Integrating Biomedical Engineering Research with Undergraduate Teaching – A Research-Teaching Nexus Approach

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Abstract

The integration of research with undergraduate teaching can further enhance the third-level learning experience, by improving learners' problem solving, critical inquiry and design thinking skills. Unfortunately, research and teaching are perceived as two diverse activities that rarely meet. The new Atlantic Technological University (ATU) launched in April 2022 in the west and northwest of Ireland will increase its research capacity and further serve the regional needs. This provides an opportunity to bridge the gap between research and teaching. Four modules within the biomedical engineering degree and two modules from mechanical engineering are shown as examples of integrating biomedical engineering research and infrastructure with undergraduate programme modules. The research-teaching nexus model was applied to aide in this interaction. The feedback from the students was very positive with comments towards the learning environment stating, "new learning experience on biomed engineering, a good change from the usual" and "there was a great atmosphere in class, yet we still were able to learn". Other student comments on interacting with the research facility was "tour of medical imaging suite assisting in my understanding of the topic" and "the actual physical interactions in the MET centre was the best part". The integration of research with undergraduate learning is a key learning resource which motivates undergraduate students for further learning and allows teachers to be facilitators of learning. We must therefore think actively about how to bring teaching and research together to enhance the scholarship of learning.

1. Introduction

Integrating research with undergraduate teaching enhances the third-level learning environment. Unfortunately, third level research and teaching at undergraduate level are perceived as two diverse activities that rarely meet. The integration of research with teaching is important as Barnett [1] states, it prepares students to move forward into the supercomplex society and challenges open critical inquiry. Academics have argued that students gain benefits from being taught by active researchers that are directly involved in the research process [2]. This interaction further facilitates undergraduate teaching by providing learners with different perspectives, various ways of knowing, multiple problem-solving techniques, and exposes them to the challenges of open critical inquiry and design thinking. The Galway-Mayo Institute of Technology (GMIT) in the west of Ireland became a Technological University (TU) in April 2022 by joining with two other third-level institutions; Institute of Technology, Sligo (IT Sligo) and Letterkenny Institute of Technology (LYIT) to become the new technological university called the Atlantic Technological University (ATU). This marks a new and exciting future for the west and northwest of Ireland. One of the main aims of this new TU is to increase its research capacity and further serve the regional needs. There is 21+ research centres within the new ATU. One these research centres in the Enterprise Ireland funded Medical Engineering Technology (MET) Gateway based in ATU Galway City. This centre supports research, development and innovation within the MedTech, life-sciences and engineering sectors. The MET biomedical engineering research centre addresses the needs of the Medtech sector by providing clinically relevant bio-simulators for advance testing of medical devices and surgical scenarios with the option of availing of MET's state-of-the-art medical imaging facility. The activities of MET addresses industry/clinical needs and supervise postgraduate research students to Levels 9 and 10.

The main aim of this paper is to highlight the challenges and the benefits of integrating research with undergraduate teaching.

2. Challenges with integrating research with teaching

There is an invisible wall separating third level research and undergraduate teaching. Roberson and Bond [3] describe this as "mutually incompatible activities" with "little or no correlation at undergraduate level". They also describe it as a "symbiotic relationship", which is a good description as both activities do benefit from each other's involvement. Over 30 years ago Boyer [4] stated

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"the time has come to move beyond the tired old teaching versus research debate" and this debate is still ongoing today. During the course of an academic year, research and undergraduate teaching have their own priorities. The research bias priorities would include acquiring funding, collaborating with industry, academia and other research centres, project deadlines, preparing for conferences, writing and submitting journal papers to name but a few. These research bias priorities are crucial for research survival otherwise if the money runs out, a research group could lose their grip on valuable office and laboratory space. The undergraduate teaching bias priorities within our university include high class contact hours, the demands of completing the syllabus within two semesters, various non research orientated departmental duties, lack of research active teaching staff and research is regarded as that other independent activity. For this invisible research/undergraduate teaching wall to break down it requires further time investment and support and as Clarke [5] states it needs to "merge in a seamless blend". Integrating research within teaching should be included as a key element of the scholarship of teaching [6]. The most influencing factors for research informed teaching are (1) individual's ability and motivation and (2) contextual factors such as resources, disciplines and university level drivers [7]. A hybrid approach of research active and teaching staff needs to be the gold standard for academics within tertiary education. This needs to be carefully managed with appropriate time allocation being provided to academics for their research and teaching activities.

3. Research-teaching nexus models

The research-teaching nexus provides a structured platform for the various types of interaction between research and teaching. Healey [2] proposes a four-quadrant research-teaching nexus with "student as audience" (teacher lead) at the bottom and "student as participant" (student lead) at the top with "emphasis on the product of research" at the left and "emphasis on the process of research" on the right. Starting at the bottom quadrants which are teacher led, we have research-led and research-oriented at the bottom left and bottom right quadrants respectively. Research-led is where the research content such as artifacts, information or data from your own research or others is informing the classroom lecture materials. Research-oriented describes the activity of teaching students about research methods, processes, approaches, and methodologies, and how to produce new research findings. As we move towards the top half of the research-teaching nexus four quadrant model, this is student led. The top right quadrant is research-tutored which describes the discussions and debate between students and staff which allow the opportunity for discussing research while research-based in described for the top right-hand quadrant and this is where students are actually being engaged in research as various research levels. Research-based is the preferred research-teaching activity as it allows higher order learning and students are actively involved in conducting research and/or analyzing research data or working within a research centre. Wuetherick and Turner [8] proposed a linear research-teaching nexus model. From left (teacher focused transmissive) to right (student focused conceptual change) their model also includes research-led, research-oriented and research-based similar to the research-teaching nexus model of Healey [2]. The model of Wuertherick and Turner [8] further splits the research-based into two sub-groups (1) explore a topic and (2) discovery of new knowledge. Exploring a new topic engages students with class activities that are derived from research or review of research article(s) which leads to inquiry or problem-based learning. The discovery of new knowledge allows students to become researchers in writing a project dissertation as would be the case for a final year project or the production and/or publication of research findings. A newer knowledge-based research-teaching nexus model was developed by Visser-Wijnveen [9]. It comprises of matrix of three rows and two columns. The bottom and top of this matrix is knowledge transmission and knowledge production respectively, while the left and right is research product and research process respectively. The bottom left and bottom right are the knowledge transmission of research products (research-led) and knowledge transmission of research processes (research-oriented). The left middle row is knowledge reproduction based on research products (research-tutored). Research-based is split into three sections comprising of: (1) knowledge reproduction based on research processes (inquiring or problem-based learning – right middle row), (2) knowledge production focused on research products (students participate in authentic research settings – top left row) and (3) knowledge production focused on research processes (students actively contribute to knowledge production – top right row). These three research-teaching nexus models provide teachers, lectures, programme developers with the examination tools for assessing where the research emphasis lies in a module and/or programme.

4. Research and undergraduate teaching interaction

Our research center and undergraduate teaching interaction will be discussed in two phases:

Phase 1 will describe our initial interaction and

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phase 2 will refer to our current day interaction.

4.1. Our initial research and undergraduate teaching interaction

Since the formation of our biomedical research centre named Galway Medical Technology centre (GMedTech) in 2005 and later Medical Engineering Technologies (MET) in 2014, there were various research-teaching interactions from 2005 to 2017 with increased activity from 2017 onward following the introduction of the three (Level 7) and four (Level 8) years Bachelor of Engineering (BEng) in Biomedical Engineering programmes. This interaction comprised of

- First year induction tours during the first week of college life. These tours were used to provide new students motivation in pursuing a career in engineering and was also a retention initiative.
- Final year fourth year BEng (Honours – Level 8) in Mechanical Engineering students who selected the biomedical engineering specialization stream were given a tour and short demonstration of the research facilities. These tours and demonstrations were given once per semester. Also, the research output was used to inform teaching notes.
- Since 2005, a cohort (one to ten students per year) of final year (Stage 4) and third year students would have completed their final year projects and work placement within our biomedical research centre. This provided hands on experience for the undergraduate students and facilitated the interaction of PhD candidates and research staff with the undergraduate students.

Unfortunately, during this time period, there was clearly not enough research teaching interaction for the majority of the mainstream undergraduate students who were in this case pursuing a career in biomedical engineering. The end of year feedback from these students in regard to research interaction consisted of the following:

"More tours of GMedTech"

"More time spent in GMedTech"

"Definitely some trips to GMedTech/ experiments or practical work would be very engaging"

"Do more practical's labs/demonstrations, watching real devices working"

"Incorporate hands on labs, which are always interesting"

"Let students to try a bit"

As can be seen from the above students' comments, there was a desire to have more integration of research within the programme and especially what was relevant to the course and to include practical labs which would involve the undergraduate students. This is further incorporating research based as described by the research-teaching nexus models.

4.2. Our research teaching interaction post 2017

In 2017, the author (LM) was the programme lead in introducing a four-year Bachelor of Engineering (BEng) in Biomedical Engineering. There was 80% commonality with the Bachelor of Engineering (BEng) in Mechanical Engineering with the introduction of ten new biomedical related modules embedded within the programme for all four stages of the programme.

The introduction of biomedical engineering provided an opportunity to further bridge the gap between our research centre and undergraduate teaching. The author (LM) lectures four of these modules (Medical Image Generation of Anatomical Structures and Functions; Biomechanics of Soft Tissues; Medical Devices I and Medical Devices II) and supervises between 3 to 5 final year projects per year.

5. Incorporating the research-teaching nexus

To fully achieve the integration of research-teaching within any module or programme, it is necessary to incorporate all quadrants of the research-teaching nexus as described by Healey [2]. The following are examples of this integration.

5.1. Research-led examples

Research data, anatomical models, medical devices, medical data and research publications were brought into the classroom via classroom notes and displays. These inclusions augment the teaching material and environment and further motivate the students to learn. This is a teacher led activity.

5.2. Research-oriented examples

A teacher led activity in which the process of research is described within the classroom environment. The importance of grant writing in acquiring funding from various funding agencies is described as well as report and review paper writing. Demonstrations within our centre and the importance of the ISO 9001 quality standard for performing research and industry collaborations are further

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emphasized to the undergraduate students from Years 2 to 4.

5.3. Research-tutored examples

The explanation of the products and processes of research lead to dynamic discussions within the classroom and research centre. This provides the learners with an opportunity to fully engage with the material in a meaningful way. MET research staff have provided guidance to undergraduate students on projects completed within the centre. Some collaborators of research centre are very generous with their time and give guest lectures with a questions and answers session afterwards. These guest lecturers have been from our MET research centre (research engineers, manager of the centre and PhD candidates), surgeons and industry (R & D and manufacturing engineering managers, CEOs and co-founders from start-ups to multinationals).

5.4. Research-based examples

This is student lead and are actively involved in the research process. Students write and present review papers on a variety of topics which include diseases (year 3), medical devices or therapies (year 4 – semester 1) and up-and-coming medical technologies selected from Enterprise Ireland's Big Ideas or Cleveland Clinic Innovations or a start-up medical technology from the ATU's incubator hubs (year 4 – semester 2). In year 2 of the programme, learners are introduced to medical image datasets provided by our research centre and apply the open-source software 3D Slicer to segment the images and generate virtual and 3D printed anatomical models. These medical image datasets are further analyzed by the undergraduate students in years 3 and 4 for anatomical structure & function assessment, and disease-medical device evaluation respectively. Students conduct various laboratory experiments using the state-of-the art equipment within our research centre. For example, learners (Year 3) get to assess the flow field with a 4D ultrasound machine within an anatomical model of the human aorta with pulsatile flow simulated with a bio-simulator. Learners also deliver and monitor the performance of an endovascular medical device for the treatment of coronary artery disease & aneurysms, and surgically replacement heart valves within our medical imaging suite which comprises of a Philips Azurion image-guided therapy system with 4D ultrasound. Final year project and work placement students would work within the research facility gaining further insights on the work carried out and how to complete a project within a research-based environment. These interaction examples with our research facilities and hands-on approach with a range of medical devices further develops students' interest and understanding of the topic.

6. Students' voice

The feedback from the students was very positive and complementary regarding the various stages of research-teaching interaction as described by the research nexus four quadrant model. The followings are feedback for various aspects of the research nexus model.

6.1. Research-led and research-oriented feedback

This teacher lead activity is grouped together as both the research product and process inform the moduli syllabus:

"Notes were excellent"

"Very well taught"

"New learning experience on biomed engineering, a good change from the usual"

"It was different to most modules more interesting"

"Work done in research centre was very interesting"

"Interesting to see how these machines work in person"

6.2. Research-tutored feedback

The first two students' feedback are related to class interaction dynamic while the latter two refer to the guest lecture talks.

"There was a great atmosphere in class, yet we still were able to learn"

"Our lecturers enthusiasm made the class very enjoyable"

"Very good advice, got an insight from multiple people with experience in the field"

"*Very interesting and a good insight into the career of an engineer*"

The feedback regarding the inclusion of a questions and answers section

"*Good idea, other students asked questions I would not have thought of*"

6.3. Research-based feedback

The followings are the feedback on the student interaction with the research facilities.

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"I really enjoyed the review article for soft tissues allowing us to do some self guided research"

"Tour of medical imaging suite assisting in my understanding of the topic"

"The actual physical interactions in the MET centre were the best part"

Further feedback on what students liked the most included:

"The real-life aspect"

"Hands on with devices"

7. Discussion

This paper shows an example of how the research-teaching nexus is being used within four modules of the biomedical engineering programme with the ATU – Galway and taking the students' voice into consideration. Teaching and research have been seen within universities as two separate activities and the word 'nexus' which means 'linkage' or 'connection' is an important link that needs to be formally acknowledged. Tight [10] reviewed the literature in examining the linkage between research and teaching at a global level. They found that many cases reported a weak to no link between research and teaching within the third-level sector. Over thirty years ago, Boyer [4] stated the following "the most important obligation now confronting the nation's colleges and universities is to break out of the tired old teaching versus research debate and define, in more creative ways, what it means to be a scholar". The research-teaching nexus has not fully developed within academia when compared to scholarship of teaching and learning [10]. However, Tight [10] did report many publications showing the integration of research and teaching within many discipline areas including engineering. The integration of research within teaching should be included as a key element of the scholarship of teaching [6].

The integration of research with undergraduate learning is a key learning resource which motivates undergraduate students for further learning. Students learn when they are involved and engaged. Research-informed teaching via the research-teaching nexus, provides students with a learning platform which promotes a greater, deeper, and more enriched understanding of the subject matter. The four-quadrant nexus model provides a guided pedagogical approach for integrating research material and infrastructure into the undergraduate curriculum from the teacher lead perspective to the more enriched student led activities, especially the research-based quadrant. This allows the teacher to be a facilitator of learning. Providing a research-teaching environment facilitates the interaction of PhD candidates and research staff with undergraduate students. This gives the undergraduate students the opportunity to work with the postgraduate candidates and use the research facilities. This interaction develops the undergraduates' interpersonal, problem solving, research, and critical thinking skills. Also, the postgraduate students develop their interpersonal, mentoring and teaching skills. The research interaction showcases the multi-disciplinary nature of biomedical engineering. This is further supported by guest lecture talks from various experts based within our research centre – presenting our latest research, from the medical device technology industry sector and from the clinical community. The analysis and assessments completed by the students are now on at the higher end of Bloom's taxonomy, which allows students to critically examine the topic. As a result of this, the students have learned a new topic area and have a greater understanding of the interaction of engineering with medicine. As can be seen from our study, the students have commented very positively towards the incorporation of research within the classroom and coursework. Over the years, many students have completed final year projects within our research centre, and this has resulted in the author (LM) supervising to completion four former PhD graduates who have gone all the way from undergraduate level within ATU-Galway (formerly GMIT) to PhD (level 10).

8. Conclusion

Access to the resources within the Research centre can be booked in advance. The laboratories within this centre are not designed for large group sizes of 16 – 24, therefore group sizes are spilt into smaller sub-groups to accommodate this interaction. There is excellent cooperation between the research staff and the author (LM) in setting up experiments and research equipment for undergraduate learning.

For research teaching interaction to work it needs to be an acknowledged activity at department, school and university level and fully resourced not just the good will of a few individuals. It just cannot be done on an ad hoc basis. Ideally, the academic researcher should be teaching the relevant modules as was reported in this study.

We must therefore think actively about how to bring teaching and research together for the benefit of all learners including the postgraduate students and research staff. It is critical that this activity is acknowledged and promoted within the scholarship of teaching and learning.

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