INTRODUCTION

Modeling is a foundational practice of science (1). Models serve to explain and/or predict phenomena and are therefore different from other visualizations that just represent or recreate. Conceptual modeling strives to show how or why something works and to explain the effects of perturbations on a system (2). Conceptual modeling can allow students to integrate topics instead of simply compartmentalizing knowledge using artificial barriers of chapters, exams, or even courses. Students in molecular genetics need to be able to relate molecular reasoning and mechanisms to an organism’s phenotype and inheritance, as well as to the population in terms of evolution. However, the majority of students are unable to articulate how genes mechanistically determine phenotype and are unable to connect gene expression and protein activity with phenotype (3–4).

To address this deficiency, conceptual models known as Structure Mechanism Relationship Function (SMRF) models or Structure Behavior Function (SBF) models were introduced (5–9). SMRF models are similar to concept maps but differ in significant ways (2, 9). SMRF models do not encompass all of the student’s knowledge about a topic; instead, they focus on the function of a specified system. In the formatting of this model, structures refer to specific objects or elements that are placed in boxes. These structures in boxes are then connected by verbs placed on arrows describing mechanisms, relationships, or behaviors. The SMRF model provides a shared format for the course that enables discussion, feedback, and assessment.

Modeling is a challenging activity for students because they need to develop content understanding as well as modeling skills. To assist students as they learn to model, scaffolding was introduced. Scaffolding refers to instructional techniques that move students progressively towards stronger understanding and/or ability (10–13). Scaffolding techniques provide support to students attempting difficult tasks and are intended to decrease or prevent students’ frustration, intimidation, and discouragement during the learning process. Scaffolding techniques were utilized in molecular genetics to primarily help students develop modeling skills that enhance and support content understanding of how genotype affects evolution through expression of phenotype. Modeling skills and abilities are a core Vision and Change competency of undergraduate biology education, but they are not intuitive. Progressively developing modeling skills is essential for student success (2, 14, 15).

PROCEDURE

Molecular Genetics is a part of the core sequence of four courses and is traditionally taken by freshmen. Class sizes ranged from 15 to 32 per section. This study was approved by the IRB under protocol number 13.026 with renewals, and S19.041 with informed consent was gathered each semester. At the beginning of the semester, students have a training activity that allows them to discover modeling, what a SMRF model is, and why SMRF models are used in the course. SMRF modeling was first used in the Molecular Genetics course in 2016, with only a training activity. Starting in 2017, scaffolding activities were added before students attempted their first SMRF model to help them understand SMRF model formatting and expectations (Appendix 1). These activities were constructed to require minimal class time. Subsequently, throughout the course, students were provided with at least two practice SMRF model questions per unit. Small-stakes assignments were given for them to complete these practice questions. Class time allowed students to work with a group in constructing, critiquing, and revising models and for instructor feedback. Each of the four exams and the cumulative final contained a SMRF model.

Supplemental materials available at http://asmscience.org/jmbe

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CONCLUSION

Evaluations of Exam 1 SMRF models for four semesters were performed to determine the impact of introducing scaffolding activities (Fig. 1). Across the semesters, the specific SMRF questions changed, so the analysis focused on formatting and question context that best aligned with the scaffolding activities’ content. The 2016 students had no scaffolding but had training and practice; their average performance was 69% ± 23% (Fig. 2). Addition of the two scaffolding activities in 2017 improved the average to 78% ± 18%. These activities were further refined, producing a significant increase in the average student grade in 2018 and 2019, relative to 2016, resulting from a decrease in the lower range of scores (Fig. 2). In addition to these quantitative differences in student performance, there was a difference in student attitude and satisfaction with the modeling. In classroom observation and in survey data, students without the scaffolding activities expressed frustration with understanding how to start the models and how the models would be evaluated. Introduction and refinement of the scaffolding activities has greatly reduced student frustration, leading to a more productive classroom environment (Fig. 3). Another benefit was better use of class time. Since less feedback was needed about formatting, more time could be devoted to the substance of the model and addressing the specific question’s scope and focus.
WILSON: SCAFFOLDING SMRF MODELS

FIGURE 3. Scaffolding activities are rated as effective and may decrease student-perceived difficulty of modeling. (A and B) Data from 2020 immediately following administration of exam 1 (N = 42). (A) Student-rated effectiveness of scaffolding activities represented by the percentage of students reporting moderate to extremely effective activities. (B) Representative quotes in answer to the question “Were graded assignments to complete the Exam 1 SMRF practice questions helpful for you to learn how to model? Why or why not?” (C) These data from 2016 (N = 15) and 2018 (N = 40) were taken from the end-of-semester survey, which asked about the difficulty of SMRF modeling tasks at the beginning of the course. The scale is 1 (extremely easy) to 5 (extremely difficult), i.e., the perceived difficulty of the task is lower when average ratings are lower.

SUPPLEMENTAL MATERIALS

Appendix 1: Training and scaffolding activities, with instructional notes and answer keys
Appendix 2: Semester topics, SMRF modeling questions, and grading criteria

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