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The Use of Digital Resources in Civil Engineering Education: Enhancing Student Learning and Achieving Accreditation Criteria

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Abstract

The use of digital resources in higher education has risen significantly over the last ten years and will continue to do so for the foreseeable future. The challenge for educational instructors is in determining how to utilise digital resources effectively; the basis for this should not be their availability alone, but rather their ability to enhance the student learning experience and achieve desired learning outcomes. This paper describes the successful widespread integration of digital resources in the undergraduate teaching of civil engineering at the National University of Ireland, Galway. Various types of digital resources, including animations, videos, design software and case studies, are utilised. The recently completed Engineering building is itself a digital resource. Designed as a living laboratory, the building's structure, energy systems and internal environment are heavily instrumented and the structural, environmental and energy datasets are used as teaching tools.

The higher education teaching of Engineering differs significantly from that of other disciplines, such as the Arts or Humanities, in that engineering degrees are typically subject to a strict accreditation process by the national professional engineering body. In Ireland, this body (Engineers Ireland) prescribe six programme outcomes for Level 8 engineering degree programmes. The learning outcomes of individual course modules must therefore map onto one or more of these prescribed programme outcomes. The aim of this paper is to elucidate how digital resources have been used successfully by academic staff in the teaching of civil engineering subjects to help achieve professional accreditation criteria whilst also providing a more engaging student learning experience.

1. Introduction

Digital technology is an integral part of the modern world. Texting, web-browsing, video-gaming and online social-networking are all common activities in the daily lives of today's teenagers and students arrive at university with many years of exposure to digital media. As a result, it is often argued that teachers should incorporate digital resources in their teaching methods in order to properly engage these technology-savvy students, or ‘digital natives’ as they are sometimes called (Prensky, 2001). While there is not yet sufficient empirical evidence to verify the truth of this argument (Pedró, 2009), there is no doubt that digital resources have enormous potential as teaching tools. Images, videos and animations, design software, databases and scientific publications are just some examples of the digital resources available to teachers; however, not all digital resources make for useful teaching tools and even those that do can be misused, such that they may actually detract from the student learning experience.

The rapid acceleration of information available via the internet has meant that the use of digital resources in higher education has risen dramatically in recent years. In a 2008 survey of 119 institutions of higher education in the United States investigating their use of digital resources for scholarly purposes (Mc Martin et al., 2008), a majority (59%) of the respondents felt that digital resources were of "great value" to their instruction. While the internet means that digital resources are easy to source, their proliferation can present its own problems. Sometimes, teachers incorporate digital resources inappropriately simply because they are easily available, while, conversely, some teachers struggle to incorporate them at all because they are overwhelmed by the sheer volume available. Indeed, McMartin et al. (2008) also note that "the rapid acceleration of information available via the internet makes locating high-quality, accurate, and truly useful educational resources challenging for teachers".

Two important questions when considering using digital resources as educational tools are:
1) Why is the resource being utilised?
2) How will it be integrated in the course?

In answer to these questions, the authors believe that digital resources should only be used as teaching aids if, first, they enhance the student learning experience and, second, they enable the student to achieve one or more learning outcomes. In some instances, it may be the case that the former is accomplished while the latter is not, i.e. the student learning experience is enhanced without directly enabling the student to achieve a learning outcome, but it should never be the case that the latter is accomplished in the absence of the former. Other important issues which may enable one to answer the two key questions above are the quality of the resource, its applicability to the subject area, its ease-of-use and the level of interaction/ engagement it affords the student.

Within a context of increased digital resources and the relatively recent availability of content on-line, engineering education has been well positioned to take advantage of these developments. Academic staff in the Discipline of Civil Engineering at the National University of Ireland, Galway (NUI Galway) have successfully integrated many different forms of digital resources in the teaching of civil engineering undergraduates. Digital resources are utilised as teaching tools across all of the fundamental areas of civil engineering including structural, geotechnical, hydraulic and environmental engineering. The teaching of Engineering in higher education institutes differs significantly from that of other disciplines, such as the Arts or Humanities, in that engineering degrees are typically subject to a rigorous accreditation process by the national professional engineering body. In Ireland, Engineers Ireland (2007) prescribes six programme outcomes for Level 8 engineering degree programmes. The learning outcomes of individual course modules must therefore map onto one or more of these prescribed programme outcomes. Digital resources, if used, must therefore not only enable students to achieve individual module learning outcomes, but also the programme outcomes specified in the accreditation criteria.

This paper describes how digital resources have been successfully deployed by academic staff in the teaching of civil engineering subjects to help achieve the professional accreditation criteria whilst also facilitating an enhanced student learning experience. The professional accreditation criteria prescribed by Engineers Ireland and the educational ethos of the Discipline are described. Examples of the integration of digital resources in the teaching of various programme modules are presented and are supplemented with some qualitative and quantitative analyses of anonymous student feedback. It is hoped this paper will provide encouragement and ideas for teachers of engineering, as well as those of other disciplines, who may be considering the use of digital resources.

2. Civil Engineering at NUI Galway

Civil Engineering is one of four disciplines in the College of Engineering and Informatics at NUI Galway, and it is the host discipline for the BE (Bachelor of Engineering) in Civil Engineering. It is one of the oldest disciplines in the University and dates back to the opening of the university in 1849, from which time there has been an unbroken tradition of producing Civil Engineering graduates. Initially, the degree was three years in duration but this was increased to four in 1958. The current BE in Civil Engineering is a four-year, full-time course. NUI, Galway implements the European Credit Transfer System (ECTS) with an academic year being worth 60 credits and 240 credits being required for graduation. By the 1970s, Civil Engineering had expanded significantly and produced about 50 graduates per year. From the late 1990s, student numbers increased steadily, due in part to the enormous demand for Civil Engineers. The numbers reached a peak in 2010 with a graduating class of 130. More recently, the numbers entering the programme have dropped due to a decline in the construction industry in Ireland. While class sizes have fluctuated over the years, the intellectual and technical content of the BE Civil Engineering continues to evolve and is strong across all branches of Civil Engineering.

2.1 Educational Ethos and Programme Design

Differences in curricula between subject areas can be effectively demonstrated using the descriptive framework suggested by Barnett and Coate (2005). This framework describes different curricula using the three domains of *knowing*, *acting* and *being* which relate to content, skills acquired and student development, respectively. Programme curricula can be differentiated by the relative contributions of these three domains to the programme and the extent of interaction between domains. Barnett and Coate (2005) conclude that one of the main differences between engineering or 'professional' programmes and those from arts and humanities is the relative contributions of the *knowledge* and *action* domains. The *knowledge domain* is a substantial component of an arts or humanities programme as these curricula tend to be designed first and foremost by the knowledge content that is deemed necessary. In contrast, the *action domain* is a more substantial component of engineering programmes, as graduates must learn the practices and skills of an engineer. The civil engineering curriculum at NUI Galway (Table 1) has been designed accordingly. It is therefore imperative that teaching pedagogies allow students to practice skills as they acquire them such that they 'learn by doing'. It is shown in the next section that digital resources serve as very useful tools in this respect.

Important aspects of the educational ethos of the civil engineering programme at NUI Galway include:

- a strong emphasis on the mathematical and physical sciences in the first two years
- a fundamental grounding in computing and engineering graphics
- a clear focus on discipline-specific design
- a significant percentage of practical and laboratory work
- the use of industry-standard software in many of the modules
- the requirement for students to gain structured professional experience
- an emphasis on student development in: ethics; social responsibility; communications; lifelong learning; and individual, team and multi-disciplinary work

The educational ethos and overall learning experience for the students is also enhanced through the research-active nature of the Civil Engineering discipline. From their interaction and involvement with research-active staff and postgraduate students, the spirit of enquiry among the undergraduates is fostered. This contributes to their capacity for and interest in life-long learning.

2.2 Accreditation Criteria: Programme Outcomes

Through the *Institution of Civil Engineers of Ireland* (Charter Amendment Act 1969), Engineers Ireland is compelled to "set up and maintain proper standards of professional and general education and training for admission to membership or to any category of membership of the Institution". In fulfilment of this purpose, Engineers Ireland has formally accredited engineering degree programmes in the Republic of Ireland since 1982. Engineers Ireland (2007) specifies the following programme outcomes (PO) which apply to all honours Bachelor degree (Level 8) engineering programmes aimed at satisfying the educational standard for the title of Chartered Engineer up to 2012:

(a) The ability to derive and apply solutions from a knowledge of sciences, engineering sciences, technology and mathematics.
(b) The ability to identify, formulate, analyse and solve engineering problems.
(c) The ability to design a system, component or process to meet specified needs, to design and conduct experiments and to analyse and interpret data.
(d) An understanding of the need for high ethical standards in the practice of engineering, including the responsibilities of the engineering profession towards people and the environment.

(e) The ability to work effectively as an individual, in teams and in multidisciplinary settings together with the capacity to undertake lifelong learning.
(f) The ability to communicate effectively with the engineering community and with society at large.

Year	Course Code	Subject Name	ECTS
1st Year	MA140	Engineering Calculus	6
	MM120	Mathematical Methods For Engineers	6
	MP120	Engineering Mechanics	6
	PH104	Principles of Physics	6
	CH111	Engineering & Medical Chemistry	9
	CE107	Fundamentals of Civil Engineering	3
	CE118	Introduction to Surveying	6
	CE112	Engineering Graphics II	9
	CE117	Introduction to Computing	9 (60)
2nd Year	CE219	Year's Work in Civil Engineering	18
	CE207	Engineering Materials	3
	EOS216	Geology for Engineers 1	3
	CE202	Principles of Building	6
	MA256	Engineering Calculus	3
	MA254	Engineering Algebra	3
	MA278	Engineering Statistics	3
	MP254	Engineering Applied Mathematics I	3
	MP252	Engineering Applied Mathematics II	3
	CE217	Elementary Hydraulics	6
	CE213	Strength of Materials	6
		Foreign language *or* Numerical Analysis	3 (60)
3rd Year	CE306	Year's Work in Civil Engineering	18
	CE307	Environmental Engineering	6
	CE330	Engineering Hydraulics I	6
	CE318	Construction Operations I	3
	CE312	Elementary Soil Mechanics	3
	CE313	Highway & Traffic Engineering I	3
	CE319	Construction Operations II	3
	CE320	Solids and Structures I	6
	CE322	Design of Concrete Structures	3
	CE321	Solids and Structures II	6
	CE323	Design of Steel Structures	3 (60)
4th Year	CE411	Year's Work in Civil Engineering	12
	CE412	Engineering Project and Report	6
	CE451	Engineering Hydrology I	3
	CE405	Design of Structures	6
	CE421	Structural Analysis I	3
	CE439	Coastal Engineering	3
	CE414	Geotechnical Engineering	6
		Plus	
		21 credits from 16 optional modules	21 (60)
			Total: 240

Table 1: NUI Galway civil engineering programme curriculum.

The three domains of *knowing*, *acting* and *being*, identified by Barnett and Coate (2005), are addressed by the programme outcomes. PO(a) and PO(b) address *knowledge*, PO(c) and (d) address *action*, i.e. the engineering skills, while PO(e) and

PO(f) address *being*, i.e. the development of the person as an engineer and the engineer as a person.

Inputs such as entry standards, programme duration and structure, and resources, including buildings, laboratories, equipment, academic and support staff, must also be of an appropriate standard for successful accreditation. Accreditation can be awarded for up to a maximum period of five years, after which time re-accreditation must be sought. The accreditation process involves the submission of an accreditation report followed by on-site assessment by an accreditation panel. It is incumbent on staff to demonstrate, using supporting evidence, that each programme outcome is adequately addressed by the programme curriculum.

3. Use of Digital resources in Undergraduate Teaching

Educational digital resources range from simple teaching support tools such as photographs, images and videos, through to complete courses that are developed, managed and delivered online. For the purposes of this paper, the integration of digital resources is discussed under the following categories:
1) videos and animations
2) software and databases
3) learning technologies
4) the Engineering building

Videos and animations are generally used by staff as an aid to the explanation of particular engineering concepts or principles and are therefore grouped together. Digital images generally fall into the same category, but as their use is relatively commonplace they are not discussed here. Software and databases are grouped together as their integration in teaching is usually in a design context. Students undertake design projects in the areas of structural, geotechnical, transport, hydraulic and environmental engineering, and central to these projects is the use of digital software packages, from Microsoft Excel to advanced finite difference/element models, and digital databases. Learning technologies include online learning systems, Blackboard in the case of NUI Galway, and in-class systems, such as electronic classroom response systems, better known as 'clickers'. Both Blackboard and clickers are used by our staff to encourage student engagement in, and out of, the classroom. Finally, the new Engineering building is a digital resource that is unique to NUI Galway. The building, completed in 2011, houses all of the engineering disciplines and is the largest engineering education building in Ireland. More importantly, it was designed to be a teaching and research tool. Hundreds of gauges and sensors collect data relating to the building's structural behaviour, energy performance and internal environment and these data are logged and stored in a data repository where they can be accessed by staff and/or students.

The following sections provide examples of how these four categories of digital resources are used by staff to enhance the student learning experience and to help achieve programme outcomes.

3.1 Videos and Animations

In the Soil Mechanics and Geotechnical Engineering modules, videos are used as learning support for many of the concepts covered in lectures. One of the most popular videos is a 21-minute documentary of the Rissa Landslide produced by the Norwegian Geotechnical Institute (NGI), recently made available on YouTube (http://www.youtube.com/watch?v=3q-qfNlEP4A). In the process of constructing a foundation for a small barn in April 1978, 700m^3 of excavated material was stockpiled on a lake shore and triggered a landslide with a final volume of 6,000,000 m^3. The documentary includes some live amateur footage of the retrogressive sliding activity. The footage is dramatic and the documentary successfully frames the slide in the context of the underpinning soil mechanics principles, including water content/Atterberg limits, shear strength and geochemistry. The two former topics are fundamental topics in introductory soil mechanics modules and therefore help achieve PO(a) of the accreditation criteria. In addition, an exposure to geochemistry stimulates a curiosity about how soils were formed and shows that processes other than mechanical ones can have an influence upon likely behaviour today.

Kentledge is the term used in geotechnics to describe a stacked arrangement of concrete blocks used to load test piles. Another powerful YouTube video shows a dramatic Kentledge collapse at a construction site at Gilstead Road, Singapore in January 2011 (http://www.youtube.com/watch?v=14JM2-Yj2bY&feature=related). Some of the concrete blocks tumbled over the site boundary and caused damage to the gas pipeline under the road. This accident could potentially have led to a loss of life. In addition to providing a clear illustration of how pile load tests are performed in practice, this video has an important secondary learning outcome, highlighting the importance of responsibility, ethics and health and safety matters in construction (PO(d) in the accreditation criteria).

Online videos and animations are also utilised in the teaching of Elementary Hydraulics. For example, a java applet of Newton's Cradle (Figure 1a) is used to demonstrate the laws of conservation of momentum and energy, thereby helping to achieve PO(a) of the accreditation criteria. If a single ball from the left side of the Cradle is pulled outward and released (Figure 1b), it swings and strikes the second ball. On impact, the momentum of the first ball is transferred through the series of balls, causing the last ball on the right to swing outward while the other balls remain motionless (Figure 1c). When this ball swings back, its collision again results in momentum transfer and the first ball swings outward to repeat the process. Pulling away several balls results in the same number of balls moving away at the other end. The animation provides a very visual demonstration of the conservation laws. Students find it quite intriguing and are motivated to use the applet themselves to vary the number of balls that are pulled away and observe the result.

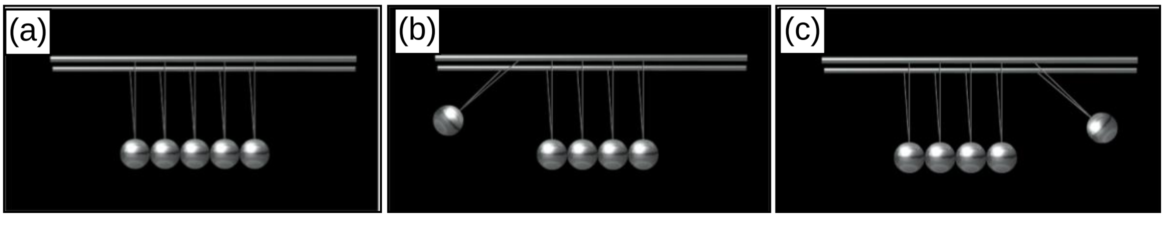

Figure 1: Screenshots of Newton's Cradle animation (courtesy of: http://www.school-for-champions.com/science/newtons_cradle.htm).

In the area of environmental engineering, recent investment into wastewater treatment processes means it is now possible to use 'before and after' digital data to illustrate and discuss with students the impacts of engineering activities on the environment and society. Using videos and images, the theory of operation of these systems is explored and fundamental questions relating to the inter-relationship between engineering and society are discussed. Questions are posed such as: Would the students, as future consulting engineers, recommend such systems for the treatment of wastewater? What are the environmental/social consequences of installing these systems? Are there health or safety concerns associated with these systems? Working with 'real world' examples, digitally projected in the lecture hall, concepts of design versus practicability versus public health and safety are explored. This type of critical thinking forms part of the training of an engineer and addresses a number of Engineers Ireland programme outcomes, particularly PO(c) and PO(d).

3.2 Software and Databases

As part of the Geotechnical Engineering module at NUI Galway, students are required to design a suitable surcharge scheme to reduce post-construction settlements for an embankment constructed on soft alluvium. The ground conditions are based on those in existence in the vicinity of the Limerick Tunnel approach embankments, reported on in Engineers Ireland publications by Buggy and Peters (2007) and Buggy and Curran (2011). The project, conducted in Enquiry Based Learning mode, requires the students to interpret geotechnical parameters for themselves and grapple with the natural variability inherent in natural soft soils before deciding what mathematical models are appropriate.

The surcharge design requires students to predict the excess pore water pressure dissipation over time after the surcharge is applied, and they are required to implement this in MS Excel using a finite difference (FD) solution to Terzaghi's theory of 1-D consolidation (Figure 2). Students develop experience in the choice of appropriate time and depth steps for their Excel grid to guarantee convergence of the FD equations, while also developing solutions to predict the variation of pore water pressure with depth and time and taking account of boundary conditions. An additional benefit of this activity is that students can assess how sensitive their final surcharge solution is to the initial choice of soil parameters, and make adjustments as appropriate. Brighter students are capable of modelling the fact that surcharge schemes are not constructed instantaneously but are built gradually over time, and such loading-time relationships can also be integrated into the Excel model. PO(a), PO(b) and PO(c) are all achieved by this digital design exercise as students develop solutions to the design problem by applying their knowledge of soil mechanics.

There are many instances of the use of advanced engineering design software in the BE Civil Engineering programme and familiarity with such software products is a necessary learning outcome of all engineering degree programmes. An interesting example is the use of the Bridgebuilder™ software package (http://www.bridgebuilder-game.com/) in the design-and-build component of the first year Fundamentals of Civil Engineering. Working in small groups, students are required to design and build a bridge using only spaghetti and glue (Figure 3a). Students are given maximum dimensions for the bridge (length x width x height) but are free to choose any design they wish; therefore, a critical part of this problem-based learning project is a review of bridge designs. As well as using online resources for this task, students are also required to experiment with Bridgebuilder^{TM}, an educational computer game where bridges are constructed to span different terrains (Figure 3b). Bridges are tested by passing a train over them and those structural members that are in tension or compression are highlighted accordingly. This gives students an insight into basic structural mechanisms and helps them identify the areas of their design that need strengthening. Bridgebuilder^{TM} brings an element of fun into the classroom and encourages students to truly engage with the module outside of the classroom. At the same time, the software helps students to achieve a number of programme outcomes; for example, the ability to solve a real engineering problem (PO(b)), the ability to design a structure (PO(c)), an awareness of cost and the responsibility of an engineer to the public and to the environment (PO(d)).

Surcharge assignment solution template

Surcharge amount	100	kPa	
cv	2.5	m2/year	maximum value that arises in brief is 4 m2/year
beta	0.109514		
Δt	0.010951	years	4 day intervals needed (for worst case cv, and ΔH=0.5m to have data at midpoint of 5 x 1m layers for settlement calcs)
DH	0.5	m	
Cc/1+e0	0.12		
Cs/1+e0	0.025		
surcharge duration	6	mths	

PORE PRESSURES

z (m)	t=0 (days)	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.5	100	89.0	80.5	73.7	68.2	63.6	59.8	56.5	53.7	51.3	49.2	47.3	45.6	44.0	42.6	41.4
1	100	100.0	98.8	96.9	94.7	92.3	89.9	87.6	85.3	83.1	81.0	79.0	77.2	75.4	73.7	72.2
1.5	100	100.0	100.0	99.9	99.6	99.1	98.4	97.7	96.8	95.8	94.8	93.7	92.7	91.6	90.5	89.4
2	100	100.0	100.0	100.0	100.0	99.9	99.9	99.7	99.5	99.3	98.9	98.6	98.1	97.7	97.2	96.6
2.5	100	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.8	99.7	99.5	99.3	99.1	98.8	98.4
3	100	100.0	100.0	100.0	100.0	99.9	99.9	99.7	99.5	99.3	98.9	98.6	98.1	97.7	97.2	96.6
3.5	100	100.0	100.0	99.9	99.6	99.1	98.4	97.7	96.8	95.8	94.8	93.7	92.7	91.6	90.5	89.4
4	100	100.0	98.8	96.9	94.7	92.3	89.9	87.6	85.3	83.1	81.0	79.0	77.2	75.4	73.7	72.2
4.5	100	89.0	80.5	73.7	68.2	63.6	59.8	56.5	53.7	51.3	49.2	47.3	45.6	44.0	42.6	41.4
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 2: Finite difference grid used in surcharge design problem.

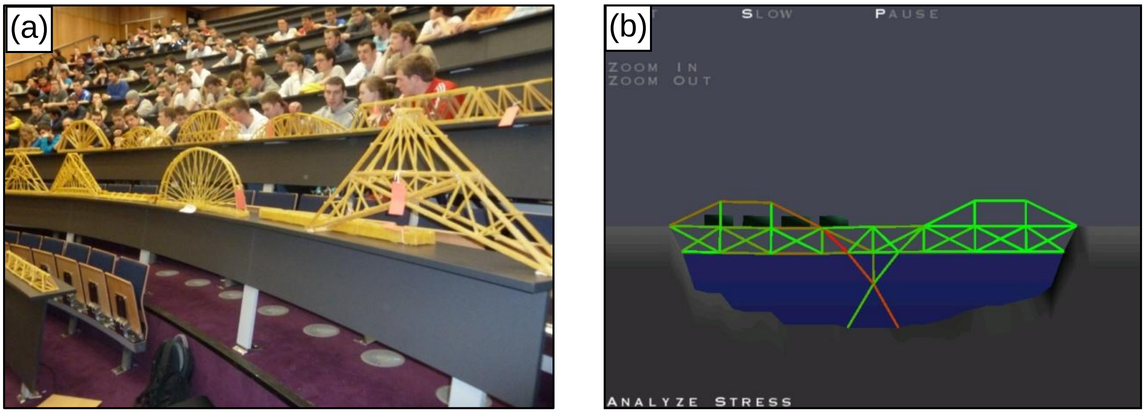

Figure 3: (a) Examples of spaghetti bridges built by 1st year students and (b) screen grab from Brudgebuilder^{TM}.

Environmental engineering design is a good example of an area in civil engineering where multi-media content, legislative instruments and ethics are integrated. For example, civil engineers must consider all of these issues when they are designing, constructing and operating water and wastewater treatment units. The availability of digital resources has brought about substantial changes in the way that staff at NUI

Galway now teach such topics. Taking an example of applying for planning permission to build a septic tank, the lecturer and the class interrogate digital maps and databases available from the Environmental Protection Agency (EPA; www.epa.ie) and the Geological Survey of Ireland (www.gsi.ie) websites (Figure 4) to determine whether the characteristics of an area, such as soil type or groundwater vulnerability, are appropriate for the location of such a treatment system. These on-line resources aid the teaching process, as they encourage the students to critically and independently evaluate the suitability of an area for a particular engineering activity; these are skills that contribute directly to PO(c) and PO(d) of the accreditation criteria.

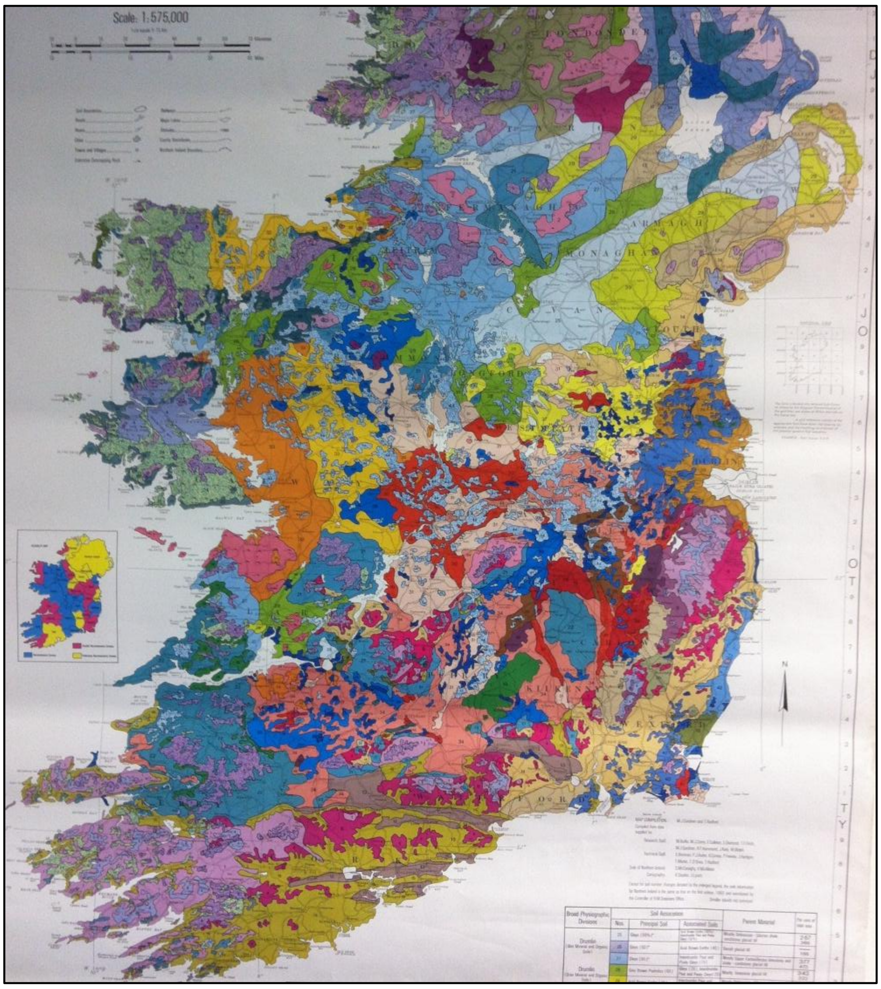

Figure 4: The General Soil Map of Ireland, which is used to determine suitable locations for septic tanks and percolation areas.

3.3 Learning Technologies

The Blackboard learning technology (www.blackboard.com) is in widespread use on engineering courses at NUI Galway and its “quiz” feature (Figure 5) is sometimes used as a form of marked or unmarked assessment. There is flexibility in the type of quiz question posed, to include *multiple choice and multiple answer, fill in the blank, ordering* and *true or false* responses. For engineering modules, the most effective can be the *calculated formula*-type question which is used extensively on the Soil Mechanics module. With this type of question, a range of suitable values can be assigned to each of the variables in a formula, and a set of random variables (typically 100 or more depending on class size) can be chosen. The main benefit of this approach is each student taking the quiz gets a different set of parameters for the same question which helps prevent plagiarism. In addition, a pool bank of questions can be developed, and for each quiz questions can be drawn at random from one or more pools, again ensuring variety in the questions received by each student. These quizzes have been found to be effective in engaging students with the material throughout the semester, rather than cramming at exam time, and a set of three quizzes contribute 3x10% of the final grade for the Soil Mechanics module. In an example of formative learning, a practice quiz on the key concept of effective stress has given students greater confidence in tackling problems on this topic.

In the fourth year Project Management module, *multiple choice*-type questions are extensively used as a learning tool to improve understanding of a broad range of concepts and theories. From the large pool banks of questions that have been developed, the students receive a randomised selection. To encourage learning, prior to completing a quiz for a graded mark, students are permitted, and encouraged, to make multiple attempts at each quiz. In this way they get instant feedback on which questions they answered correctly helping them to measure and improve their level of understanding of the topic under consideration. The online quizzes described generally test the students' understanding of core principles of engineering and project management and therefore help satisfy PO(a) and PO(b).

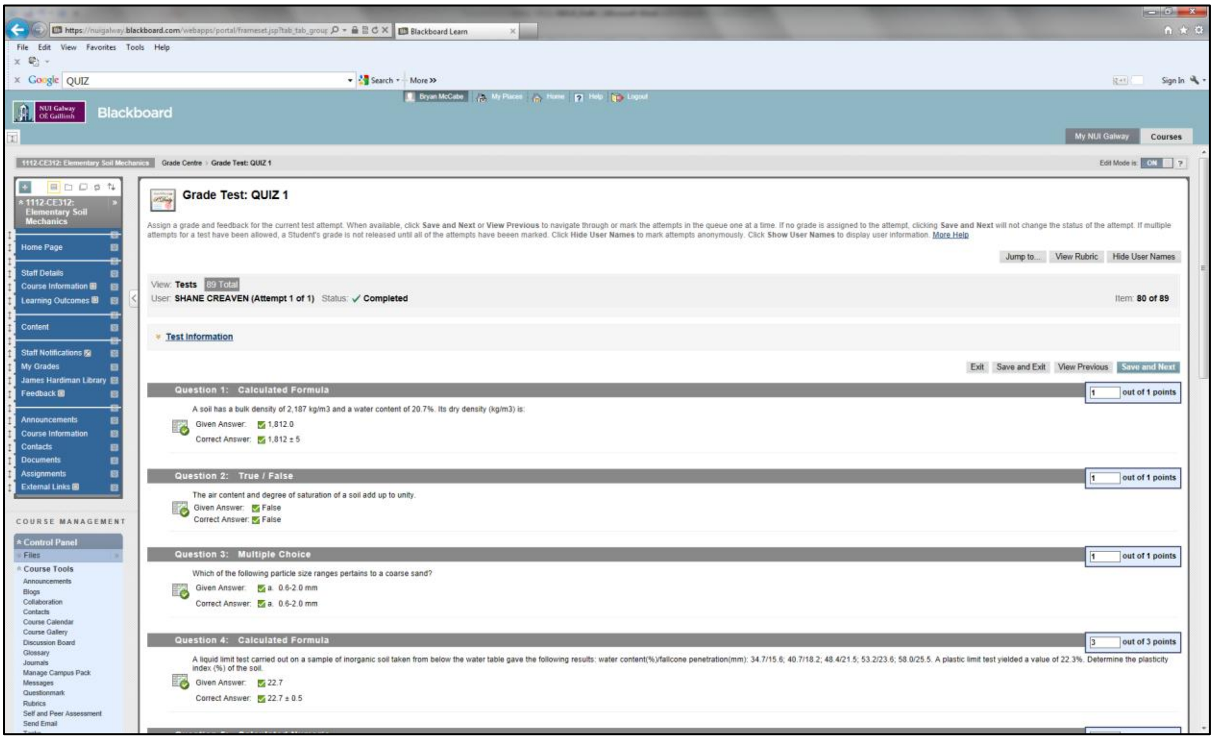

Figure 5: Screenshot of typical Blackboard quiz.

Electronic classroom response systems are interactive technologies which allow students to use wireless transmitters, or *clickers*, to answer questions posed by the instructor. Answers are then collated via a USB receiver and supporting software on the instructor's PC and a graphical summary of student answers is produced and shown to the students. The technology has been successfully integrated in the teaching of Elementary Hydraulics to facilitate peer instruction, a teaching approach developed by the leading Harvard physics lecturer Eric Mazur (Mazur, 1997). The peer instruction process can be explained as follows. A particular engineering hydraulics concept is explained to the class. The lecturer then poses a ‘concept question’ (Figure 6) aimed at establishing student understanding of the concept. Students are given two chances to answer concept questions; the first without any peer discussion, and the second following peer discussion. During the small-group peer discussions, the students who correctly understand the concept can teach those who do not; in this way, peer instruction takes place. Concept questions were developed in MS PowerPoint and are available to download from the National Digital Learning Repository (NDLR) (http://hdl.handle.net/ 10633/38558). The use of concept questions and peer instruction helps improve student understanding of the fundamental principles of hydraulic engineering and therefore ensures that students achieve programme outcomes (a) and (b) of the accreditation criteria.

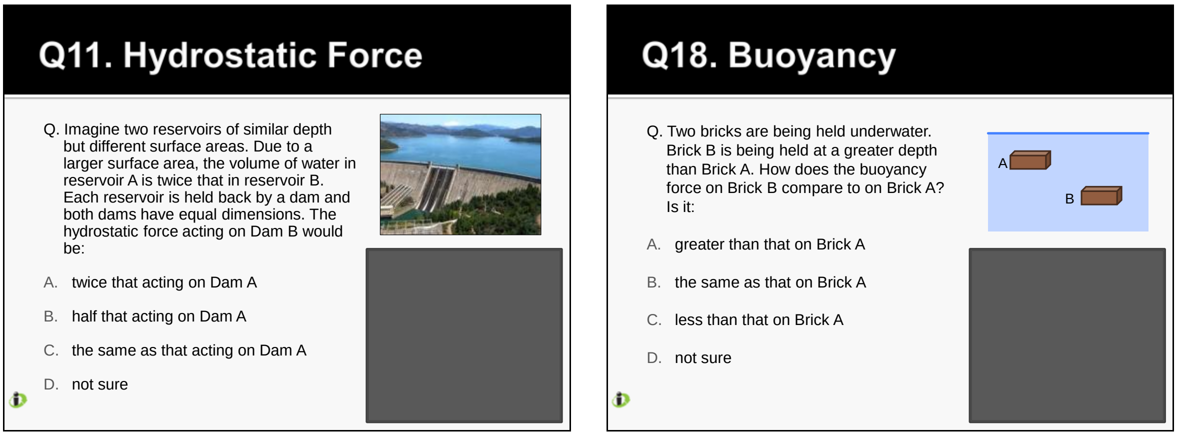

Figure 6: Sample concept questions used in teaching of Elementary Hydraulics.

3.4 The Engineering building

Recent research and reports (Royal Academy of Engineering, 2007; Jamieson & Lohmann, 2009; Sheppard et al, 2009; Atman et al, 2010) have shown that there is a critical need to provide students with a deeper understanding of the general concepts and principles of engineering and to provide them with the means to meet the challenges of the 21st century. One such report by the Royal Academy of Engineers (2007) highlighted the need for “university courses to provide more experience in applying theoretical understanding to real problems”. With these points in mind the new Engineering building at NUI Galway (Figure 7) was constructed to directly link the building into teaching methods, actively engaging with students to raise their awareness of the different aspects of building design and performance. Central to this was the instrumentation of the Engineering building and its development as an interactive teaching tool for students, effectively creating a ‘living laboratory’.

A number of structural elements in the building have been instrumented with over 260 gauges (see for example Figure 8) measuring strains, temperatures and movements due to loading of the building. Data on the building’s energy demands and performance, and internal environment (carbon dioxide, temperature and humidity), are also gathered and integrated into the smart Building Management System (BMS) which monitors and controls the building's mechanical and electrical equipment. The building contains a variety of green-building initiatives, such as wood-pellet heat generation, rain-water recycling, ground source heating, and high-tech renewable energy systems, designed to reduce the buildings impact on the environment and make it as sustainable as possible (Engineers Ireland, 2011). The performance data for all of these ‘green’ systems are also collected. All data recorded by the hundreds of sensors and gauges are stored in a permanent digital data repository. These data are being used to create interactive teaching tools for students and to facilitate the advancement of engineering teaching methods, as well as forming the basis for future research projects. Data from the building's digital data repository have already been integrated into the teaching of some modules, such as Fundamental of Civil Engineering, Principles of Buildings, and Sustainable Energy and Energy in Buildings, where they are used to improve students’ understanding of engineering concepts (PO(a)) and design (PO(c)), and their awareness of the engineer's responsibility towards the environment (PO(d)).

Figure 7: The recently completed Engineering building at the NUI Galway.

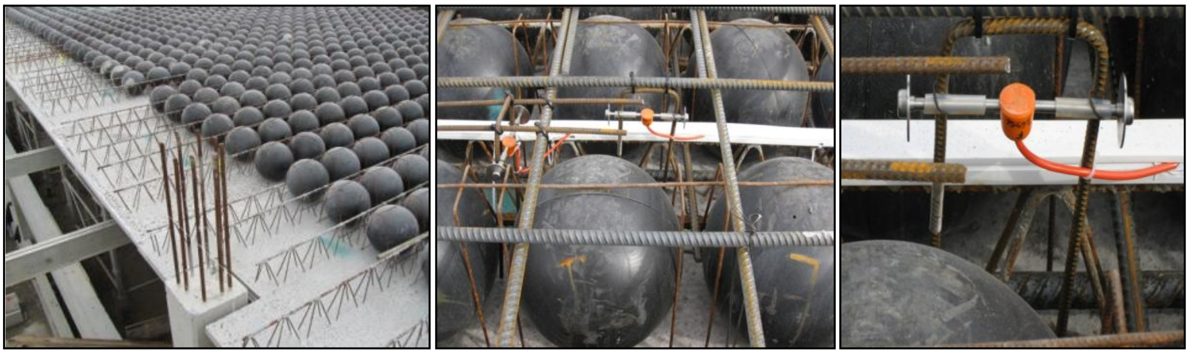

Figure 8: Void-formed flat slab with installed vibrating wire gauges (Goggins et al. 2012).

4. Discussion & Conclusions

Table 2 summarises the examples of digital resource described in the previous section. It should be noted that these examples only constitute a small snapshot of the widespread usage of digital resources in the civil engineering degree programme at NUI Galway. These particular examples were chosen to demonstrate the wide range of digital resources that are currently utilised by Discipline staff and the breadth of the subject areas in which they are used. From structural and geotechnical engineering through to hydraulic and environmental engineering, digital resources are helping teachers and students to achieve programme outcomes in ways that traditional teaching methods cannot. In addition, they are facilitating a more interactive, engaging student learning experience inside, and in some cases even outside, the class room.

Resource Type	**Examples of Resources**	**Module**	**Programme Outcomes**
Videos + Animations	Video of land slide Video of 'Kentledge' collapse Animation - Newton's Cradle Videos of wastewater treatment technologies	CE312 Soil Mechanics CE414 Geotechnical Eng. CE217 Elementary Hydraulics CE307 Environmental Eng.	(a) (d) (a) (c), (d)
Software + Databases	MS Excel finite difference model Bridgebuilder™ game Environmental databases	CE414 Geotechnical Eng. CE107 Fund. of Civil Eng. CE307 Environmental Eng.	(a), (b), (c) (b), (c), (d) (c), (d)
Learning Technologies	Online quizzes via Blackboard™ Concept questions via clickers	CE312 Soil Mechanics CE217 Elementary Hydraulics	(a), (b) (a), (b)
New Engineering building	Structural, energy and environmental datasets	CE107 Fund. of Civil Eng CE202 Principles of Building CE454 Sustainable Energy and Energy in Building	(a), (c), (d)

Table 2: Summary of selected digital resources and related programme outcomes.

The authors believe that a digital resource should only be used as a teaching tool if, in the first instance, it helps achieve a learning outcome, and in the second instance, it enhances the student learning experience. Since the learning outcomes of individual course modules enable the achievement of the programme outcomes (in an engineering context the outcomes stipulated by the professional accreditation criteria), it follows that the metrics used to evaluate the impact of digital resource use should be:

- their contribution to achievement of programme outcomes; and
- their enhancement of the student learning experience

From Table 2, it can be seen that all the examples of digital resources used by staff enable students to achieve one or more programme outcomes. Analyses of anonymous student feedback provide further evidence that these digital resources contribute to their achievement of programme outcomes. The following are some examples of this:

- 3rd year Soil Mechanics: in an grouped student evaluation reported in 2010, students reported that "the use of YouTube clips helped (them) to understand the topic"

- 3rd year Soil Mechanics: in annual end-of-module surveys the average class response to the statement “The Blackboard quizzes were effective in encouraging me to study the notes and understand the concepts at an early stage” has ranged from 4.3 to 4.6 over the last 5 years (1 being 'strongly disagree' and 5 being 'strongly agree') [Total respondents: 50+ annually]
- 1st year Fundamentals of Civil Engineering: 78% of students rated the usefulness of Bridgebuilder™ to their learning as 4 or better on a scale of 1 to 5 (1 being 'of no use at all' and 5 being 'very useful') [Total respondents (2011): 64]
- 2nd year Elementary Hydraulics: 98% of students agreed that the concept questions helped improve their understanding of the course material and 100% of students rated the instructional value of the animations/videos as a 4 or better on a scale of 1 to 5 (1 being 'of no value' and 5 being 'of great value') [Total respondents (2011): 25]

In relation to the second metric of evaluation, analyses of anonymous student feedback also provide evidence that the digital resources used by lecturers do indeed enhance the student learning experience. Some examples are:

- 2nd year Elementary Hydraulics: 100% of students answered 'yes' when asked if they enjoyed using the clickers and 100% of students also answered 'yes' when asked if the clickers improved their engagement with the course. Furthermore, 92% of students said they would like the clickers to be used in other programme modules. The combined use of clickers, concept question, videos and animations meant that students generally found the module quite stimulating; when asked to rate the lectures on a scale of 1 ('very boring') to 5 ('very interesting') 84% of students gave a rating of 4 or better [Total respondents: 25]
- 3rd year Soil Mechanics: in annual end-of-module surveys the average class response to the statement "The use of Blackboard enhances my learning experience" has ranged from 4.2 to 4.45 over the last 5 years (1 being 'strongly disagree' and 5 being 'strongly agree') [Total respondents: 50+ annually]
- according to a 2011 3rd year civil engineering student “The new Engineering building has really enhanced my learning experience ... the building has sensors all over the place so we can monitor and analyse how the building is working using software in our labs”
- many students in Fundamentals of Civil Engineering and Sustainable Energy noted the use of the Engineering building data as one of the most interesting features of their lectures

The deployment of digital resources has also facilitated the introduction of a number of more student-focussed teaching pedagogies, such as, enquiry- and problem-based learning (e.g. the use of the bridge design game for the spaghetti bridge project), peer instruction (made possible by deploying clickers), small group teaching (again making use of clickers) and formative learning (e.g. the 'practice' online quizzes). These student-focussed teaching approaches have created a much more stimulating, interactive and engaging learning environment for students.

The unremitting advances being made in technology, knowledge and understanding within the engineering industry mean that the practice is continuously evolving. It goes without saying that to keep up with these developments there is an incessant need for teaching methods to evolve to ensure that future generations of engineers are educated to the highest level. There is no doubt that digital resources will play a significant role in this evolution. This is demonstrated by the wide range of digital resources already being used by civil engineering staff at NUI Galway in their teaching of undergraduate engineers. From their experiences to date, the authors have found that digital resources, used in an appropriate manner, can help achieve programme outcomes (and, by extension, the professional accreditation criteria), while also improving the student learning experience. It is recommended that these metrics are used when considering the use of digital resources as teaching tools and when evaluating the impact of such usage.

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