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Teaching and Learning for the Next Era of Digital Innovation

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In a nutshell, what is your research about?

This research is about teaching and learning for the next era of digital innovation. It explores the challenges and opportunities presented by digital innovation across the disciplines and within each discipline. This work is future focussed with the present used as context to best adapt to the rapidly approaching digital horizon. Ultimately the goal of this research is to provide a solid footing to help Ireland produce graduates who are best prepared for the world they will enter regardless of discipline. By definition this is a continuous process, driven by the constantly accelerating pace of digital innovation. This research will culminate in a professional development course for educators in any discipline, aimed at helping them be better positioned to foster the skills, knowledge, and competencies to deal with realities such as cloud computing, big data, the internet of things and artificial intelligence. These innovations are only just beginning to revolutionise the teaching and learning of all disciplines. Broadly, change will come from two directions: internal developments within each discipline – often fundamentally – and external developments that will affect all disciplines broadly. Importantly, this research is not just about digital tools but using digital technology to create new knowledge within the disciplines.

What prompted you to choose this topic for your Fellowship research?

I'm a Computer Scientist, and I research Computing Education. Normally this focusses on computing students, and sometimes non-computing students but even then, most often in computing courses. Either way, there is normally a computing context. However, I am aware that digital innovations are impacting students in all disciplines. I find these disciplines to be context-rich and also where there is the most evidence for digital innovation truly and directly shaping society. Disciplines from Art to Zoology have quite rapidly had many of their processes altered by digital innovations. Some have been completely revolutionised. For instance, Geology has been transformed by Geographic Information Systems (Longley, Goodchild, Maguire, & Rhind, 2005), and Architecture has been similarly revolutionised by Building Information Modelling (Kensek, 2014). However, the drivers and realities of these changes are quite different. I find this exciting – and it is equally exciting that many disciplines are yet to experience such drastic change as these. There are also intriguing developments, perhaps most notably driven by Artificial Intelligence, that stand to further transform all disciplines, including how they are taught and learned. Perhaps most exciting is the use of digital innovation to create new disciplinary knowledge (Binkley, et al., 2012) – where technology makes things possible in the classroom that without the technology are simply not possible.

Why does this topic matter to those who learn, teach and lead across the higher education community?

Digital innovation has reached all disciplines. However, to date the scale and impact varies greatly. Furthermore, the pace of innovation is accelerating and shows no sign of slowing. This will impact the teaching and learning of all disciplines. This will happen in two ways. First, there are broad and largely discipline-agnostic mechanisms affecting all disciplines. Second, there are context-dependent mechanisms affecting specific disciplines uniquely.

On the first front, digital innovation will drastically impact more general aspects of teaching and learning regardless of discipline. For instance, mastery learning and personalised tutoring/mentoring are both known to have positive effects on all teaching and learning. The bottleneck has historically been resources – most often human, time, and economic, intertwined. However, digital technologies are becoming available that will help overcome these barriers, freeing up educator time to be dedicated to aspects of the profession that absolutely require human activity. Software applications are poised to help educators and students provide and experience personalised programs of learning that are becoming more realistic, and more effective.

On a disciplinary level, digital innovation is at the extremes, creating new disciplines and specialities within disciplines. Bioinformatics is a relatively young discipline that is only possible because of digital innovation. Software copyright law is a relatively new speciality within the discipline of law. Without software it would not exist. Additionally – sticking with law – all law graduates will be most capable and competitive, regardless of speciality, if they have a command of digital technologies relevant to law in general. Such technologies will impact each discipline uniquely, but of course there will be lessons learned in one discipline that may transfer to another.

What do we already know about this topic from previous literature?

There are a few main avenues that are really quite distinct. The first is educational technology – tools that we use in the classroom to aid teaching and learning. The second is broad-brush digital competencies that are generally beneficial for all students and graduates (National Forum, 2021). For example, basic computer skills, effective use of the internet, and office productivity software proficiency. A third is teaching digital skills within disciplines where such skills are part of the discipline – for instance in computing. A well-tested example

in this domain is pair programming, where students who write computer programs in pairs have been found to have increased retention rates (Porter & Simon, 2013), and higher performance – even for already high-performing students (McDowell, Werner, Bullock, & Fernald, 2002). A fourth is teaching digital skills (for instance computer programming) to non-computing / non-STEM students. An example is contextualised computing courses (Guzdial, 2009). Interestingly pair programming also aids non-computing students (Braught, Wahls, & Marlin, 2011) – a great example of context-dependent innovation generalising to a broader context. There is a good deal of work on this front, but it often lacks rich disciplinary context and can be difficult to directly apply to discipline-specific problems. Finally, where I am focussed most, is where digital innovation impacts all disciplines in discipline-specific ways. Here, content knowledge meets digital knowledge, and new knowledge can be created. For instance, what digital knowledge, skills and competencies do Earth Science graduates need to be the best professionals they can be? How can digital innovation be applied to make new knowledge in this area? There is not a large coherent body of work available on this front, at least from a multidisciplinary point of view, where lessons can be learned by educators in disparate disciplines. Much of the work is siloed within discipline-specific venues and communities and the literature is quite fragmented, unsurprisingly, along disciplinary lines. An example is teaching explainable Artificial Intelligence (AI) to lawyers (Górski & Ramakrishna, 2021). However, that's not to say that the principles of AI required by lawyers are not useful to those in other disciplines. In this domain – the impact on teaching and learning brought by digital innovations within specific disciplinary contexts – there is the potential for many lessons to be learned by others, from others. However, this can be difficult to achieve effectively. To some extent this is because it is not entirely clear where such context-dependent yet (hopefully) multidisciplinary situated work would lie.
Take for example a music student who is preparing a symphony for a project or portfolio. Today that symphony could be played back to that student, their teacher, and classmates, with pretty decent fidelity, by a computer, for negligible cost. Not many years ago this would have required dozens of people, a concert hall, and come at great expense. Another example comes from Experimental Archaeology. There are instances where durable moulds of objects have survived from ancient times but the less durable objects these moulds were used to make have not. With 3-D scanning and printing technology (Lipson & Kurman, 2013), accurate copies of these moulds can be made, from which copies of the objects themselves can be made. This is relatively easy and inexpensive. These objects can be created, studied, and manipulated in the classroom by students in real time. They can study physical copies of objects that do not exist in the archaeological record, that they created.

Now, imagine several such examples from each discipline. Are there lessons to be learned that would generalise from one context to another? Yes, but finding these is not simple. Adapting them and putting them into practice may even be more difficult – but the potential benefits are huge.

How did you go about the research?

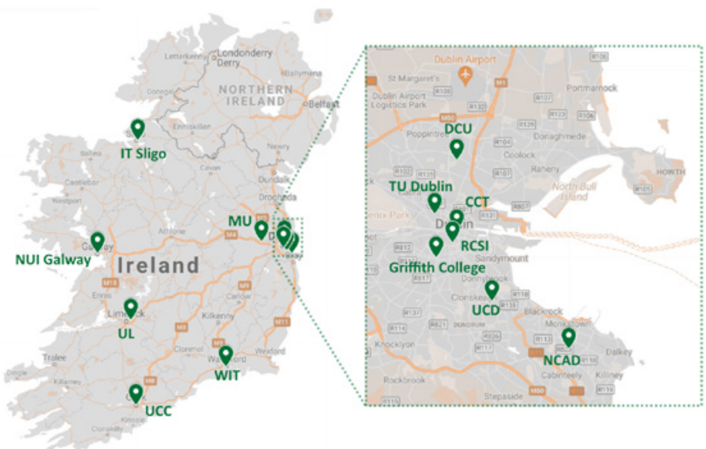
I conducted dozens of interviews with Irish third-level educators from all of the top-level ISCED fields (see Table 1) and dozens of subfields, including disciplines from Archaeology to Zoology.

Table 1: Top-level ISCED fields covered (all) (UNESCO Institute for Statistics, 2014)

00	Generic programmes & qualifications
01	Education
02	Arts & humanities
03	Social sciences, journalism & information
04	Business, administration & law
05	Natural sciences, mathematics & statistics
06	Information & Communication Studies
07	Engineering, manufacturing & construction
08	Agriculture, forestry, fisheries & veterinary
09	Health & welfare
10	Services

Interviewees were from as many Irish third-level institutions as possible. Figure 1 shows a map containing all institutions represented.

Figure 1: Institutions represented



Interviews began with an initial discussion about digital terminology, (Becker B. A., 2021b), to establish a common understanding of various terms that are used differently by different people and disciplines, as well as forming a basis to discover the difficulties and barriers that terminology presents (Becker B. A., 2021a). The interviews then explored the demand for digital technologies and innovation in the interviewee's discipline-specific teaching and learning. They also investigated current practices involving digital innovation and technologies in the classroom including challenges and opportunities. This often involved discussing digital tools, software, hardware, and curricular content. The interviews concluded with a future-focussed discussion on the impacts of digital innovation in discipline-specific teaching and learning, including advice for new educators; knowledge, skills, and competencies required for tomorrow's graduates, and professional development needs.

In addition to several international peer-reviewed publications, including two already published (Becker B. A., 2021a), (Becker

B. A., 2021b) a main output of this fellowship will be an open professional development course. The course is intended to provide a mechanism where groups of educators from any and all disciplines can learn about digital innovation impact, practices, and solutions in other disciplines. This will foster the cross-pollination of ideas, solutions, and experience between disciplines. This will have many benefits including avoiding educators getting hung up on barriers similar to those that others have overcome, and the sharing of tools and techniques that have proven effective in one context that may be applicable in others. By fostering individual connections as well as a cross-disciplinary community of practice, any and all aspects of digital innovation in the teaching and learning of all disciplines can be discussed and leveraged. Although difficult, it is clear that the disciplines which are constantly scanning the digital horizon, and well-prepared to adapt to revolutionary change, are best poised to maximise the benefits of digital innovation.

What are the key initial findings from the research?

An important initial finding has been just how differently various disciplines have experienced digital innovation. Demand for digital skills comes from different angles from different stakeholders. For some disciplines industry provides significant drive and demand. For others demand is regulatory, and for others it can be student-led. The way that digital innovation is used – tools, processes, hardware, and software – also vary greatly. The impacts of digital innovation on teaching and learning practice are also as diverse. Some disciplines have had their practices revolutionised by digital innovation and in some cases digital innovation has allowed the creation of entirely new specialities. Others have experienced less change. Although this may seem obvious the implications are extremely important.

Although there are many digital innovations that can be applied to much of teaching and learning regardless of discipline, the rich diversity of discipline-specific needs, demands, barriers, and realities presents opportunities and challenges. For instance, trying to gauge the future of the relationships between digital innovation and the teaching and learning within specific disciplines is quite challenging. Not all disciplines share the same challenges. For some they are financial – software licenses, expertise, and hardware can at times stretch budgets. For others the technology is not yet quite advanced enough to herald transformative change. However, other disciplines have already faced and overcome such challenges and have been revolutionised by digital innovation, fully embracing it, and advancing the discipline itself. Of course, not all opportunities herald revolution, yet they can be pivotal. For instance, challenges faced presently by one discipline may find opportunity from similar challenges faced and overcome by another. Often such disciplines share commonalities with others – for instance Equestrian Studies (Randle, Steenbergen, Roberts, & Hemmings, 2017) and Physiotherapy (Blumenthal, Wilkinson, & Chignell, 2018) may use sensors and kinematic software in very similar ways, albeit in different contexts. Interestingly, the roots of such sensors were originally developed in other contexts such as gaming.

The present state of digital innovation in teaching and learning can broadly be described with three observations. First, some disciplines have been impacted by digital innovation much more than others, revealing an extant disciplinary digital innovation gap. Second, the pace of digital innovation is accelerating. Third, disciplines that have embraced digital innovation are forging ahead faster than others. Looking to the future, this suggests that the disciplinary digital innovation gap will grow if those disciplines struggling with change do not overcome the challenges they face.

What, if anything surprised you in this research?

I was surprised by the variety in how digital innovation is used in different disciplines and in the impacts this has had. This research led me to equestrian centres, archaeology classrooms, ship bridge simulators, and many places in between. I learned that if you look somewhere that you think digital innovation should be prevalent or even rampant, it might not be, and vice-versa. Many of the most interesting disciplines that I ventured into were arguably quite far from STEM and often in the arts. For instance, digital innovations and the digital world we live in, has had profound effects on theatre, leading educators and students to explore questions such as: What is interaction? How is interacting live in-person different to interacting in real-time but in a technologically mediated way (Auslander, 2008)? How can technology aid students to be more creative than they can be without? Other disciplines such as Maritime Science are training students using simulators that can reproduce situations and conditions that are impossible to create on demand in the real world. For instance students can learn ship navigation in stormy seas with icebergs, other vessels, and the weather all controlled by computer. Such simulators are also used in assessment of students (Kavanagh, 2006).

What do your initial findings mean for higher education policy/practice?

The key message for the Irish education sector is that we need to prepare now for the next decade of digital innovation. The rich and diverse digital landscapes that exist within various disciplines present both challenges and opportunities at the disciplinary, institutional, and national levels. We can't afford to fall behind, particularly as the pace of digital innovation accelerates. We need to build on our strong foundations of disciplinary knowledge and invest in the future by incorporating, leveraging, and sharing digital knowledge.

Disciplines need to cope with their specific needs and capabilities while maintaining their core identity and missions. They need to leverage gains made by other disciplines, transferring skills and knowledge from across disciplines. Institutions, many of which are inherently multidisciplinary, need to understand the landscapes within their walls and how they combine to form an institutional landscape. Nationally, various institutions need to effectively work in unison with other stakeholders – first and foremost government and statutory bodies – to forge a coherent national digital innovation in teaching and learning landscape with future-focussed plans and strategies.

The first step towards this is recognising that terminology of digital innovation itself is a barrier , (Becker B. A., 2021b), (Gordon, 2014). It is used inconsistently between institutions, programmes, disciplines, and even within disciplines. It is a known barrier in the classroom. Even the word "digital" means very different things to different people. In interviews, "digital" and "digital literacy" were the most mentioned, yet the most problematic, terms (Becker B. A., 2021a). In this light, what does "digitally literate graduate" mean? Only once a common language is understood can policy be crafted that truly enables barriers to be overcome and opportunities to be realised.

At the national level the demands for, and expectations of, graduates' digital skills and competencies should be mapped, facilitating a meaningful transition of graduates into society and the workforce. This demands industry involvement. At the institutional level, graduate attributes should be revisited regularly to ensure that they are coherent while encapsulating the contexts of various disciplines and needs of employers. Creativity and digital literacy are normally agreed to be important attributes for all graduates to have, but exactly what these mean and how they are achieved are very different across the disciplines. Those in the classroom need policy that can be interpreted to ensure that disciplinary-specific teaching and learning practices are being utilised to develop digitally capable graduates in ways that complement disciplinary context.

It also needs to be ensured that all disciplines and all institutions are equipped to make best use of digital innovation. It should not be the case that one type of discipline, institution, or only certain regions excel in adapting to and exploiting digital innovation.

The Covid-19 pandemic made apparent the benefits of video conferencing, cloud-based software, and other tools. However, this broad-brush application of digital technology, where innovations are used very similarly across disciplines is relatively easy to leverage. More complex are the effects and impacts of innovations within specific disciplines. One area that demands immediate attention is Artificial Intelligence (AI) in education (Becker B. A., 2017). The pace of development in AI is breath-taking – we have abilities today that simply did not exist a few months ago. AI is already impacting many diverse disciplines and to-date the policies and practices of teaching and learning have been relatively unchanged in light of AI. This cannot, and will not, remain the case. We need to begin to advance digital possibilities and goals towards concrete AI initiatives and policies. Education is often notoriously slow to change, and the proliferation of AI technology in society has to-date been largely dictated by the economics and potential for immediate impact, which means that industry has been the first mover. However, as innovation speeds ahead, areas such as education – where returns are measured over years and decades – will feel the impact. The implications that AI can bring to education, and specifically the practices and policies of teaching and learning, have revolutionary potential for all disciplines. AI is coming fast – we can be ready, or not.

Some AI advancements will affect nearly every learner and educator. For instance, personalised learning – a key requirement for scalable mastery learning – will be a genuine possibility in the not distant future. This will test Bloom's 2-sigma problem, now nearly four decades old. The 2-sigma problem refers to a finding that mastery learning helped students by more than one standard deviation, and when combined with personal tutoring this increased to two standard deviations, a so-called 'two-sigma' effect on performance (Bloom, 1984). However, progress on this front has been held back for 40 years by the economics and time constraints of scaling education that is led by humans. AI is poised to provide the assistance for personalised mastery-based learning to become reality. This could revolutionise teaching practice in any and all disciplines.

However, the unique impact of AI on individual disciplines will be no less dramatic. For instance, in the last few years AI has become excitingly – in cases alarmingly – adept at tasks like writing poetry with human-like quality (Köbis & Mossink, 2021). In just the last few months it has become rather adept in writing computer programs. In fact, the largest computer programming AI model is built on the largest natural language AI model. This came about when it was realised that an AI designed to converse in natural language was capable of producing rudimentary computer programs despite not being trained on computer languages. The next step seemed obvious – train the natural language AI on computer programs (Chen, et al., 2021). The results surprised even AI experts.

Within disciplines, the near-term effects of AI will likely not be to replace human achievement as feared by many. AI may not even focus much on mimicking human work. Particularly in the arts, there is currently a focus on not just systems that exhibit artistic behaviour, but those that can aid the improvement of human artistic and creative endeavours – photography being a case in point – amongst many others. Freeing up time spent on repetitious and time-consuming tasks, and aiding humans to achieve even more, are obvious possibilities.

As today's educators and learners move forward into a future that promises above all else accelerating change and ever-improving technologies, the best way to keep up will be through disciplinary focussed practice informed by shared interdisciplinary experiences, guided by sound policy. The digital horizon is getting closer.

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