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Develop Web-based Modules to Educate High-School Students in Studying Microbial Fuel Cell Dynamics

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Develop Web-based Modules to Educate High-School Students in Studying Microbial Fuel Cell Dynamics

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Abstract: USA high-school students are falling behind their peers from other countries such as Finland and Korea in their mathematical performance. Solving ordinary differential equations (ODEs) is especially challenging to USA high-school and college students. It is thus necessary to re-generate the momentum of inspiring or stimulating high-school students to participate in more math-related trainings or projects. In this work, we developed the first version of a web-based training approach to train high-school students modeling skills to simulate the dynamics of microbial fuel cells (MFCs) in MATLAB Simulink. Due to its capability of digesting organic compounds from waste water to generate electricity, the MFC is regarded as one of the most sustainable approaches to treat waste water and generate bioenergy at the same time. MATLAB Simulink provides a friendly platform on which students can build ODE models by linking functional blocks from the Simulink module library. This makes solving ODE models as interesting as building Lego projects. As part-time student researchers, high-school students watched the training videos and reproduced the results shown in the videos within the first two weeks. They then independently built the MFC ODE model in MATLAB Simulink to quantify the electrical current signals from MFC. The MFC model consists of four differential equations, four equality equations and 25 parameters. High-school students were able to finish the project within four weeks by working on the project on weekends. While high-school students generally finished the MFC project independently, the instructor provided two Skype meetings (totally one and a half hours) to check students' programs and provide suggestive comments. A survey was given at the end of the project to evaluate the improvement students' knowledge in MFC and gather what students like and dislike the web-based training approach. The result shows that it is doable to attract and train high school students with modeling skills by providing web-based training modules and Skype meetings.

I. Introduction

The math performance of US high-school students was ranked 38th out of out of 71 countries in the most Programme for International Student Assessment (PISA) in 2015 [1]. In addition, a report from President's Council of Advisors on Science and Technology shows that US would have one million deficits in technical workers in STEM fields if the STEM education is not improved in the next decade [2]. Therefore, it is urgent for US educators to create new approaches to attract more high-school students in the STEM fields, especially in math, which deals with challenging equation and symbolic operations. One way to address this issue is providing interesting modeling projects along with a powerful software that students can reply on for math operation. We did an "experiment" in Summer 2014 by introducing MATLAB Simulink to a local high-school junior student and providing him a project in which he developed Simulink Model for a microbial fuel cell (MFC). That project was quite successful, as the student presented his work in ASEE 2015 Mid-Atlantic Spring Conference [3]. The success of that project is based upon the following two factors: 1) MATLAB Simulink provides friendly user-interface so that students can build ordinary differential equation (ODE) models in Simulink like playing Lego; 2) the microbial fuel cell project deals with converting organic compounds in waste water to bioenergy. In this work, we further extend our previous projects to web-based training modules to attract and train more high-school students. The web-based training idea comes from another ASEE project of ours in which we prepared biology review and virtual experiment/training videos to enhance learning in biochemical engineering courses [4].

II. Materials and Teaching Methodology

The materials of this project mainly include: 1) a handout introducing MATLAB and Simulink and showing one example on solving a CSTR ODE model using Simulink; 2) four videos, the first one for general introduction of MATLAB, the second one for the introduction of Simulink, the third one showing step by step on how to build a CSTR ODE model (Equations (1)-(3)) in Simulink, and the last one for the introduction of the MFC model; 3) the project problem statement showing the detail of the MFC models and the model parameters. All these materials were sent to students via email, and the videos were uploaded onto YouTube for students to watch.

$$\frac{dc_A}{dt} = \frac{q}{V}(c_{A,i} - c_A) - kc_A \tag{1}$$

$$\frac{dT}{dt} = \frac{w}{\rho V}(T_i - T) + \frac{(-\Delta H_R)k}{\rho C}c_A + \frac{UA}{\rho VC}(T_c - T) \tag{2}$$

$$k = k_0 \exp(-E/RT) \tag{3}$$

where concentration of species A (c_A), the bulk flow temperature (T), and the reaction rate constant (k) are influenced by the cooling water temperature T_c. This model describes that the heat ($-\Delta H_R$) released from the chemical reaction changes the bulk flow temperature (Equation (2)) and the reaction rate constant k (Equation (3)) The meanings of all other parameters can be found in the textbook written by Seborg et al., 2010 [5]

The MFC model shown in Equations (4) - (8) describes the consumption rate of the substrate S (e.g., acetate) by the exoelectrogenic microorganism (i.e., x_a) and the methanogenic microorganism (i.e., x_m) and the profile of the oxidized mediator M_{ox} that transfers electrons from the exoelectrogenic microorganism to the anode electrode. I_{MFC} is the current produced by the MFC reactor. The meanings of all parameters shown in Equations (4) - (8) can be found in our previous ASEE paper [3]. The model contains 4 differential equations, 9 equations, and 25 parameters.

$$\frac{dS}{dt} = -q_a x_a - q_m x_m + D(S_0 - S) \tag{4}$$

$$\frac{dx_a}{dt} = -\mu_a x_a - K_{d,a} x_a - \alpha_a D x_a \tag{5}$$

$$\frac{dx_m}{dt} = -\mu_m x_m - K_{d,m} x_m - \alpha_m D x_m \tag{6}$$

$$\frac{dM_{ox}}{dt} = -Yq_a + \gamma \frac{I_{MFC}}{mF}\frac{1}{Vx_a} \tag{7}$$

$$I_{MFC} = \frac{E_{ocv}}{R_{Ext} + R_{Int}} \frac{M_{red}}{\varepsilon + M_{red}} \tag{8}$$

The teaching methodology was developed by the coauthor (Huang) in Summer 2016 to educate high-school students modeling skills in MATLAB without really meeting students in person. The teaching methodology was implemented by the following steps: 1) in the first week, the student watched the three MATLAB training videos and followed the video step by step to reproduce the simulation result for the CSTR model; 2) in the first half of the second week, the student watched another video that introduced the MFC ODE model so that he knew the application and on-going research in MFC; 3) the student began to build the MFC ODE by himself in the second half of the second week; 4) at the end of the third week, the instructor made a Skype meeting with the student to answer the student's questions. If necessary, the instructor debugged the student' program by accessing the student' computers using the software Teamviewer; 5) at the end of the fourth week, the instructor made another Skype meeting with the student to evaluate the student's understanding of MFC; 6) at the end of the fifth week, the student submitted a report on the project, summarizing the simulation results from his model.

A survey was given at the end of the project. While the instructor tried to make the survey anonymous, students mainly sent their survey back to the instructor via emails. The survey consisted of three section: 1) students ranked their improvement in using MATLAB to solve ODE models in Section 1 (shown in Table 1); 2) students evaluated their learning experience in the web-based training approach in Section 2 (shown in Table 2); and 3) students answered open-ended questions on the aspects they like and dislike the web-based module approach.

Table 1, Survey on students' improvement in MATLAB and ODE solving skills

One of the major goals of the MATLAB videos is to make you more competent in solving ordinary differential equations (ODEs) of microbial fuel cells using MATLAB.	None				All
(1) Rate the extent to which you are able to solve ODE models before taking MATLAB training module	①	②	③	④	⑤
(2) Rate the extent to which you are able to solve ODE models after taking MATLAB training module	①	②	③	④	⑤
(3) Rate the extent to which you are able to use MATLAB in solving ODE models before taking MATLAB training module	①	②	③	④	⑤
(4) Rate the extent to which you are able to use MATLAB in solving ODE models after taking MATLAB training module	①	②	③	④	⑤
(5) Rate the extent to the knowledge you know microbial fuel cells before doing this mini-project	①	②	③	④	⑤
(6) Rate the extent to the knowledge you know microbial fuel cells after doing this mini-project	①	②	③	④	⑤

Table 2, Survey on students' evaluation on the web-based module approach

Please think about your learning experience in the web-based training approach	Strongly disagree				Strongly agree
(1) The web-based training format is effective in conveying the MFC knowledge and MATLAB training	①	②	③	④	⑤
(2) The videos are clear and easy to follow to reproduce the simulation results shown in the videos	①	②	③	④	⑤

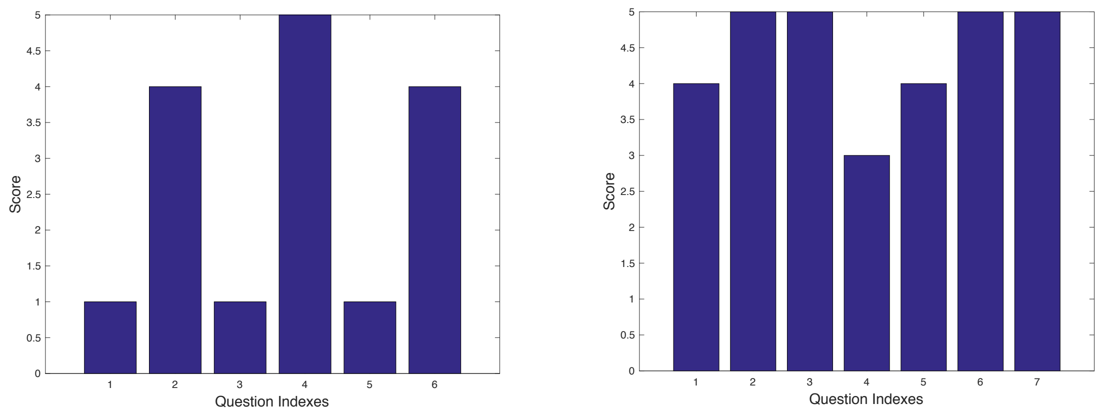
(3) The Skype-phone calls are effective to substitute in-person communication in the Q&A section	① ② ③ ④ ⑤
(4) The project is too challenging to a high school student	① ② ③ ④ ⑤
(5) You will recommend this project to other high-school students	① ② ③ ④ ⑤
(6) A real life-related project like microbial fuel cells makes the project more attractive to you	① ② ③ ④ ⑤
(7) This project encourages you to pursue a college major in STEM field (i.e., Science, Technology, Engineering and Mathematics)	① ② ③ ④ ⑤

III. Results and Discussion

Two junior high-school students (Guo and Kail) from two local high schools participated in this project in Summer 2016. Both of them mainly worked on the project during the weekend. The simulation results from one of two students matched the result from the instructor's model well, while the other one got 80% matching accuracy. The results from these web-based learning students were comparable to the result from the student who got training and did the project on site in Summer 2014. The survey results from the two students were shown in Figure 1, which indicates that students' skills in MATLAB, ODE solving, and MFC were significantly improved and which shows that students were generally positive with the web-based training approach. In particular, students' skills in MATLAB were improved from 1 to 4 out of 5 after the training. Similarly, the improvement in students' knowledge in ODE solving and MFC was from 1 to 5 and from 1 to 4, respectively.

As shown in Table 2, students offered the highest score (5 out of 5) for the following items: "the videos are clear and easy to follow to reproduce the simulation results shown in the videos", "The Skype-phone calls are effective to substitute in-person communication in the Q&A section", "A real life-related project like microbial fuel cells makes the project more attractive to you", and "This project encourages you to pursue a college major in STEM field (i.e., Science, Technology, Engineering and Mathematics)". Students did think the project was challenging to high-school students (score 3 out 5), but they did recommend this project to their peers (score 4 out of 5).

Students' answers to the open ending questions show the following positive feedback on the designed web-based training approach: 1) it is possible to attract high-school students in STEM fields by providing interesting mini-projects that are related to their daily life (e.g., bioenergy production and waste water treatment); 2) the web-based training approach was effective in conveying the training materials; 3) Skype meetings were helpful but students preferred in-person meetings; 4) the web-based training approach offered flexibility in students' schedule; 5) after the training, students liked the research in STEM field and planned to find a STEM major for their college study. Students also mentioned that this project was suitable for students interested in programming and science. To make the project easier, the participating students should know Calculus, and basic Chemistry and Biology. The major negative feedbacks from students include: 1) students can't ask questions right away when they have questions in watching videos and doing projects; 2) students may be distracted by surrounding environment and have lower working efficiency when compared to the on-site students; 3) the major challenge in using Simulink is understanding how the blocks linked together as the many lines make it hard to see the connections; 4) one student mentioned that it is challenging to find the right blocks for certain equations in the MFC model. Students mentioned that high-school students with GPA higher than 3.0 should be able to do the project with limited help.



(A) (B)

Figure 1, the survey result for Table 1 on evaluating students' improvement in MATLAB skills and MFC knowledge (A); and the survey result for Table 2 on students' evaluation of the web-based training approach in this project.

IV. Bibliography

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