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TOWARDS INTEGRATION OF THE FINITE ELEMENT MODELING TECHNIQUE INTO BIOMEDICAL ENGINEERING EDUCATION

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ABSTRACT

Biomedical engineering (BME) is a multidisciplinary field, resulting in a heavy course load from different fields. We hypothesize that the engineering curriculum be tailored according to the requirements of the BME profession. In this study, we focus on the teaching of the finite element modeling (FEM) technique by redesigning the course to address the needs of the BME profession by some custom-made changes to meet the unmet needs. After the completion of the course, evaluation methods of the students were analyzed and detailed over a survey providing feedback from the students. The surveys were related to the teaching the theory of FEM, the laboratory sessions, and the project sessions. The survey results were evaluated using statistical methods. The Pearson correlation coefficient showed a linear agreement between theoretical and practical sessions indicating efficient blending of skills because of the custom-made changes. The survey analysis showed that the students were in favour of the changes, allowing them to be more resourceful and confident with their skills. The positive results indicate a positive attitude among the students towards their profession. As the course design addresses the needs of the profession allowing students to fit in better, the students might follow their own profession after graduation. A wider follow-up study might be planned next to compare the results between who received tailor-designed courses and those who did not.

Keywords: Biomechanics; Finite element method; Course design; Applied engineering; Project reporting; Validation; Verification; Writing skills.

INTRODUCTION

Biomedical engineering (BME) is an emerging field in engineering education. Biomedical engineering education has been evolving and proliferating since the 1950s in the last century.[1] The first program in BME master's education launched officially at Drexel University, Philadelphia, PA, USA, in 1959. Following this, PhD programs at Johns Hopkins University, Baltimore, MD, USA and the University of Pennsylvania, Philadelphia, PA, USA[2] were launched. Currently, undergraduate BME education is emerging as a single discipline, rather than a hybrid specialization of interdisciplinary subjects. The development of new curricula in this field is taking place rapidly around the world, following the recent trend. These programs are diverse and they vary in content.[3–5] Today, BME consists of many specialties such as artificial organs, assistive technology and rehabilitation

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engineering, bio-electromagnetism, bioethics, biomaterials, biomechanics, biotechnology, biomedical instrumentation, biomedical sensors, bio-nanotechnology, bio-robotics and bio-mechatronics, clinical engineering, medical and bioinformatics, medical and biological analysis, medical imaging, neural engineering, physiological systems modeling, simulation and control, prosthetic and orthotic devices, tissue engineering, and regenerative medicine.[4,6] Each one of the key divisions in BME is considered as a field of study or research on its own.

Biomechanics is one of the essential key divisions in BME.[7] The dictionary definition of biomechanics is "the study of mechanical laws relating to the movement or the structure of living organisms".[8] Although BME is thriving as a field of its own, the division of biomechanics significantly uses the basic principles and advanced topics of mechanical engineering. On the other hand, in mechanical engineering, there are many other key divisions such as statics, dynamics, mechanisms, the strength of materials, theory of machinery, numeric methods, finite element modeling, thus establishing sound and firm fundamentals for mechanical engineers. One of the methods which is widely used in biomechanics is the finite element method (FEM). In mechanical engineering, FEM is a key division using numerical techniques to obtain approximate solutions to a class of problems governed by partial differential equations (PDEs) while using boundary value conditions to solve PDEs. In mechanical engineering education, structural FEM courses require students to have completed courses of statics, differential equations, the strength of materials, and numerical methods. In BME, FEM is a widely used and significant methodology for solving complex problems in the biomechanical engineering discipline, especially in areas of orthopaedics. However, the fact that there are more than 20 key divisions in the undergraduate education of BME, covering a wide range of topics from anatomy, electrical engineering, molecular biology, and genetics to tissue engineering, makes it impossible to expect BME students to have built the required fundamentals for FEM courses by completing the list of prerequisite courses as in the mechanical engineering education. Due to the limited time and the wide range of courses, bringing students up to the level of FEM applications — as in mechanical engineering education — is a challenge. To overcome this challenge, there is a need to carefully design the course that is dedicated to the teaching of BME.

Computational modeling, which is another widely used term covering FEM, has been a challenge and point of interest in engineering education already. The papers of Babuska and Oden provide detailed information on the history of FEM.[9] Time-consuming numerical equations and solutions are required in FEM, in addition to programing skills either in MATLAB[10] or in any other programming languages such as FORTRAN, C++, and Python. For an engineering student to be competent in FEM applications, programing increases the burden in the already-overloaded portfolio of courses in BME.

Brinson *et al.*[11] covered new methods in design and computational mechanics for undergraduate education in mechanical engineering education. The initial implementations which required significant changes in the way of teaching were due to the advancement of computers in the field. In the current courses (i.e. statics and strength of materials) there was an addition of extra courses: linear algebra, introduction to matrix methods of structural analysis including truss elements in one and two dimensions, and constant strain triangle. For the application, design analysis projects were also added. They integrated programing applications into the course design. In a study[11] performed at the end of the last century, only integration of MATLAB was mentioned due to the ease of its access and the ease of coding. However, software packages for engineering analysis (EA) were missing as it was the early years of package software programing applications in mechanical engineering, which is a norm nowadays.

Although programing and the advancement of computers eliminate human-based errors and make life simpler for engineers, in the case of FEM models, there is a need for verification and validation processes. In FEM analysis, validation steps provide evidence. This stage is very important for the results to be evaluated correctly. Validation tasks require either experimental work or comparing the results to previously validated models. Without validation, finite element (FE) results are just computer output lacking underpinning evidence. Previously, Cyr *et al.*[12] emphasized the importance of experimentation in undergraduate mechanical engineering education in their paper titled "A Low-Cost, Innovative Methodology for Teaching Engineering Through Experimentation". In his work, he exampled the importance of low-cost experimental methods and how it helped engineers have a proper understanding of engineering topics. However, his work did not include the FE methodology or its validation, which is a fundamental need in BME education. BME relies heavily on evidence-based research and, in order for medical designs to be accepted, there is a need for evidence generated from computer-aided design tools and simulation programs, validated by experimental results supporting computer simulations. This way, the designs can be approved and passed into clinical trials. For this reason, in BME education, there is a need for the inclusion of theoretical calculations, as in FEM, as well as for experimentation including verification and validation of the model demonstrating how to conduct evidence-based projects to BME students.

In this study, instead of pure theoretical teaching of FE modeling techniques to BME students, a more interactive approach is preferred. As described in the paper "Polishing the Gem: First-Year Design Project",[13] BME students were asked to design their own product. Involving students in the design process allowed them to use their creativity, critical thinking skills, and to translate theory into practical applications. Via computer simulations, students were able to observe the effect of different decision points by entering multiple variables as an input for their design and it also allowed them to analyse the results accordingly during the course.

One of the major challenges of engineering education is the lack of integration of writing skills into the curriculum. In engineering education, students make a common mistake: they use formulas as shortcut recipes without understanding the fundamentals behind them. For BME professionals, it is very important to provide detailed reports of already applied scientific methods with evidence. Newcomer and Steif[14] designed a study to investigate the understanding of students in the usage of concepts while answering multiple-choice exam questions. Here, instead of using multiple-choice exam questions, which are not encountered in real-life engineering applications, we follow a more pragmatic approach, and we require students to produce professional reports instead. By providing a report template for students, we aim to improve the professional report-writing skills of the BME students. As mentioned in the study of Wheeler and McDonald,[15] the similarities between writing and design processes were utilized to emphasize that there is often not only one "correct" solution, since feedback and revisions are often required and are crucial for both. The benefits of students developing their writing skills in that study were thoroughly explained. In our study, we integrated report writing into the course, which required students to internalize the knowledge to use critical thinking skills in order to produce real-life engineering reports, unlike any other routine problem-based classical exams where FEM is taught.

It has also been highlighted by Dym *et al.*[16] that engineering curricula should be more specific than generic. For this reason, custom-made changes are required according to the needs of the evolving engineering profession. BME professionals are obliged to work as a part of a team, rather than on their own. Engineering is a social activity as pointed by Dym *et al.*[16] With this mindset, in our course design, students were asked to complete their design projects in teams, rather than individuals to produce more skilled engineering graduates to survive in real-life engineering projects in the future.

In this paper, we demonstrate the design of a new course, considering the needs of the BME students. When compared to pure theory teaching of FEM methods without considering the needs of BME students, this course offers unique features. After the course was completed, in the following semester, a questionnaire was given to the students to assess their learning experience, the results were analysed to measure and assess the efficiency of the new features by receiving feedback for these new features.

MATERIALS AND METHODS

The computational biomechanics course relies heavily on the usage of the FEM, which was firstly used for stress analysis of aircraft bodies in the 1950s.[17] FEM requires solving multiple equations and iterative solutions. With the advancement of computers, this computationally expensive technique started to become very popular in many engineering fields, including BME education. In the FEM method, complex geometric shapes are divided into smaller pieces to define a limited number of elements. This process is called meshing. Elements come together to form a node. This approach simplifies the solution due to the usage of a limited number of elements connected by nodes. Then, the structure of the equations is created. The system of equations is solved according to the boundary conditions and to the applied load to obtain the analysis results. The result obtained is the approximate solution to the problem. However, FEM requires verification and validation of the model. Verification is to make sure that the underlying mathematical equations are correct. It is checked if the code is performing correctly. Whereas, in validation, it is checked if results are meaningful and comparable to reality as observed by the controlled experiments. A flowchart of the finite element analysis (FEA) problem under a general perspective is provided in Fig. 1. The validation part might be completed in different ways depending on the nature of the problem. In BME, testing on the human body is not feasible and not permitted due to ethical reasons. For this reason, comparison of the results against previously published

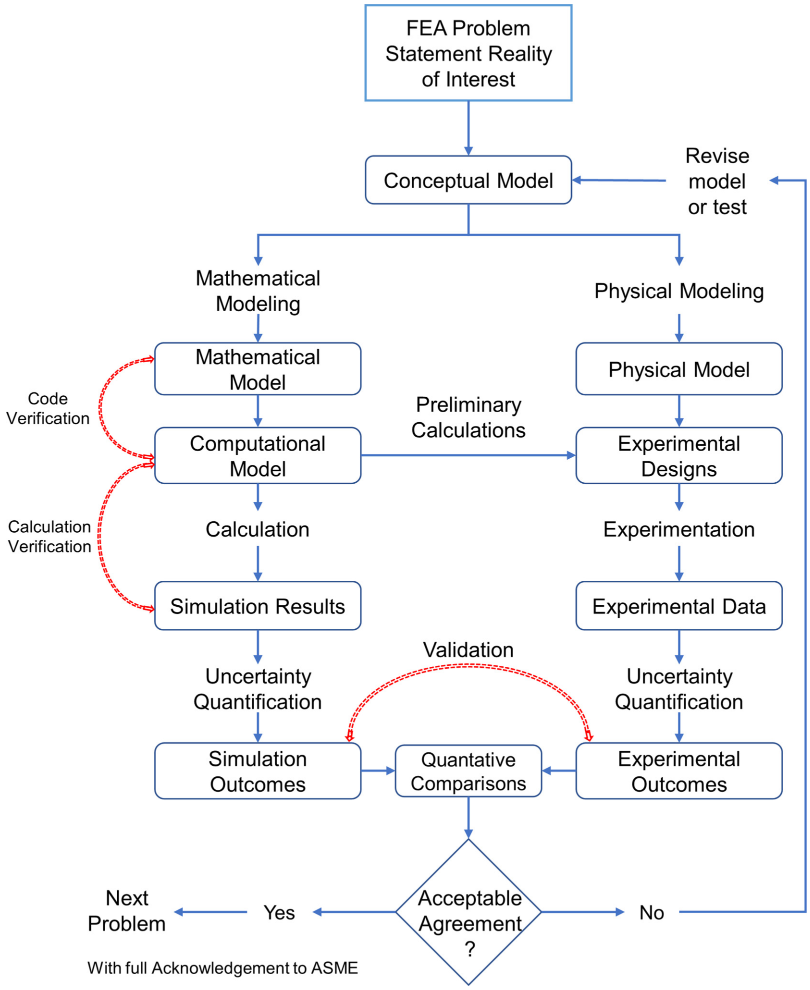

Fig. 1 Flowchart describing the general application of FEM in general in engineering education (ASME).

results, validated models, animal experiments, ex vivo tissues, explanted bones, or other outputs of validated computer simulations are some options.

In our computational biomechanics course, 18 people enrolled consisting of 15 females and 3 males among the third and the final year students. This course was designed as an elective course in BME education. The students were asked to work in groups of two, composing nine groups overall. During the first semester, the basic theory was taught to the students in lectures involving small engineering problems. A course hour consisted of 60 min. Each theory part consisted of 20 min of lecturing on deriving of the equations and a video demonstration of an application of the problem in industry or a relevant published academic work involving verification and validation stages of the problem. This was shown to the students for another 20 min. Within the last 20 min of the course, a sample problem was solved using the theory explained at the beginning of the lecture. The timescales of each session were planned carefully to make use of the maximum attention span of the students.

Theoretical Content Blended with Practice

FEM requires a bulk usage of equations and matrix algebra. For this reason, handouts were distributed to the students at the beginning of the term to revise the matrix algebra. Matrix multiplication, addition, inverse, determinant, transpose, symmetry, transpose of products, differentiation, integration, solution of algebraic equations such as Gauss substitution, and Cholesky Factorization methods were covered. Once the required mathematical background was covered, basic steps of the FEA were covered. The structural potential and strain displacement concepts were explained to derive the stiffness matrixes, FE formulations were used to calculate the stresses from the displacements matrices. At each lecture, pen- and paper-based theory was given for one-dimensional trust element, beam theory, and two-dimensional elements, each with a sample manual hands-on problem-solving session. After the completion of the theoretical part, the students were asked to install the computer-aided design and the FEM software package to solve the same problems with different variables, which were solved during the lectures using hand calculators. This time, the solutions were given using the package software tools. During the lab sessions, the students were asked to provide their own hand calculations, and their own generated results via CAD-FEA software to be marked after each laboratory session. The students worked out solutions in pairs of two for gaining group work habits. Each group had different model constants to prevent any abuse of collaboration between the groups. The students were asked to perform sensitivity analysis by changing the inputs and to also make use of the axis of symmetry for improving their practical understanding of the given assignments. The flowchart describing the method for blending the theory with practice is shown in Fig. 2.

After building the fundamentals of theory and providing students with the confidence to run the models via CAD–FEA software, the students were given a term project with a guideline on how to write the report by working in groups of two, to be submitted by the end of the term. The project work was given instead of a midterm exam. Apart from the laboratory sessions, no other assessments were given during the term. Only the final exam on the theory was given at the end of the term, requiring students to solve problems by using the derived equations during the theoretical sessions, by using hand calculators, pen, and paper on their own in an in-class exam. Our expectation was to improve the understanding of the theory by applications made in the lab sessions and in the project. For this reason, the evaluation of the students in the theoretical parts was left for the final exam to measure their skills when they reached the highest potential of understanding throughout the course.

Term Projects and Documentation

As a term project, the students were asked to design a fixation plate, acting as an international consultancy firm by producing a professional report that demonstrates each step of their design work, providing all the evidence for the optimal design. The students were supposed to design the fixation plate themselves, blending their theoretical and practical skills gathered during the course. The students were asked to work in groups of two. Each group was asked to produce a task list demonstrating work-load share and contribution for a fair evaluation. Each group was also asked to use the licensed software to draw its product [SolidWorks (Dassault Systèmes, Waltham, Massachusetts, USA) provided by the engineering faculty]. The students were then asked to produce two models, using 2D plate elements and 3D

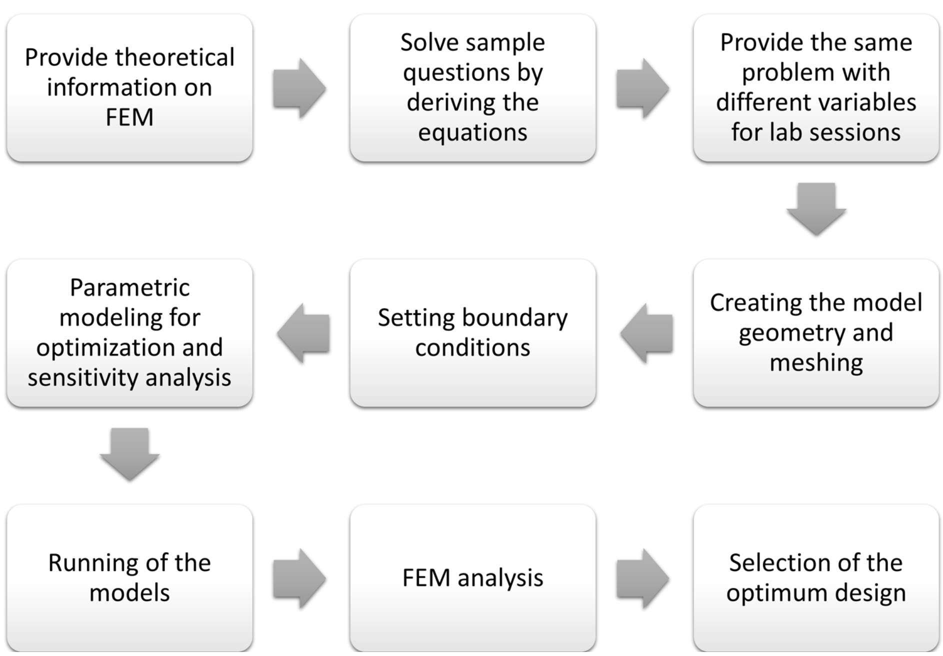

Fig. 2 Flowchart of the course designed for BME students blending theory and practical parts for special BME problems.

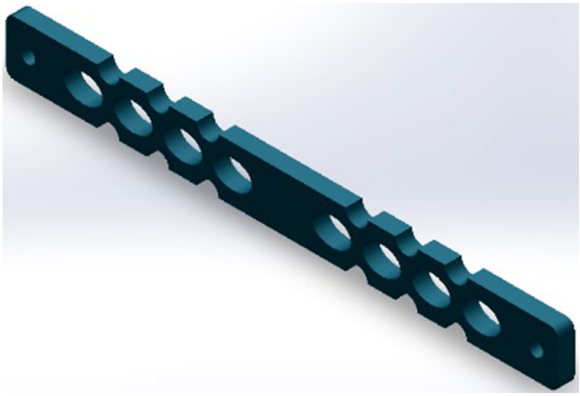

Fig. 3 A sample drawing of bone fixation plate represented in SolidWorks (base frame design).

solid elements. The drawing limits of the design were set as follows; plate length ranging from 70 mm to 100 mm (Min-Max), respectively, and plate thickness ranging from 5 mm to 9 mm (Min-Max), respectively. The students were required to conduct a literature review to find out the intended use conditions for a fixation plate and the expected boundary conditions during the lifetime of the fixation plates and to use their engineering knowledge, skills, their engineering intuitions, and their creativity while deciding on the geometry of the fixation plates. A base design figure was supplied as a starting point for the students to understand the geometry of the required product (Fig. 3). No limitation was set on the number of holes for the plate. The locations of circles, radius, and fillet coefficients were to be changed so as to find out the optimum design. Each group was asked to design their models using the ANSYS software by setting their appropriate boundary conditions and to run its models to analyse the results. Hand calculations were performed to make sure that their computer solutions were reasonable. Each group was asked to provide a demonstration of a working model.

After the demonstration of their working models, further analyses on the models, such as alterations of the boundary conditions and other input parameters for optimization procedures, were conducted. The students had to define their own decision points on the "fitness for the purpose" criteria. If they were making any assumptions or simplifications, they had to explain the details in their reports.

For the reports to be at a professional level, students were asked to produce them with certain sections and page numbers. A report consisted of a cover page, abstract, table of contents at the beginning, followed by a 12-page limit for introduction, methodology, results, discussions, and conclusion, ending with references and appendix sections. In the appendix, the students could provide Gant charts for their project and any ISO standards they referred to during the design. In the introduction, each group conducted their own literature review and their acceptance criteria for a successful product under specified loading conditions. In the methodology, hand calculations and any simplifications for the provided boundary conditions were detailed. As a part of verification, mesh convergence of their models and control of boundary conditions under the defined scenarios were provided. The set of sensitivity tests and the reasons for sensitivity analysis were given in the methodology section. The results section provided images, deflections, and stress values of the model. In the discussion, they were asked to provide details on the validation procedure and explain their decision for the optimal design.

For the validation part, once the students completed their FE analysis *in silico* and decided on their optimum design, they exported their model to the 3D printer software to produce the physical product. The finished product was subjected to tension/compression test equipment in order to produce stress versus strain curves for each product. Each group performed their own experimentation under the supervision of the lab assistant and gained practical skills over the use of test machines (Fig. 4). The FEA results were compared to the experimental results produced by the tensile test

Fig. 4 **(A)** Production of students' designs with a 3D printer, **(B)** failure as a result of applying the tensile test, **(C)** performing the test by Shimadzu Tester.

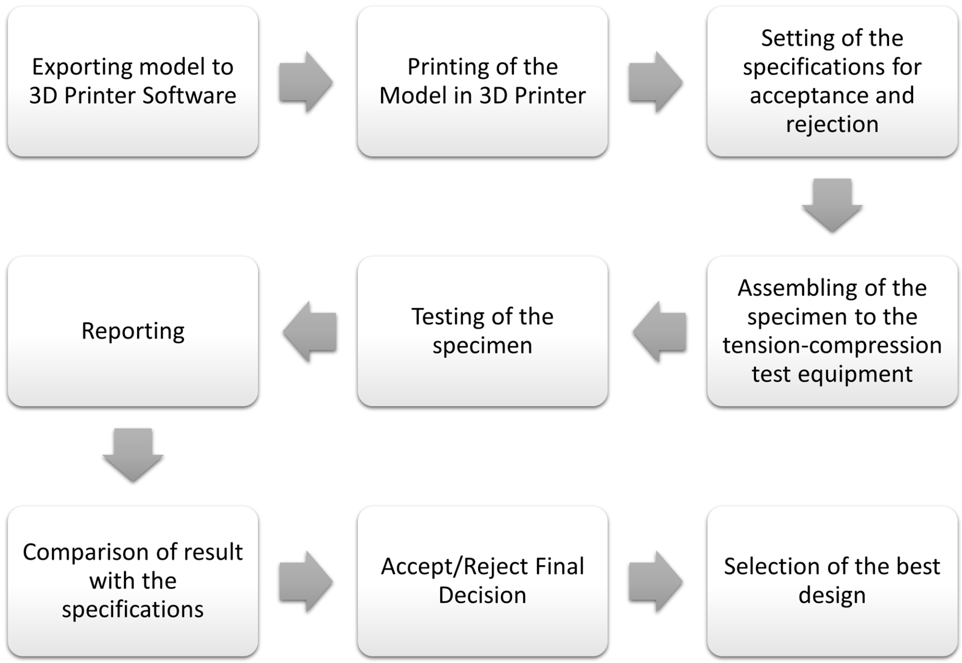

Fig. 5 Flowchart for the validation and documentation of the fixation plates, as a part of the term project.

equipment for the given loading conditions. By comparing the model results against the test, the students completed the validation of their models. The products were compared against the acceptance criteria for which they were designed. The students documented and provided their technical reports including all the calculations as a piece of evidence for their work. The flowchart of the term projects is provided in Fig. 5.

In order to integrate the lectures with the external world of BME education, a network with the industry was established. To achieve that, technical trips to local implant design factories were arranged. The students met with the R&D, management, manufacturing, and quality control departments of implant manufacturing firms. They were able to observe the whole process, understand the requirements of BME jobs, ask questions, and conduct fruitful discussions with possible future colleagues. The technical trips took place immediately after the students started their projects, triggering their motivation for the project. The meetings with R&D engineers, applying similar problem-solving techniques, aimed at integration of students with the real-world settings to allow them to fit in their jobs easily in the future.

Evaluation

During the term, only laboratory sessions were evaluated. Online learning platforms were utilized by uploading course materials, slides, and self-testing problems for students to test themselves on the Canvas Network. The course material was uploaded on the online platform immediately after each class for the students to attend the classes regularly and to revise the material afterward. The term project was evaluated at the end of the term to improve the skills of the students during the term, while each laboratory session was marked and announced before the following laboratory session. A final exam was conducted in the classroom after the submission of the project reports. The students were given theory-based-questions and carried on their own calculations by using their own calculators and pen and paper.

After the final exams, an online questionnaire was designed and uploaded on the online platform, asking students to provide feedback on their learning experience on a volunteered basis. The answers were recorded anonymously so that the participants were free to provide their inner thoughts without any hesitation. The questionnaire consisted of three sections (Appendix A). The first section consisted of two questions and was about understanding the background of the students. The first question was the effort level of the students spent on the course; such as weak (1), average (2), adequate (3), good (4), and excellent (5). The second question was the main motivation that led them to choose the course, such as (a) suitability of the course hours, (b) interest in the subject, (c) preference of the instructor, and (d) any other personal reason. In the second part of the questionnaire, the questions were related to the way the course was processed as: strongly disagree, disagree, agree, and strongly agree (details in Appendix A). The neutral option was omitted for students to take a side to make a better understanding of their feedback. The final part was verbal, asking the students to express themselves using their own words on what they liked about the course most and on what needed to be improved. After the expiry of the questionnaire completion deadline, analyses were made on their responses.

RESULTS

The first evaluation during the term was on laboratory performance. During the laboratory sessions, the students were supposed to demonstrate their particular skills for each task in pairs of two and complete the term project at the end. The applications conducted through the term time were planned to blend theory and practice via laboratory sessions and via the term project. To investigate the correlation between the grades of the term project and the final exam, the Pearson Correlation Coefficient was calculated as 0.76 between the student's final exam papers (which were mostly theoretical) and the term projects (which were a combination of both the theory and the practice).

The classroom average calculated for the final exam was 71 ± 11.5 (Std), for the laboratory sessions 73 ± 21.3 (Std), and for the term project 83 ± 9.2 (Std) out of 100. In the laboratory sessions, one of the student groups consisting of one male and one female student attended half of the laboratory sessions and another student group consisting of two male students missed one of the laboratory sessions. This is the reason for the large standard deviation in the laboratory grades.

DISCUSSIONS

Evaluation of the Questionnaire

The online questionnaires, which were filled in anonymously by the students, were evaluated in Microsoft Excel. The calculated average effort level of the students was adequate (3), with three students describing their effort level as good (4), and three of them describing their effort level as average, while the remaining describing it as adequate (3). Four of the students reported having chosen the course for the suitability of the course hours to their timetable while two of them chose the course because of the instructor, while the remaining number of students indicated that their interest in the topic was the reason why they selected this course.

In part two, the students evaluated the features that made this course different. In the first question, the students were asked if the revision chapters provided at the beginning of the course were useful for them. The majority of the students (80%) answered in favour of the course. The students were asked if blending theory with practice made it better to understand the FEM techniques: (a) 95% of the students responded positively. The students were asked to assess if the modular structure in the course for solving the problems and the online problems were helpful in mastering the theory and practice; (b) 80% of the students responded positively; (c) 80% of the students also answered that they found the online teaching material consisting of solved example problems and online self-assessment questions useful to them; (d) 100% of the students agreed that solving the problems both using the formulas and solving them in the laboratory sessions using ANSYS increased their confidence in engineering applications; (e) 94% of the students agreed that integration of current technologies, such as the use of 3D printers, in the course contributed to their education positively and integration of the validation and testing steps increased their knowledge and skills about these procedures, while integration of technical trips enabled combining the school work in BME with the outside world. The students were asked about the integration of reporting skills via two questions; (f) 94% of the students answered that preparing a project report had been a useful practice to experience the professional engineering reporting application. They also agreed that preparing a project report affected their writing and reporting skills positively as engineering students. When they were asked if they think that their transferable skills had increased through this course, 94% of the students showed a positive response; (g) 100% of the students answered that what they learned in this course was useful for them to be an engineer in their future career. They also agreed 100% that the changes made in the way this course was taught made a positive difference compared to the classical method; and (h) 94% of the students said that they would recommend this course to their colleague-students.

In the third part of the questionnaire, the students were asked to express their own opinions about the course, as what could be improved and what they liked the most about this course. Although they had all the freedom to provide different answers, their responses were in a similar manner. They mentioned that they liked the laboratory sessions, by learning and using the FEM software the most. They wrote that adding command of FEM software into their CVs made a difference. Being able to solve the problems using ANSYS increased their level of confidence, and they now felt more motivated and skillful to learn more about this sort of application. Since the university had an access to the student version of the ANSYS program, it was possible to use this software during laboratory sessions. However, once having grasped the fundamentals of using software for solving FEM problems, the students can easily adapt to any other software in the future when they work as engineers. In addition to this, being able to observe the industrial applications, via technical trips, increased their level of interest in the topic to learn more. Integration of the practical applications with theory was most preferable for the students. Some of the students mentioned that the course was too condensed to cover one term only and that it could be extended to cover more details over two terms as an improvement point. In classical engineering education, elective courses are mostly designed to be for one term only. For this reason, extending the course over two terms might not be feasible. Many of them mentioned that they grasped the practical applications more than the theoretical details. They asked for more interactive problem-solving sessions in order to understand theory. In classical engineering education, lecturing is usually performed by the instructor. Even though students were integrated into some of the sessions, the course did not have any extra tutorial sessions arranged by course assistants. It might be possible to provide tutorial hours by the course assistants to perform more problem-solving sessions in the following years, after feedback from the students.

The evaluation of the questionnaire indicates that the changes made to the curriculum to adapt the course material to the needs of the BME students were appropriate. Some of the students mentioned that they learned the practical side of the course more than the theoretical parts. Since most of the engineering students chose to work directly immediately after graduation, this might not be a deficiency. For undergraduate students, it is very important to create a hybrid of both theory and practice. Any course missing one of these ingredients would be deficient and might not be very promising for the future of engineering. For those students who consider learning more of the theory, graduate school courses could be the solution, as this would require a certain level of highly resourceful students to understand mathematics and the associated dedication level to learn these complex methods. Without having a certain level of mathematical skills, providing too much theoretical information to engineering students could produce adverse effects, such as not willing to work as an engineer after graduation, losing their interest in the topic, dealing with too many non-transferable skills, and feeling insecure with lack of transferable skills in the job hunt for working as engineers. For this reason, it is very important to design engineering courses to invoke curiosity in the subject and to let it continue by designing challenges with an optimum level of detail and complexity to allow students build self-confidence. It is also crucial to maintain their interest levels to work in the profession after they graduate. BME education is a niche area, which is costly, and it has been hard to find qualified people in the profession. For this reason, BME educators should keep students' interest active in the field to guide their work in the profession after education.

In this paper, we focused on a fixation plate as an example. There are many other possible applications, which could be applied for designing and testing of other implant models such as hip, knee, wrist, ankle, and spine.[18–27] A similar methodology to that explained in this paper could be utilized for teaching of FEM to BME students.

CONCLUSION

With the increase of diverse fields in engineering education, there is a need for customizing and designing courses according to the needs of engineering students. Engineering as a field focuses more on applications and practical skills. Traditional lecturing provides students with lots of theoretical engineering background, without providing enough transferable skills. To enable engineering students to integrate into the industry, the needs of the industry and the backgrounds of the students should be considered carefully.

In this study, a new course was designed, considering all these points, to address the needs of the industry and also the needs of BME students. The generated feedback from the questionnaire filled by the students demonstrated that correct steps have been taken. With the evolution of new technical tools, methods, and strategies, the course design should always be updated, so that the engineering graduates can be more confident with their transferable skills to fulfil the requirements of their career. With this approach, it is possible to keep them working in the field for which they got educated and to enable them to work in the field that they enjoy.

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REFERENCES

1. Patterson RP, Otto Schmitt: A father of biomedical engineering and master Gadgeteer, *Proc* 25*th Annual Int. Conf. IEEE Engineering in Medicine and Biology Society*, Cancun, p. 3461, 2003.
2. Pilkington TC, Long FM, Plonsey R, Webster JG, Welkowitz W, Status and trends in biomedical engineering education, *IEEE Eng Med Biol Mag* **8**:9, 1989.
3. Abu-Faraj ZO, Bioengineering/biomedical engineering education and career development: Literature review, definitions, and constructive recommendations, *Int J Eng Educ* **24**:990, 2008.
4. Abu-Faraj ZO, *Handbook of Research on Biomedical Engineering Education & Advanced Bioengineering Learning*: *Interdisciplinary Concepts*, IGI Global, p. 1123. 2012.
5. Abu-Faraj ZO, *Project Alexander the Great*: *An Analytical Comprehensive Study on the Global Spread of Bioengineering/Biomedical Engineering Education*, in Laskovski NA (ed.), *Biomedical Engineering*, *Trends*, *Researches and Technologies*, IntechOpen, p. 549, 2010.
6. Bronzino J, *Biomedical Engineering*: *A Historical Perspective*, in Enderle J, Blanchard S, Bronzino J (eds.), *Introduction to Biomedical Engineering*, 2nd edn., Academic Press, San Diego, p. 1, 2005.
7. Bronzino JD, Peterson DR, *Biomedical Engineering Fundamentals*, CRC Press, London, 2018.
8. Simpson JA, Weiner ESC, *The Oxford English Dictionary*, Clarendon Press, Oxford, 1989.
9. Babuška I, Oden JT, *Computational Mechanics*: *Where Is It Going*? in Engquist B, Schmid W (eds.), *Mathematics Unlimited* — 2001 *and Beyond*, Springer, Berlin, p. 23, 2001.
10. Brenner SC, Carstensen C, *Finite Element Methods*, in *Encyclopedia Computer Mechanics*, 2nd edn., John Wiley & Sons, NJ, p. 1, 2017.
11. Brinson LC, Belytshko T, Moran B, Black T, Design and computational methods in basic mechanics courses, *J Eng Educ* **86**:159, 1997.
12. Cyr M, Miragila V, Nocera T, Rogers C, A low cost, innovative methodology for teaching engineering through experimentation, *J Eng Educ* **86**, 1997.
13. Petroski H, Polishing the gem: A first-year design project, *J Eng Educ* **87**:445, 1998.
14. Newcomer JL, Steif PS, Student thinking about static equilibrium: Insights from written explanations to a concept question, *J Eng Educ* **97**:481, 2008.
15. Wheeler E, McDonald RL, Writing in engineering courses, *J Eng Educ* **89**:481, 2000.
16. Dym CL, Agogino AM, Eris O, Frey DD, Leifer LJ, Engineering design thinking, teaching, and learning, *J Eng Educ* **94**:103, 2005.
17. Clough RW, Early history of the finite element method from the view point of a pioneer, *Int J Numer Methods Eng* **60**:283, 2004.
18. Chethan KN, Bhat SN, Zuber M, Shenoy SB, Finite element analysis of different hip implant designs along with femur under static loading conditions, *J Biomed Phys Eng* **9**:507, 2019.
19. Chethan KN, Zuber M, Bhat SN, Sheno SB, Comparative study of femur bone having different boundary conditions and bone structure using finite element method, *Open Biomed Eng J* **12**:115, 2018.
20. Chethan KN, Bhat SN, Zuber M, Shenoy SB, Patient-specific static structural analysis of femur bone of different lengths, *Open Biomed Eng J* **12**:108, 2018.
21. Chethan KN, Bhat SN, Zuber M, Shenoy SB, Finite element analysis of hip implant with varying in taper neck lengths under static loading conditions, *Comput Methods Programs Biomed* **208**:106273, 2021.
22. Chethan, Ogulcan G, Bhat SN, Zuber M, Shenoy SB, Wear estimation of trapezoidal and circular shaped hip implants along with varying taper trunnion radiuses using finite element method, *Comput Methods Programs Biomed* **196**:105597, 2020.
23. Wang L, Peng X, Sun C, Wang H, Li D, Zhu J, Jin Z, Mihcin S, Liu C, The determination of the volumetric wear for surgically retrieved hip implants based on Cmm, *J Mech Med Biol* **16**:1650059, 2016.
24. Mihcin, S, Methodology on co-registration of MRI and optoelectronic motion capture marker sets: In-vivo wrist case study, *Hitite J Sci Eng* **6**:99, 2019
25. Mihcin, S, Spinal curvature for the assessment of spinal stability, *Int J Biomed Eng Technol* **20**:226, 2016.
26. Mercader A, Röttinger T, Bigdeli A, Lüth TC, Röttinger H, A patient-specific 3D model of the knee to compare the femoral rollback before and after total knee arthroplasty (TKA), *J Exp Orthop* **8**:1, 2021.
27. Ampla R, Vasiliadis AV, Katakalos K, Numerical simulation of the posterior malleolus fracture with the finite element method, *J Funct Biomater* **11**:14, 2020.

APPENDIX

Part 1 About you

Q1) *Describe your effort level for this course*

a) Weak, b) Average, c) Adequate, d) Excellent

Q2) *Select the reason why you registered for this course*

a) For the instructor b) For the time table,
c) Having interest in the topic, d) Other (Please specify)____________

Part 2 Evaluation of the course

Please indicate your answers based on these choices

a) Strongly Disagree □, b) Disagree □, c) Agree □, d) Strongly Agree □

Q1) *The revision unit, given at the beginning of the lesson, for the matrices was useful.*

a) □, b) □, c) □, d) □

Q2) *The theoretical and practical training of the course helped me learn and apply the FEM technique.*
a) ☐, b) ☐, c) ☐, d) ☐

Q3) *The modular structure followed in the course and the questions we solved in the computer environment were useful for combining theoretical knowledge with practical skills.*
a) ☐, b) ☐, c) ☐, d) ☐

Q4) *Uploading lecture notes, presentations and sample questions on canvas made it easier for me to follow the lesson.*
a) ☐, b) ☐, c) ☐, d) ☐

Q5) *Solved sample questions and evaluation questions enabled me to grasp the fundamentals of the subject.*
a) ☐, b) ☐, c) ☐, d) ☐

Q6) *Being able to solve the problems that we can solve manually with the software package called ANSYS in computer environment, has increased my confidence in engineering applications.*
a) ☐, b) ☐, c) ☐, d) ☐

Q7) *Integration of current technologies such as use of 3D printers in the course contributed to my education.*
a) ☐, b) ☐, c) ☐, d) ☐

Q8) *Learning by applying the validation and testing steps increased my knowledge and skills about these procedures.*
a) ☐, b) ☐, c) ☐, d) ☐

Q9) *The technical trips enabled me to combine the school work in biomechanics with the outside world.*
a) ☐, b) ☐, c) ☐, d) ☐

Q10) *Preparing a project report has been a useful practice for us to practice the professional engineering reporting application.*
a) ☐, b) ☐, c) ☐, d) ☐

Q11) *Preparing a project report affected my writing and reporting skills positively as an engineering student.*
a) ☐, b) ☐, c) ☐, d) ☐

Q12) *I think that the knowledge and skills that I can transfer directly to the industry have increased through this course I took.*
a) ☐, b) ☐, c) ☐, d) ☐

Q13) *What I learned in this course was useful for me as an engineer for my future career.*
a) ☐, b) ☐, c) ☐, d) ☐

Q14) *I think that the changes made in the way of this course taught made a positive difference compared to the classical method.*
a) ☐, b) ☐, c) ☐, d) ☐

Q15) *I recommend this course to my other friends.*
a) ☐, b) ☐, c) ☐, d) ☐

Part 3 Personal thoughts

Q1) *What were the most useful or valuable parts of this lesson?*
Type in your answer here

Q2) *Please specify if you have any other thoughts about the course that can be improved?*
Type in your answer here