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Scaffolding Activities Increase Performance and Lower Frustration with Genotype-to-Evolution Models in Molecular Genetics

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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.

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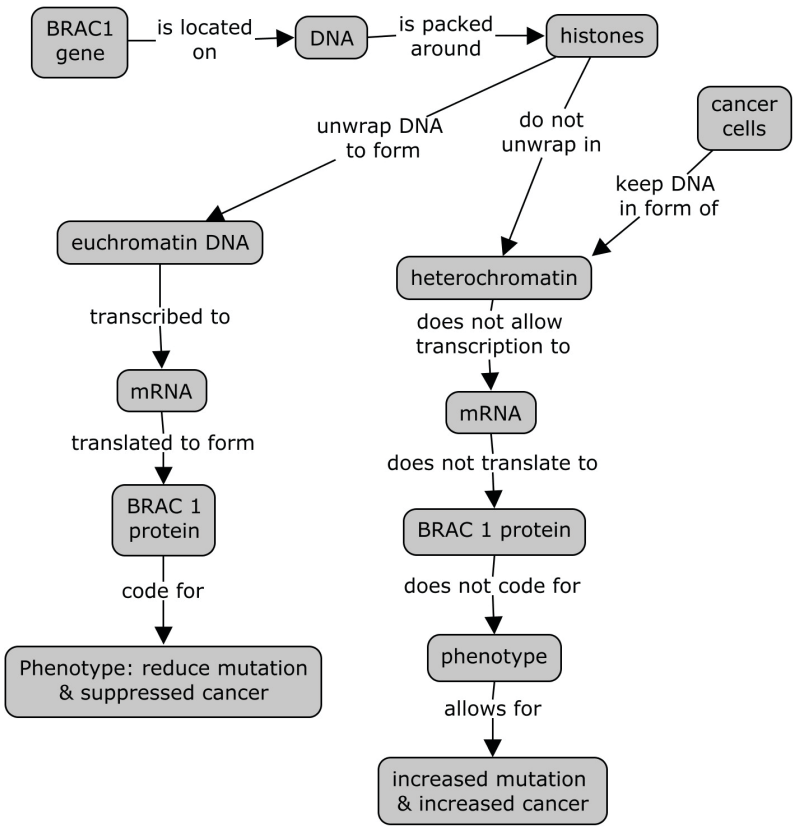

FIGURE 1. Example of Exam 1 SMRF model drawn by a student and then digitally transcribed using CmapTools.

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.

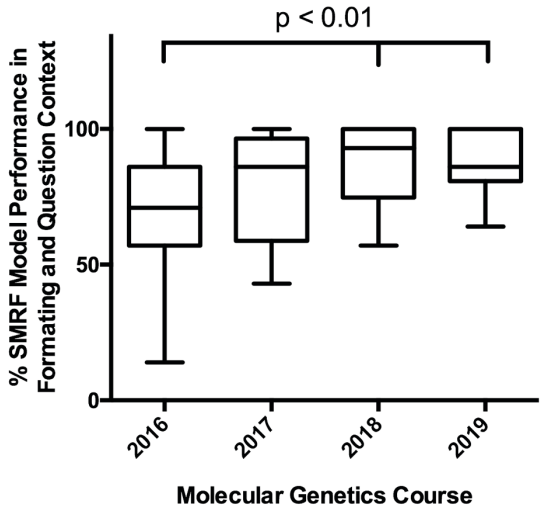

FIGURE 2. Scaffolding activities increase student performance on SMRF model formatting and inclusion of question context. These data from 2016 (*N* = 16) and 2017–2019 (*N* = 20 randomly selected SMRF models each) from Exam 1 were evaluated by the instructor. Data presented in box-and-whisker plot were calculated using GraphPad Prism and the Tukey method of calculation. Statistical significance was calculated in GraphPad using a one-way analysis of variance with Tukey's multiple-comparison test. The median is represented by the midline, the 25% confidence intervals by the boxes, and ranges of scores by the whiskers. Multiple-comparison test revealed that 2016 vs. 2018 and 2016 vs. 2019 were statistically different.

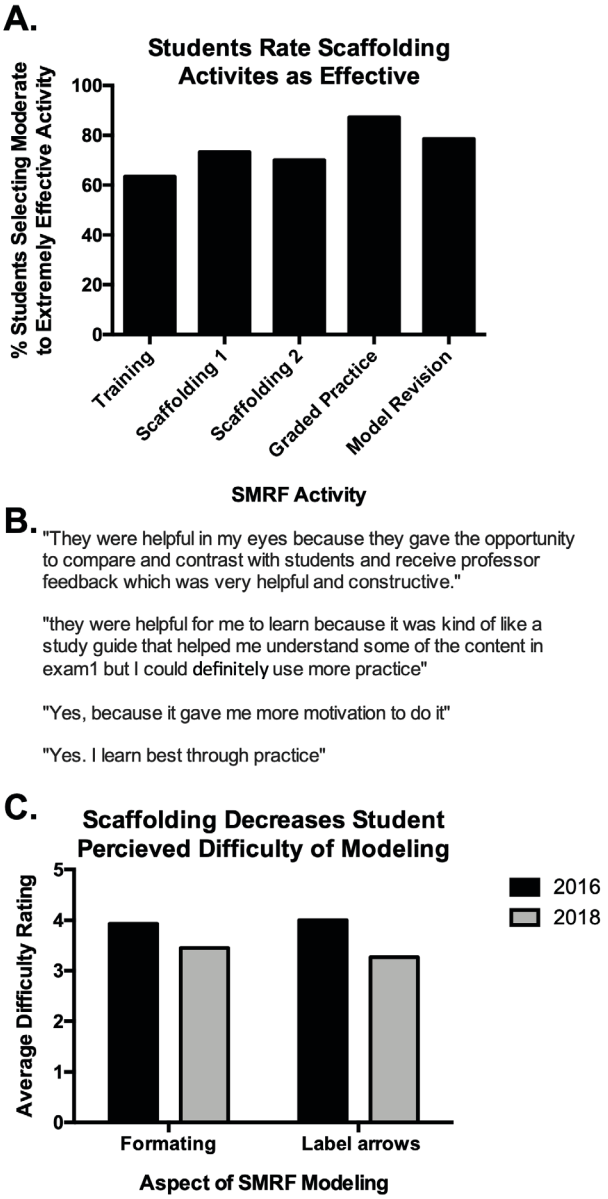

FIGURE 3. Scaffolding activities are rated as effective and may decrease student-perceived difficulty of modeling. (A and B) Data from 2020 immediately following administration of exam 1 (N = 42). (A) Student-rated effectiveness of scaffolding activities represented by the percentage of students reporting 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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REFERENCES

1. Gilbert SW. 1991. Model building and a definition of science. J Res Sci Teach 28:73–79.
2. Wilson KJ, Long TM, Momsen JL, Bray Speth E. 2020. Evidence-based teaching guides: modeling in the classroom—making systems and relationships visible. CBE Life Sci Educ 19:fe1.
3. Marbach-Ad G. 2001. Attempting to break the code in student comprehension of genetic concepts. J Biol Educ 35:183–189.
4. Lira ME, Gardner SM. 2017. Structure-function relations in physiology education: where's the mechanism? Adv Physiol Educ 41:270–278.
5. Dauer JT, Momsen JL, Bray Speth E, Makohon-Moore SC, Long TM. 2013. Analyzing change in students' gene-to-evolution models in college-level introductory biology. J Res Sci Teach 50:639–659.
6. Dauer JT, Long TM. 2015. Long-term conceptual retrieval by college biology majors following model-based instruction. J Res Sci Teach 52:1188–1206.
7. Hmelo-Silver CE, Pfeffer MG. 2004. Comparing expert and novice understanding of a complex system from the perspective of structures, behaviors, and functions. Cogn Sci 28:127–138.
8. Reinagel A, Bray Speth E. 2016. Beyond the central dogma: model-based learning of how genes determine phenotypes. CBE Life Sci Educ 15:ar4.
9. Bray Speth E, Shaw N, Momsen J, Reinagel A, Le P, Taqieddin R, Long T. 2014. Introductory biology students' conceptual models and explanations of the origin of variation. CBE Life Sci Educ 13:529–539.
10. Offerdahl EG, Arneson JB, Byrne N. 2017. Lighten the load: scaffolding visual literacy in biochemistry and molecular biology. CBE Life Sci Educ 16:es1.
11. Hobbs FC, Johnson DJ, Kearns KD. 2013. A deliberate practice approach to teaching phylogenetic analysis. CBE Life Sci Educ 12:676–686.
12. Christian N, Kearns KD. 2018. Using scaffolding and deliberate practice to improve abstract writing in an introductory biology laboratory course. J Microbiol Biol Educ 19 doi:10.1128/jmbe.v19i2.1564.

13. Cardinale JA, Johnson BC. 2017. Metacognition modules: a scaffolded series of online assignments designed to improve students' study skills. J Microbiol Biol Educ 18 doi:10.1128/jmbe.v18i1.1212.
14. Novick LR, Catley KM. 2018. Teaching tree thinking in an upper level organismal biology course: testing the effectiveness of a multifaceted curriculum. J Biol Educ 52:66–78.
15. Trujillo CM, Anderson TR, Pelaez NJ. 2016. Exploring the MACH model's potential as a metacognitive tool to help undergraduate students monitor their explanations of biological mechanisms. CBE Life Sci Educ 15:ar12.