysis (modules) were: MANm1 is a third-year module: 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 module: groups produce and present a market research report to their real client. MANm4 is a final year module: students evaluate the communications of a public/non-profit-making organisation.

1. ICT proficiency for management students involves mainly MS Office packages. Students are influenced by academics (Beetham, McGill, & 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.

2. 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. Managers work with data similarly, e.g. with business intelligence tools or data mining software to identify customer behaviour trends. One manager's company generates their own market research, which is faster 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".

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).

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 et al., 2017). The critical 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, e.g. whether students are given a real-life challenge to find out about a particular market or 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; and (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" are 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), or other

tools (e.g. Lync or Yammer) to connect with clients and colleagues. Employees in larger companies collaborate via institutional tools, e.g. SharePoint and OneDrive. Rebecca, a self-employed co-owner of a marketing company, communicates with clients via social media: 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 of management students is similar: they use digital resources (VLE, captured lectures) and digital tools for reading, annotating and note-taking. UniB's smartphone SkillsApp is aimed at strengthening the relationship between their digital capability, confidence and self-efficacy via reflection (Becker et al., 2017). Managers similarly partake in online tutorials and courses run by their organisation.

6. Digital identity is addressed by academics and career advisors educating management students that being able to positively manage their online identity can "make you more employable" (MANstd-Reem). Broadly speaking, management students are present on digital platforms, e.g. Facebook, Instagram and Snapchat, though they tend to keep to private social media spaces for learning (Beetham, McGill, & Littlejohn, 2009). Managers make careful decisions regarding the digital platforms they use, depending on their company type and discipline. LinkedIn is the most significant professional platform both for management students and managers.

Findings show that in engineering, digital problem-solving and collaboration, followed by data/information literacy, seem to be the most key capabilities. In management, data/information literacy, overlapping with problem-solving, and, together with digital content communication, form this discipline's most characteristic capabilities. These emphases are not accidental, but strongly align with the discipline's signature pedagogies.

Discussion: signature digital capabilities

This study set out to explore the nature of disciplinary digital capabilities which enable engineering and management students to transition from education to networked learning communities of their profession, with the expectation that certain capabilities might be more prominent than others. Detected patterns and associations (Ritchie 2011) suggest that disciplinary digital practices align with their signature pedagogies, referred to as 'signature digital capabilities'. These also signal that networked learning varies in different subject contexts.

Engineers' values and attributes are summarised as collaborative problem-solvers who are resilient, creative, and act with integrity. Engineers apply science and mathematics to real-world, open-ended problems in teams, whether economic, social, environmental, or local/global. Dym et al. (2005) identify design thinking and project-based learning as two signature pedagogies in engineering. Another signature pedagogy gets students "thrown into teamwork from day 1" (ENG1-Thomas). 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); a worldwide educational framework which sets engineering fundamentals in the context of real-world systems and products (Crawley et al., 2014). Accordingly, collaboration, problem-solving and information/data literacy are engineering's most typical digital capability elements.

In contrast, managers analyse/interpret information/data for communication and decision-making. The implicit values and attributes of a good manager 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 a) developing students' understanding of the link between management theory and application, b) their commercial and strategic awareness, and c) a mix of subject-specific and transferable skills. Despite the fact that management is an umbrella term for distinct sub-disciplines, CAIC (Collect-Analyse-Interpret-Communicate) emerged as one of its overarching signature pedagogy (discussed below). Aligned with these disciplinary traits, digitally-capable managers concentrate on information/data literacy, digital problem-solving and communication.

Below, four of these distinct digital practices, or 'signature digital capabilities', are discussed. Simulation and modelling (1); and open-ended collaborative design projects (2) in engineering; and in management, digitally-mediated CAIC (3) and using technologies to connect theory to practice (4).

1) Simulation and modelling have emerged as 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 e.g. 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).

2) Open-ended collaborative design projects from day 1 are signature to engineering, e.g. from designing slot cars to humanitarian drones. Relating this to digital capability, 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. Findings above 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 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.

3) Digitally-mediated CAIC (Collect-Analyse-Interpret-Communicate) emerged as management’s overarching signature digital capability, by MAN1-Sam. It is “us[ing] 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” (programme outcome). Digital skills are required in all its stages of this module task: (Collect) students work on searching academic and other literature relating to companies’ e-business strategies (using numeric/textual data, information, diagrams, etc.); (Analyse), students critically analyse their data, developing their information, data and media literacy; (Interpret) students identify solutions relating to an e-business strategy through critical analysis; (Communicate), students report their business strategy, integrating diagrams and charts. Identifying this is one contribution of this study.

4) Connecting theory to practice has been identified as another signature pedagogy in management. With respect to signature digital capabilities, technologies, e.g. simulation game or schema-building in spreadsheets, can help students acquire managers’ “habits of the mind” (Shulman, 2005a). 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. While 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.

Conclusion

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 digital capability elements manifest in engineering and management, in alignment with the professions’ signature pedagogies. Digital signature capabilities of engineering and management were also identified.

Implications for teaching practice involves suggesting potentially effective ways of supporting students' transition into professional life in a networked learning context. These include: 1) preparing graduates for being able to problem-solve in different digital contexts, employing their resourcefulness and self-efficacy; 2) immersing students in authentic digital settings and resources; 3) developing students' critical stance on technology use and technology choice; 4) giving students a sense of the breadth of industry-standard software, instead of in-depth training in specific tools, future-proofing them against continuous software updates and institutional/company differences; and, 5) focusing on academic guidance for students' technology use with respect to teamwork, intercultural and professional collaborative practices and preferences.

The theoretical implication of this study is its conceptual framework, which combines DigiCap with the notion of signature pedagogies (Shulman, 2005b). This combined conceptual framework proved insightful and effective for disciplinary mapping of digital capabilities and networked learning in a professional context, as demonstrated by the interview process. The study shows limitations with respect to the range of sub-disciplines, sectors explored, since digital resources and infrastructure vary, even from one organisation to another. Finally, given that many innovations are interdisciplinary arising from collaborations between different fields (Tsatsou, 2017), further research could explore signature digital capabilities in such interdisciplinary contexts.

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