Education for Chemical Engineers 24 (2018) 52–59

Contents lists available at ScienceDirect

Education for Chemical Engineers

journal homepage: www.elsevier.com/locate/ece

Implementation and assessment of an undergraduate tissue engineering laboratory course

Cheryl Bodnar[a], Thomas R. Christiani[b], Kevin Dahm[c], Andrea J. Vernengo[b,c,*]

[a] Experiential Engineering Education Department, Henry M. Rowan College of Engineering, Rowan University, United States
[b] Biomedical Engineering Department, Henry M. Rowan College of Engineering, Rowan University, United States
[c] Chemical Engineering Department, Henry M. Rowan College of Engineering, Rowan University, United States

ARTICLE INFO

Article history:
Received 5 December 2017
Received in revised form 7 May 2018
Accepted 18 July 2018
Available online 20 July 2018

Keywords:
Tissue engineering
Mesenchymal stem cells
Assessment
Concept maps
Adaptive expertise

ABSTRACT

This study focused on examining how students' perception and understanding of the tissue engineering field changed as a result of their participation in a hands-on experiential learning module. The module involved the cellular and biochemical characterization of three-dimensional cultures of mesenchymal stem cells in chondrogenic media. Students were instructed to complete concept maps depicting their perception of the tissue engineering field both prior to and after completion of the module. Similarly, they had to respond to provided design prompts and identify experimental tests and questions for doctors that would allow determination of their adaptive expertise. The results from this study demonstrate that students significantly broaden their perception of the tissue engineering field through statistically significant changes in their comprehensiveness and correctness scores on the concept map rubric. Similarly, the results of the adaptive expertise analysis demonstrate that students significantly increased adaptive expertise upon completion of the module in comparison to their responses at the start of the module. These results imply that a hands-on experiential module can be a beneficial tool for teaching students the complexity associated with a multidisciplinary field such as tissue engineering.

1. Introduction

Tissue engineering, a rapidly growing area in biomedical engineering, has shown tremendous promise as an alternative to tissue harvesting, artificial tissues, and prostheses (Lysaght and Reyes, 2001; Mooney and Mikos, 1999). Tissue engineering aims to restore or regenerate lost or damaged tissues in the body by combining cells, scaffolds, and growth-stimulating signals (Lanza et al., 2013). The scaffolds provide structural support for cell attachment during the process of extracellular matrix (ECM) formation by the cells. Therefore, tissue engineering has continued to evolve as a multidisciplinary field involving biology, material science, engineering, and medicine.

As organ transplants have major limitations such as rejection and lack of donors, and medical devices do not completely restore tissue function, tissue engineering is a field of emerging importance as it has potential to provide better solutions to tissue repair in the clinic. Despite the demand for better technology to meet the needs of the growing aging population, there are a very limited number of literature articles published on tissue engineering education, although some have been reported. For instance, an activity was developed in which students evaluated the viability, attachment, and proliferation of fibroblasts on one-dimensional polymer film (Saterbak, 2002). In another module, students look at the effects of mechanical loading on differentiation behavior of mesenchymal stem cells (McCord et al., 2004). In 2013, *A Laboratory Course in Tissue Engineering* (Micou and Kilkenny, 2013) was published, the first text teaching hands-on tissue engineering techniques to upper-level undergraduates or graduate students. The laboratory activities cover advanced topics such as evaluating cell patterning, measuring cell motility, and microfluidics.

In this paper, we describe in detail a hands-on module that was implemented into a senior-level chemical engineering elective, Fundamentals of Tissue Engineering. In contrast to previously developed activities (McCord et al., 2004; Micou and Kilkenny, 2013; Saterbak, 2002), the labs we report here are aimed towards engineering students who have little or no experience with sterile technique, mammalian cell culture, cell biology or concepts in regenerative medicine. Thus, the curricular materials are readily adaptable into core classes in chemical or biomedical engineering programs. Furthermore, the activities utilize equipment that exists already in most academic facilities and course instructors

---

* Corresponding author.
E-mail address: vernengo@rowan.edu (A.J. Vernengo).

https://doi.org/10.1016/j.ece.2018.07.002

will not need specialized expertise in order to implement them in their courses.

The module was designed to contribute to important learning outcomes in STEM disciplines by uniquely integrating clinical medicine and engineering, providing students with a better understanding of the breadth of this field. In addition, it was hypothesized that the module would increase students' adaptive expertise. Engineers with expert-level adaptive expertise approach engineering problems by analyzing them from multiple perspectives and adapting to the challenge by developing unique and effective solutions (Bransford et al., 2000). Herein, we give an overview of a hands-on module on tissue engineering of cartilage and an assessment of its impact on the development of students' understanding of the breadth of the tissue engineering field and their adaptive expertise development.

Specifically, we seek to answer the following two research questions:

1. Does the tissue engineering module contribute to increasing students' understanding/perception of tissue engineering through an increase in concept map scores?
2. Is there any change in students' adaptive expertise as a result of their participation in the tissue engineering module?

2. Methods

2.1. Study design

This study was conducted with a class of 22 students that participated in a hands-on module that was implemented into a senior-level chemical engineering elective, Fundamentals of Tissue Engineering. As part of their course work, students were asked to complete a concept map that describes their understanding of the tissue engineering field along with respond to two design scenarios to assess their perception of the tissue engineering field and level of adaptive expertise both prior to the start of the hands-on module as well as at the end of the course. Prior to completing their concept maps, students were guided through a concept mapping exercise using a well-known item as the central idea. This allowed students the opportunity to learn about how concept maps are created and methods for integrating concepts that appear on the map.

All assessment products, concept maps and adaptive expertise responses were labeled with identifiers that allowed for the analysis to be performed with de-identified data. Proper human subjects' approval was obtained prior to the completion of this study.

2.2. Concept map analysis

Concept maps were selected for their use in this study as they have been shown to be effective assessment instruments at demonstrating how students' personal comprehension and understanding of a field is changing over time (Farrell et al., 2017). They have also been used to evaluate programs that involve inter-disciplinary concepts such as green engineering (Borrego et al., 2009), sustainability practices (Bielefeldt, 2016), and systems medicine (Lasota et al., 2015), which makes them particularly relevant as an assessment tool for this hands-on module within tissue engineering.

We selected to analyze the concept maps using the Integrated Rubric for Scoring Concept Maps (Besterfield-Sacre et al., 2004). This rubric evaluates the concept map on the basis of its comprehensiveness, organization and level of correctness. Comprehensiveness is used as a measure of how students are able to capture the breadth and depth of the existing field through the concepts that they include on their maps. Organization reflects how the students place concepts on the map and the linkages that they include between different concepts. Finally, correctness measures whether students are appropriately making connections between the concepts that they have placed on their map. As was observed previously (Lasota et al., 2015), we also found that the concept maps did not fit specifically into any of the three scores provided and thus used half-point scores (1.5 and 2.5) for scoring. This modification to the scoring approach was used to more accurately capture the students' level of graphical organization applied within the concept map. For instance, a concept map that was rated a 1.5 (versus a 1 or 2) was defined to be a concept map that has a combination of the features outlined in 1 and 2 but does not fit well into either category. A similar approach was taken for the concept maps that were rated a 2.5. Modification to the scoring rubric was performed at the onset of the study to ensure consistency and allow for all concept maps to be scored using the modified rubric.

Two raters met with the content expert on this study to determine what metrics would be used when evaluating the concept maps. The raters were both chemical engineering faculty members with experience in educational project assessment. One of the raters had a background in tissue engineering from prior research work while the other rater did not have a technical background in the tissue engineering field. The raters evaluated a subset of the concept maps, 5 total, on an individual basis and met to discuss any discrepancies with the content expert. Once the raters were aligned in their assessment approach, all of the student maps were separately evaluated by both raters after which final scores for each dimension of the rubric were determined. Total concept map scores as well as scores for each individual dimension were compared between the start and completion of the hands-on module using a paired samples t-test and a Wilcoxon Rank Sum test to account for the small sample size. Both the parametric and non-parametric test results were found to be in good agreement with one another.

2.3. Adaptive expertise

Schwartz et al. (2005) reported that there are three dimensions of adaptive expertise: efficiency, innovation, and confidence. Efficiency, in terms of engineering design, is defined as the ability to develop appropriate strategies to address a design problem. It requires the ability to retrieve and apply skill and knowledge. Innovation can be described as the students' ability to "think outside the box" by considering a problem from multiple perspectives and solving it by breaking away from routine approaches. Research has also shown that adaptive expertise requires high confidence coupled with high competence to support successful resolution of engineering problems (Walker et al., 2006).

The impact of the module on adaptive expertise was assessed using the technique published by Walker et al. (Walker et al., 2006) The pre and post-assessment consisted of complex, open-ended design scenarios (Fig. 1) that were developed by the project investigators to represent potential real-life engineering problems encountered by clinicians. The design scenarios were presented to the students immediately before and after the module. Different design scenarios were provided to students as part of the pre-and post-assessment performed as students would receive feedback on their responses to these questions as part of course activities and we did not want this feedback to influence our measurement of changes in students' adaptive expertise. For each design scenario, student responses to three questions were analyzed. The first question, "What do you need to do to test the doctor's hypothesis?" was used to assess student efficiency. The second, "What questions do you have for the doctor?", was used to assess innovation. The third question addressed the third dimension of adaptive expertise, "How confident are you in your answers?"

Assessment of the student responses to these questions was based on what was reported by Walker et al. (Walker et al., 2006).