Tasting Genuine Research in a Course on Tissue Engineering

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1 BACKGROUND AND THEORETICAL FRAMEWORK

Engineering education has been criticized for neglecting to provide students with opportunities to develop skills that are crucial to practicing engineers [1]. These skills include, for example, communication, team-working, project management, and problem-solving [2, 3]. In research-intensive areas of engineering, education should provide additional experiences such as exposure to the primary scientific literature, formulation and evaluation of hypotheses, and the scientific methodology [3, 4]. These aspects need to be moved into the focus of engineering education to prepare students for their future professions.

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Interventions to improve engineering education, such as the implementation of active and collaborative learning, have mainly targeted first- and second year courses. Little work has been done to improve teaching and learning in later courses. It is, however, important to keep students interested throughout their education and help them to advance beyond simply memorizing knowledge. One interesting approach that has gained momentum in this respect lately is to create a stronger link between research and teaching in higher education. David Lopatto conducted an extensive study of the impact of *extracurricular* undergraduate research on student learning, and benefits from the experience [3]. He identified ten areas where students develop, improve and benefit from undergraduate research experience: Interaction and communication skills, data collection and interpretation skills, professional development, personal development, design and hypothesis skills, professional advancement, information literacy skills, responsibility, knowledge synthesis, and computer skills.

There are different approaches to link research and teaching in a course setting, rather than in *extracurricular* activities. These can be captured in a framework developed by Healey, focusing on the level of student engagement and whether the emphasis is on the results or the methods of research [5]. Based on this framework, four distinct approaches can be discerned: *research-led*, *research-tutored*, *research-based*, and *research-oriented*. These are described in Figure 1.

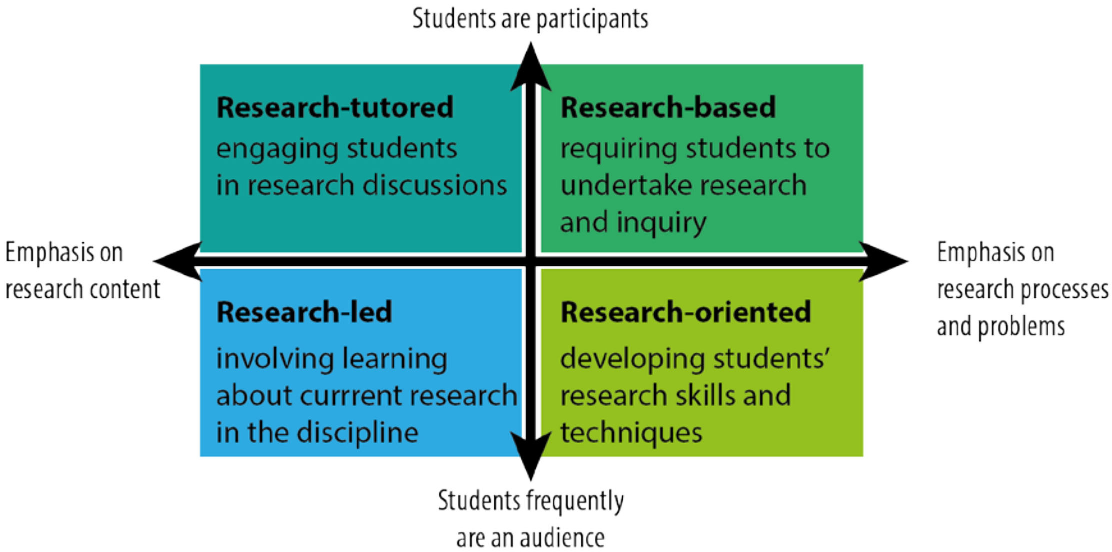

Fig. 1. Four different approaches to linking research and teaching [5].

In this paper, we draw on the framework above to discuss the design of the Master's level course *Tissue Engineering* at Chalmers University of Technology. We wanted to explore different possibilities to establish a link between research and teaching in this course, and investigate the practical consequences it creates for teaching. A strong link between research and teaching is crucial in tissue engineering education, because it is very research intensive both in academia and industry, and graduates that are going to work in the field are required to have the ability to advance the scientific frontier. Our aim here is to see how the different approaches to linking research and teaching affect students' learning and their perception of the course.

We first provide an overview of the course, the teaching and assessment methods, and how different links between research and teaching are made according to Healey's framework. This description is followed by an analysis of students' perception of the course and self-reported learning outcomes, gathered over six years (2007-2012), using the benefit categories from Lopatto. We end this article by discussing some challenges in integrating research and teaching in this course.

2 TEACHING AND ASSESSMENT METHODS IN THE COURSE

The tissue engineering course is an advanced level course worth 15 ECTS-credits and most students take it in the first year of their master program. The course is listed in the Biotechnology as well as Biomedical engineering Masters programs, but there are also a few students from Materials engineering and Applied physics taking the course. There is a maximum of 20 students that can take the course due to a limit in the course budget. The aim of this course is to introduce student to scientific methodology and experience experimental research. The course also provides students with a general overview on tissue engineering, a chance to interact with researchers in academia and industry, and prepare them for later work in the field.

The course draws on the framework by Healey [5] to create different types of links between research and teaching. *Research-led* teaching is used to communicate general aspects of tissue engineering in lectures (see section 2.1). *Research-tutored* teaching is used in article review session to improve students' capabilities to read, discuss and evaluate primary literature (see section 2.2). Furthermore, there are site visits to companies working in the field (see section 2.3). *Research-based* teaching is used throughout the course in the group projects (see section 3).

2.1 Lectures: Research-led teaching

Throughout the course, students have lectures on general aspects of tissue engineering. The majority of these lectures are not directly coupled to the project work, but rather provide a holistic view of the field and knowledge in areas that are relevant for all projects. There are basically two different kinds of lectures. Lectures directly coupled to the content of the textbook, and lectures from experts in the field, including clinical, industrial and other academic researchers, who can couple certain topics of the course to their own research activities.

2.2 Article review sessions: Research-tutored teaching

During the course, students have article review sessions, where they learn the basics about critically evaluating scientific literature. The articles for these sessions are not related to their own project, but highlight recent key breakthroughs or scientific findings of general interest for tissue engineering. After reading the article, students write a short two page report pointing out strong and weak points in the article, the main message and possible ways to improve it. These reports form the basis for a discussion, where 8-10 students meet with one teacher. Students discuss their findings amongst each other in smaller subgroups of 2-3 and later with everybody. The teacher gives some background information about the peer-review system in general and explains important aspects of publishing scientific results.

2.3 Site visits to companies

Site visits to companies are part of the course to give students a chance to get in direct contact with people working in industry on tissue engineering related questions, as well as to show how tissue engineering is commercialized. The site visits illustrate differences between academic and industry working environments, both with respect to physical working conditions and working approaches.

2.4 Assessment

Student learning is assessed in the middle and at the end of the course. General aspects of tissue engineering are covered by a written and oral exam, and the article reviews are graded. The project grade consists of two parts: a group grade and an individual grade. The group grade is based on a half-time planning report and presentation, a final written report and presentation, and the ability to answer questions and discuss project findings at the presentation. The individual grade is calculated as the average of grades given by fellow group members.

3 THE GROUP PROJECT: RESEARCH-BASED TEACHING

The main teaching and learning activity in the course is the project, which runs over the entire five-month period of the course. All projects are directly coupled to ongoing research efforts, thus allowing students to work on relevant scientific questions. This strong connection is at the heart of research-based teaching and encourages *inquiry-based learning* [6]. The aim is to teach students not only the outcome of research experiments, but to give them the opportunity to learn and experience research as it is conducted. The key objective is that students learn scientific methodology and understand scientific research.

The main research questions and background of the projects are presented to the students in short five minute presentations during the first day of the course, and afterwards students sign up for the project they want to work on. Students can choose freely, but there are limited places for each project to ensure an equal distribution. After the selection process, students meet with their tutor and get a more detailed introduction to their project. The aim for the project is that students and tutor form a team, that students get practical training on analytical methods and discuss different ideas together in order to answer a research question via the project work.

3.1 Project design

All projects are directly coupled to ongoing research efforts at the two hosting institutes. It is important that the scientific question of the project is both relevant for the research field and even more importantly suitable for the students to work on during the five-month project period.

The projects differ each year and between groups, as they are related to ongoing work. However, the general layout is similar in all projects and can be divided in four phases that capture the entire scientific process. In *phase 1*, the students need to get an overview of the scientific field and do literature reviews to see what other people have done. During this phase, students are encouraged to develop their own ideas and hypothesis that they want to investigate in the project. In *phase 2*, the students get practical training in how to work in the laboratory and how to operate the equipment needed for their experiments. The experiments start in *phase 3*, which normally takes around 8-10 weeks depending on the specific project. In *phase 4*, students analyze their data and evaluate their results. They need to reflect on their own results and methods, go back to the literature to put their findings in the context of previous research, as well as propose future experiments. At the end of the course, each group prepares a self-reflection file, where they compare the project expenses with their projected budget, reflect on their time planning versus actual time spent on the different parts of the project, as well as reflect on the overall experience they had working as a group and give advice to next year's students.

3.2 Project tutoring

Each project has one or two tutors who help the students during their work. Most tutors are graduate students or postdocs; the majority are former course students. The tutor plays a very important role in the project, as he/she is in constant and direct contact with the students. The tutor is the main responsible to teach students practical skills in the lab, show them how to work with the equipment, guide them through their project, help them if they have questions or when problems occur, and intervene if things do not work as planned. Furthermore, he/she should also help the students to develop over time through feedback and discussions.

4 EVALUATION OF THE COURSE

The results presented here are based on student self-reflections and course evaluation forms collected between 2007 and 2012. Self-reflection files are written by the project groups (N_{groups}=17) and are directly linked to specific projects, and evaluation forms are filled out anonymously by individual students ($N_{students}$=103) at the end of the course.

Overall, the approach we used is very successful and 85% of the students fully agree that the course is worthwhile (14% partly agree and 1% strongly disagree). The students also think that they get a good overview of the tissue engineering field (74% strongly agree and 25% partly agree). The research-based teaching, in the form of student projects, is perceived to be worthwhile by 96% of the students. They also report that learning from the project is rewarding (89% fully agree, 9% partly agree and 1% are hesitant):

"We can say that the project was very interesting and useful for all of us, gaining high amounts of knowledge in such a short period of time."

"No literature reading nor demonstrations can give a better understanding for anything as one gets with hands-on experiments."

In detailed analysis of the data, we see similar results as David Lopatto in his work on *extracurricular* undergraduate research projects [3]. We want to highlight five of the ten categories Lopatto used to describe the benefits of undergraduate research.

Personal development

We find that nearly all students are very motivated to work on their projects and that they spend a lot of time on them. The strong link to research makes the project relevant and something valued by others, which is very important for the students:

"Further the project felt very essential in being up to date, and we felt that the project could be a part of the future or constructing our future."

The students also see the project experience as a great possibility for personal development and learn important aspects far beyond tissue engineering:

"I think we (I) have to become more confident, responsible and able to take initiatives, while keeping a good communication to the group I was working with. I am also learning how to deal with the fact that every person has his/ her own way of working and how these situations can be turned to the advantage of the group instead of making it dysfunctional. It has taken energy and time but it is very helpful."

The students are very ambitious and want to deliver good results. This can sometimes be difficult, especially if experiments do not go as planned. In these cases, it is important that the tutor helps the students and also makes them realize what they have accomplished throughout their project, even if they could not get results from their main experiments:

"Although we did not manage to accomplish a complete product in our work, we have constructed a system that definitively has potential in future research."

Design and hypothesis skills

Scientific methodology is one of the core learning objectives of the course. It is part of the article review session, some of the lectures and especially important in the projects. The aim is to provide students with an overview and an experience of the entire scientific process. Through the projects, students learn many practical aspects of science often not covered in lectures:

"It was also instructive to face the huge difference that exists between what looks basic on the paper, and takes hours in the lab."

Students develop their own questions and hypotheses, evaluate the literature, perform their experiments, analyze their results, discuss their findings and present their work in written and oral form. The article review session complements the project work nicely, as the last step of scientific publication is not covered within the project.

Data collection and interpretation skills

Students are responsible for the results that they get during the project, but they are guided and provided with help from their tutor. The quantitative data shows that the students prefer this approach and have a strong desire to perform experiments on their own. 92% prefer "to perform more experimental work yourself, with no guarantee of results but opportunity for hands-on experience", whereas only 8% prefer "to allow others to perform most or all of the tasks, with higher chance for successful results, and you get to analyze the data which others collected".

"We got the opportunity to perform most of our work ourselves and it was really useful and gave us really good experience!"

Information literacy skills

We see positive responses for the article review sessions in our course where 75% of the students report that the article review session was worthwhile (23% somewhat worthwhile, and 2% not useful). The research-tutored approach with article review sessions complements the other teaching approaches within the course and helps the students to acquire literacy skills like reading, understanding and evaluating scientific articles:

"The article reviews really gives you an opportunity to learn how to read and learn from scientific articles. I find this to be one of the best things that a course can have."

"I think article reviews is the good way to practice analytical thinking and should be done more"

The advantage in our course is that we are able to take one further step, because the students can directly apply their literacy skills to the projects. The article review sessions help them both in evaluating the literature and to write their own report:

"It provides the points which you should care about when you write your own report."

Knowledge synthesis

The project gives students the possibility to intensively work on a defined topic for five months. This is very important for students, as it allows them to develop the ability to synthesize a coherent body of knowledge:

"We are happy this project is part of the tissue engineering courses, as we feel that a project work is a good way to delve deeper into a subject of choice, and thereby

increase our knowledge."

"From a general point of view, it was interesting to have enough time to explore the whole theoretical part in the first part of the course and experiment it in a practical way during the second part."

It is very difficult for students to have a similar experience in a classic lecture setting. The experience is further enhanced by the written and oral presentation at the end of the project, because students need to put their results and knowledge into context in a way that others can understand and follow.

5 DISCUSSION

Mixing different approaches to link research and teaching provides our students with a very rich learning experience. When designing the course, we decided to draw on more than just one of the four research-teaching links, as we believe that they address different aspects and can improve student learning in different ways. If only research-based teaching had been used in the form of group projects, it would not have been possible to give a good overview of the field. To achieve this, lectures and site visits are necessary. Article review sessions are needed to help students to develop literacy skills like reading, understanding and evaluating scientific articles. The combination of research projects and site visits gives students the possibility to interact both with academia and industry, and to experience the differences. As not everybody wants to stay in academia, it is important to provide different options and help students in their professional development from a holistic perspective.

Students become part of the academic research environment through their projects, the article review sessions and the lectures. All students are in close contact with faculty and researchers during the projects and can build up relations. They also get in contact with other researchers during the invited lectures and with different companies during the site visits. Unfortunately, we do not have any detailed follow up data on what our students are doing after they graduate, and only know for a limited number where they work now. However, we have received good feedback from companies and other research labs that have taken students for thesis projects, indicating that they are pleased with the high level and wide range of skills the students have acquired.

We agree with Lopatto [3] and others that project design and tutoring are essential to provide students with a good learning experience and for them to achieve the desired learning outcomes. The project scope needs to be carefully considered to help students develop in all ten categories identified by Lopatto. The strong connection between tutor and students means that the tutor has the main responsibility for the project related learning outcomes. In the data from the last six years, we see that learning outcomes can vary widely between different projects. We currently study in detail possible reasons for these variations and consider different measures to allow all students to have a fruitful research experience. The aim is not to make all experiences the same, because we strongly believe that the close connection to research and freedom in the project outweighs the possible disadvantages of disparities, but every student should have equally good opportunities.

There are several important differences between undergraduate research as an extracurricular experience, as Lopatto studied, and our method where undergraduate research is part of a course. One challenge in the course setting is the evaluation and assessment. Many of the learning outcomes are very difficult to measure and can only be seen in the in context of the entire experience. We try to address this problem by a grading scheme that looks at all the different parts of the course and peer-grading helps to assess individual contributions. In general, this works well and students are satisfied. Even more importantly, students often realize that they learn a lot for themselves and highly value the experience that they get. The second difference of the course approach, at least in our case, is that students work in groups rather than alone. We think that this is actually an advantage, because they will most likely work in groups later on in their careers and thus the acquired skills in group-dynamics and communication will be helpful for them. It also allows for a larger number of students to have a research experience during their studies.

Given the very positive comments from both our students and external stakeholders, we encourage other engineering educators to adopt or adapt the approaches to integrating research and teaching described in this paper to their own teaching context to enhance student learning.

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