Using online decision trees to support students’ self-efficacy in the laboratory

Sarah McLean,1,2 Ken N. Meadows,3 Austin Heffernan,1 and Nicole Campbell1

1Department of Physiology and Pharmacology, Western University, London, Ontario, Canada; 2Department of Anatomy and Cell Biology, Western University, London, Ontario, Canada; and 3Centre for Teaching and Learning, Western University, London, Ontario, Canada

Submitted 28 January 2019; accepted in final form 17 June 2020

McLean S, Meadows KN, Heffernan A, Campbell N. Using online decision trees to support students’ self-efficacy in the laboratory. Adv Physiol Educ 44: 430–435, 2020; doi:10.1152/advan.00016.2019.—Failed experiments are a common occurrence in research, yet many undergraduate science laboratories rely on established protocols to ensure students are able to obtain results. While it is logistically challenging to facilitate students’ conducting their own experiments in the laboratory, allowing students to “fail” in a safe environment could help with the development of problem-solving skills. To allow students a safe place to fail and encourage them to think through a laboratory protocol, online decision trees were created to lead students through protocols and give them timely feedback. The online decision trees present students with a scenario, then students execute a protocol by selecting options that will lead them down different paths and result in various realistic results from their experiments. They receive feedback and instructional tutorials throughout the simulation that are dependent on their choices. The significance of this new resource for student learning is that it allows students to practice their problem-solving skills and gain theoretical knowledge about the purpose of various experimental steps. The purpose of this research study was to evaluate whether online decision trees affected students’ self-efficacy, metacognition, and motivation for completing a wet laboratory. A mixed-methods approach was used; three surveys were administered throughout the academic term. For survey 1, students completed the decision tree and survey before the wet laboratory. For survey 2, students completed the survey before the wet laboratory but completed the decision tree after the wet laboratory. Students’ reported self-efficacy and intrinsic motivation were increased with the administration of the online decision trees before the wet laboratory, but their extrinsic motivation and metacognitive scores were unchanged. For survey 3, students provided written feedback about the impact of the online decision trees, and their responses highlighted the importance of the visual components of the approach.

INTRODUCTION

The evidence for the positive impact of active learning on student performance in science continues to accumulate. A meta-analysis by Freeman and colleagues (4) concluded that active-learning classes benefit students, on average, with a 6% grade increase and with decreased failure rates; these improvements are consistent across disciplines and are not contingent on students’ status as majors or nonmajors.

Wet laboratories are a frequent active-learning approach in science. The laboratory offers an opportunity for scientific inquiry, such as making observations, investigating, and analyzing data (6). While instructors may argue that a wet laboratory itself is an active form of learning, students do not always agree with the value of laboratories. For example, work by Tsang and Harris (17) has shown that, compared with faculty, second-year medical students think that laboratories are much less effective than lecture for teaching.

Laboratories require students to use a number of different skills: procedural learning, application, and problem solving. Essentially, for a student to execute a laboratory, he/she needs to transcribe the laboratory manual instructions into an actual procedure (11). Little research has been conducted to evaluate how students effectively prepare for laboratory sessions.

One of the challenges of a laboratory is the means by which students prepare. Traditionally, students listen to pre-laboratory talks, read a laboratory manual, and/or complete pre-laboratory quizzes to prepare for a laboratory. The challenge with this approach, however, is that often students and instructors focus on the minutiae of a protocol, rather than the inquiry-based approach of science (6). While laboratory manuals are often required for most undergraduate laboratories, these manuals can be ineffective, as they can overload a student’s short-term memory, making it difficult for students to discern salient points of the protocol (11). As reviewed in Hofstein and Lunetta (6), students perceive that the role of a laboratory investigation is primarily to “follow the instructions” or “get the right answer.” As noted by Pickering (11), “A student can understand the theory perfectly and still not know that the case must be taken off a thermometer before using it.”

Laboratories often focus on the development and demonstration of knowledge. While the acquisition and application of knowledge is important, so are students’ beliefs in their abilities, that is, students’ self-efficacy. Self-efficacy, as defined by Bandura et al. (1), is the “beliefs in one’s capabilities to organize and execute the courses of action required to manage prospective situations.” Research supports the importance of these beliefs in learning. For example, self-efficacy influences motivation; individuals with high self-efficacy are more likely to work harder and persist than individuals with low self-efficacy (14). Similarly, Kurbankoglu and Akim (7) found a negative relationship between self-efficacy and anxiety in the chemistry laboratory; students with lower self-efficacy had higher anxiety in the laboratory. Self-efficacy is also a strong predictor of future accomplishment, including students’ science grades (5, 10). If one of the central tenets of science education is to support...
students’ life-long academic development, it is important to support students’ self-efficacy.

Motivation also impacts students’ academic development. When considering motivation, many dichotomous terms are used, such as mastery versus performance oriented, or intrinsic versus extrinsic motivation. Individuals who are intrinsically motivated find enjoyment or pleasure in the task itself, whereas extrinsically motivated individuals are motivated by external rewards, such as grades (8). As described by Pintrich and De Groot (12), motivation comprises student expectations of their belief to perform a task, student goals and interests about a task, and students’ emotional reactions to a task. Students who have high intrinsic motivation and self-efficacy are more likely to have greater academic achievement than those with lower levels of intrinsic motivation and self-efficacy (12).

So how can educators help physiology students prepare for the wet laboratory environment, feel confident in their abilities, and increase their self-efficacy and motivation? This work highlights the evaluation of an online tool developed for an undergraduate molecular biology laboratory course, the LaboraTREE. A LaboraTREE is an online decision tree created using branching software from Adobe Captivate (Fig. 1). Students were presented with a scientific scenario and were provided with options on how to proceed; different options would lead the student down different “paths” that would have different realistic outcomes. Importantly, these decision trees were evaluated for completion and not accuracy, to allow students to learn from their mistakes. The goal of this research was to evaluate the effectiveness of the LaboraTREEs in supporting students’ metacognition, motivation, and self-efficacy.

MATERIALS AND METHODS

Ethics

This research was approved by, and conducted in accordance with, the policies of the Office of Human Research Ethics at Western University (project ID no. 107672).

Participants

Students enrolled in four sections of a third-year medical science laboratory course (Interdisciplinary Medical Sciences Laboratory) at Western University were invited to participate in the research. Two of the sections were from the Fall 2016 term and two from the Winter 2017 term, with a total enrollment of 120. There were 61, 59, and 49 students who completed surveys 1, 2, and 3, respectively. This represents a 51, 49, and 41% participation rate, respectively, for the three surveys. The majority of students were in the third year of their program and were 20 yr old (Table 1).

LaboraTREE Tool

The LaboraTREEs were designed to engage students in the thought process of executing a protocol. To do this, the protocols for the various experiments in the class were made into individual LaboraTREE simulations using Adobe Captivate. To develop the LaboraTREEs, the various steps of the protocol were mapped out, and common errors (based on consultations with faculty members and teaching assistants) were identified. These errors were then used as options for the various branching points (see Figs. 1 and 2). As students were completing the LaboraTREEs, a wrong decision could lead them to a review video or link, or send them down a wrong path that would ultimately lead to their experiment not working. The LaboraTREEs took between 5 and 10 min to complete, and students were able to complete the LaboraTREEs as many times as desired.

Fig. 1. Overview of LaboraTREE design. Students are presented with a scenario that leads them through various steps of the protocol where they make certain choices. Their choices will lead them down different experimental paths. Although only two decisions are presented in the figure, students had, on average, five different decisions to make for each LaboraTREE.
Measures

As indicated above, the participants completed three surveys during the course. As the first two surveys were identical, they are discussed together, followed by a description of the third survey. All three surveys included three demographic items to assess participants’ gender, age, and year in program.

Surveys 1 and 2. Participants completed an adapted version of the Self-Regulated Learning Survey (SRLS) (15) to assess their perceived self-efficacy (e.g., “I expect to do well in the lessons about the concept of X”), intrinsic and extrinsic motivation (e.g., “Even when participating in the learning activities does not guarantee that I get a good grade, I still love to participate in them,” and “I normally will only learn the concepts that will be tested even though there are other concepts that are much more interesting to me,” respectively), and metacognition (e.g., “When studying the concepts of X, I will normally try to identify the concepts that I do not understand well”). The four subscales, each consisting of six items, are rated on a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree). The SRLS is based on the corresponding subscales of the Motivated Strategies for Learning Questionnaire (13), adapted to reflect learning a particular concept [e.g., magnets (15)]. With a sample of elementary school children in Singapore, Sha and colleagues (15) report Cronbach alphas on the four subscales ranging from 0.72 to 0.80. For the present study with third- and fourth-year university students, the alphas ranged from 0.68 to 0.89 (Table 2). For survey 1, students completed the LaboraTREE before the completion of the survey and also read the laboratory manual. For survey 2, students did not have access to the LaboraTREE before the wet laboratory. Students prepared for the laboratory by reading the laboratory manual. Students then completed survey 2, performed the wet laboratory, and then had access to the LaboraTREE.

Survey 3. In addition to the demographic variables outlined above, the third survey consisted of eight items rated on a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree) assessing students’ self-reported levels of preparation, knowledge, and confidence (e.g., “Because of the LaboraTREE simulations, I felt more confident with my level of knowledge prior to lab,” and “Because of the LaboraTREE simulations, I felt better prepared coming to the lab”). The third survey also included four open-ended questions assessing the perceived impact of the simulations on student learning as well as their strengths and weaknesses.

Procedures

Participants enrolled in the study completed the three surveys throughout the term. For the first survey, administered early in the term, students read the laboratory manual and were presented with the LaboraTREE simulation before the survey and the wet laboratory session. For the second survey, administered at the midpoint in the term, students read the laboratory manual, completed the survey, then

Table 1. Participant demographic information for the three surveys

| Demographic Variable | Survey 1 | Survey 2 | Surveys 1 and 2* | Survey 3 |
|----------------------|----------|----------|-----------------|----------|
| Gender, n            |          |          |                 |          |
| Female               | 31       | 32       | 16              | 28       |
| Male                 | 30       | 27       | 15              | 21       |
| Year in program, n   |          |          |                 |          |
| Third                | 56       | 55       | 27              | 47       |
| Fourth               | 5        | 4        | 4               | 2        |
| Age, mean ± SD, yr   | 20.2 ± 0.511 | 20.4 ± 0.517 | 20.4 ± 0.551 | 20.3 ± 0.555 |
| Total participants, n| 61       | 59       | 31              | 49       |

n, No. of participants. *Demographics are for the participants who had completed both surveys 1 and 2.

Table 2. Cronbach’s alphas for the self-regulated learning survey subscales at times 1 and 2

| SRLS Subscale       | Time 1 | Time 2 |
|---------------------|--------|--------|
| Self-efficacy       | 0.86   | 0.89   |
| Intrinsic motivation| 0.78   | 0.76   |
| Extrinsic motivation| 0.87   | 0.82   |
| Metacognition       | 0.68   | 0.68   |

SRLS, Self-Regulated Learning Survey.
participated in the wet laboratory, and subsequently were given access to the LaboraTREE simulation. The third survey was completed at the end of the term. Each survey took ~20 min to complete. The surveys were administered during class time by the second author, who had no connection to the course or the students.

Data Analysis

Statistical analyses. All statistical analyses were performed using IBM SPSS Statistics version 24. Means and standard deviations are reported for the SLRS subscale scores for surveys 1, 2, and 2, and frequencies are reported for the eight rating scale items from survey 3. To assess the assumption of normality of the difference between the pairs of SLRS subscale scores, a Shapiro-Wilk test was performed for each of the four subscales and were nonsignificant. To examine mean differences between surveys 1 and 2 on the SLRS subscale scores, four paired sample t tests were performed, and effect sizes (Cohen’s d) were calculated. To correct for multiple comparisons, a Bonferroni correction was applied to the paired sample t tests, such that $P = 0.0125$ (0.05/4).

Thematic analysis. Students’ qualitative feedback for each prompt was entered into an Excel spreadsheet. Each prompt was then analyzed using inductive thematic analysis. Themes were developed, coded, and counted for each prompt. Sample quotes corresponding to each theme were included.

RESULTS

Quantitative Data

Students self-reported higher levels of self-efficacy when the LaboraTREE simulations were introduced before the wet laboratory (survey 1) compared with their self-efficacy when the LaboraTREE simulations were given after the wet laboratory (survey 2) (Table 3). Similarly, students had higher self-reported levels of intrinsic motivation when the LaboraTREE simulations were completed before the laboratory (Table 3). There were no statistically significant effects of the LaboraTREE simulations on students’ extrinsic motivation or metacognition.

Thematic Analysis of Qualitative Data

The third survey prompted students to articulate their experience using the LaboraTrees. As shown in Table 4, the vast majority of students stated that the LaboraTrees had a positive impact on their laboratory preparation and understanding. Students also commented on the LaboraTrees’ impact on their confidence, which supported the qualitative results outlined above.

DISCUSSION

Our study sought to evaluate the efficacy of online decision trees in supporting student metacognition, motivation, and self-efficacy. We found that students reported higher levels of self-efficacy and intrinsic motivation when they were able to complete the LaboraTrees immediately before the wet laboratory. In contrast, when students prepared for the laboratory by reading the protocol and then accessed the simulation following the laboratory, students had decreased scores of self-reported self-efficacy and intrinsic motivation. This suggests that offering students an interactive learning tool, such as a LaboraTREE, is effective for supporting their learning. These findings are in agreement with research by Dohn and colleagues (3), who examined students’ self-reported interest, effort, and self-efficacy in laboratories. They found a significant correlation between laboratory self-efficacy and performance on the final course examination (3). Based on the work from Dohn and colleagues, it is conceivable that these simulations could also indirectly impact performance on course examinations through students’ increased self-efficacy. While our study did not evaluate student academic performance, future studies to evaluate the impact of the LaboraTrees on academic performance may be warranted. Self-efficacy is also related to students’ academic self-concept. Students’ academic self-concept is their perception of their ability in a particular domain and is influenced by comparisons to peers, interactions with instructors, and the learning environment (2). Furthermore, self-concept can be linked to a particular academic subject or discipline (11). Work by Zion and colleagues (18) has shown that supporting students’ academic self-concept by providing instruction on metacognition can increase scientific inquiry skills. In this study, the authors used four different learning approaches to teach high school science students: one of the approaches included embedded metacognitive prompts and guides (18). Students who used the metacognitive-supported learning approach showed greater inquiry skills than their peers (18). In the present study, we showed that the LaboraTrees can increase student self-efficacy and thus may positively influence students’ academic self-concept. Based on this hypothesis, it may be interesting to evaluate the ability of decision trees to support students’ scientific inquiry skills. Perhaps the LaboraTrees could be used to teach theoretical knowledge of a particular technique that could enable students to translate their learning to generate questions about the technique in a wet laboratory environment.

While supporting students’ self-efficacy is important, the visual appeal and usability of the LaboraTree was also important to students’ learning. When students were prompted to discuss why the LaboraTrees had a positive impact on their learning, several themes emerged, such as the visual design of the LaboraTrees and their ability to facilitate understanding of the protocol (e.g., “allowed me to understand why certain steps were wrong”). For the LaboraTree simulations, images of the actual equipment were used to familiarize students with

Table 3. Means, SDs, and statistical analysis for the self-regulated learning survey subscales

| Subscale           | Survey 1            | Survey 2            | n   | P Value |
|--------------------|---------------------|---------------------|-----|---------|
| Self-efficacy      | 4.3441 ± 0.51087    | 3.9355 ± 0.63636    | 31  | 0.01    |
| Intrinsic motivation| 3.9032 ± 0.58654    | 3.4570 ± 0.64974    | 31  | ≤0.01   |
| Extrinsic motivation| 3.9194 ± 0.65245    | 3.9570 ± 0.61609    | 31  | No significance |
| Metacognition      | 4.1935 ± 0.49459    | 4.0538 ± 0.08194    | 31  | No significance |

Values are means ± SD; n, no. of participants. Participants rated the survey items on a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree). Values in bold are significantly different.
the various pieces of equipment before the laboratory. Research by Modell and colleagues (9) found that having students make oral predictions about an experiment before executing a protocol increased student correction of a common physiological misunderstanding. The authors argued that making public predictions with an expert resulted in more accurate experimental predictions; in our study, performing the LaboraTREE simulation led by the instructor.

Finally, students were asked to reflect on the strengths and weaknesses of the LaboraTREE design. Many students responded positively about the visual appeal of the LaboraTREEs, their navigation, the feedback afforded by the LaboraTREEs, and their interactivity (Table 4). The main weakness of the LaboraTREE design, as reported by students, was technical issues (e.g., web browser incompatibility, inconsistency with buttons in the program) (Table 4). Technology quality has been correlated with learner satisfaction and is a key driver of successful technology-integrated learning (16).

As with all research, this study has limitations. The impact of the online decision trees was evaluated in the context of one course at one institution. The techniques that were studied of the online decision trees was evaluated in the context of one population of students have a greater benefit of using the decision trees compared with others. Future studies should be expanded to consider evaluating the content of one of the protocols as more difficult than the other. It is possible that the effects seen in the study were due to students’ prior knowledge of the techniques and had little to do with the LaboraTREEs. Furthermore, students may have perceived the impact of online decision trees in a broader context. Furthermore, it may be interesting to evaluate whether specific subpopulations of students have a greater benefit of using the decision trees compared with others.

Overall, this study identified that the LaboraTREEs supported students’ self-efficacy and intrinsic motivation. Students identified that the LaboraTREEs helped them feel more prepared and were engaging due to the visual nature of the tool. Educators who are interested in using a similar approach

### Table 4. Thematic analysis of qualitative data

| Question/Prompt | Themes (no. of responses) | Example Quote |
|-----------------|---------------------------|---------------|
| What impact do you think the LaboraTREE simulation had on your learning? | 1. Laboratory preparation/confidence (15) | 1. “It allowed me to be prepared before coming into the lab.” |
|                  | 2. Laboratory overall understanding (26) | 2. “It had its greatest impact on my understanding of lab techniques.” |
|                  | 3. Visual design (3) | 3. “Simulations allowed me to walk through the protocol.” |
|                  | 4. Unsatisfactory opinion (3) | 4. “Not a significant impact.” |
|                  | 5. Positive (2) | 5. “Positive impact.” |
| Why do you think it had that impact? | 1. Laboratory preparation/confidence (13) | 1. “Allowed me to become familiar with the protocol.” |
|                  | 2. Laboratory learning/understanding (19) | 2. “… allowed me to understand why certain steps were wrong.” |
|                  | 3. Visual design/layout (9) | 3. “It provided a visual simulation of the lab procedure.” |
|                  | 4. Unsatisfactory opinion (2) | 4. “Felt like the LaboraTREEs were okay, but didn’t help that much…” |
| What were the strengths of the LaboraTREE design? | 1. Mistake corrections/feedback (10) | 1. “Explanations that are provided after choosing the wrong option.” |
|                  | 2. Accessibility, usability, efficiency (12) | 2. “Easy to use, stand-alone (no class time).” |
|                  | 3. Visual design and navigation (10) | 3. “Video demonstrating skills.” |
|                  | 4. Interactive (6) | 4. “Interactive design was engaging.” |
|                  | 5. Increased understanding (14) | 5. “Full understanding of lab protocol and conduct.” |
|                  | 6. None (2) | 6. “Same mark no matter how I did personally.” |
| What were the weaknesses of the LaboraTREE design? | 1. None (6) | 1. “No weakness.” |
|                  | 2. Technological issues (20) | 2. “Technology issues with some LaboraTREEs.” |
|                  | 3. Lacks detail and critical thinking (6) | 3. “Needs to have more in depth details for anyone that requires it.” |
|                  | 4. Information differs from protocol (2) | 4. “Doesn’t exactly follow the given lab protocol so it was confusing at times.” |
|                  | 5. Visual design (3) | 5. “The inconsistent format of buttons and images.” |
|                  | 6. Accessibility (date assigned and length) (4) | 6. “Having the LaboraTREE after the lab was not beneficial.” |
should consider common errors in protocols when informing the design of the LaboraTREEs and aim to make them visually appealing by using images of the actual equipment that students will use in the laboratory. Instructors should also consider the technical requirements of their learning management system and investigate support for technology-integrated learning at their institution.

ACKNOWLEDGMENTS

The authors acknowledge Dr. Jay Loftus and Weikai Huang for assistance in the technical development of the LaboraTREEs. The authors also acknowledge the Centre for Teaching and Learning at Western University for ongoing support.

GRANTS

S.M. was the recipient of a Teaching Fellowship through the Centre for Teaching and Learning at Western University. The funds from the teaching fellowship supported the development of the LaboraTREEs as well as the research outlined in this paper.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

AUTHOR CONTRIBUTIONS

S.M., K.N.M., and N.C. conceived and designed research; S.M. performed experiments; S.M., K.N.M., and A.H. analyzed data; S.M. and K.N.M. interpreted results of experiments; S.M. and A.H. prepared figures; S.M. and K.N.M. edited and revised manuscript; S.M., K.N.M., A.H., and N.C. approved final version of manuscript.

REFERENCES

1. Bandura A, Freeman WH, Lightsey R. Self-efficacy: the exercise of control. J Cogn Psychother 13: 158–166, 1999. doi:10.1891/0889-8391.13.2.158.
2. Cooper KM, Krieg A, Brownell SE. Who perceives they are smarter? Exploring the influence of student characteristics on student academic self-concept in physiology. Adv Physiol Educ 42: 200–208, 2018. doi: 10.1152/advan.00085.2017.
3. Dohn NB, Fago A, Overgaard J, Madsen PT, Malte H. Students’ motivation toward laboratory work in physiology teaching. Adv Physiol Educ 40: 313–318, 2016. doi:10.1152/advan.00029.2016.
4. Freeman S, Eddy SL, McDonough M, Smith MK, Okoroafor N, Jordt H, Wenderoth MP. Active learning increases student performance in science, engineering, and mathematics. Proc Natl Acad Sci USA 111: 8410–8415, 2014. doi:10.1073/pnas.1319030111.
5. Glynn SM, Brickman P, Armstrong N, Taasoobshirazi G. Science motivation questionnaire II: validation with science majors and nonscience majors. J Res Sci Teach 48: 1159–1176, 2011. doi:10.1002/tea.20442.
6. Hofstein A, Lunetta VN. The laboratory in science education: foundations for the twenty-first century. Sci Educ 88: 28–54, 2004. doi:10.1002/sce.10106.
7. Kurbanoglu N, Akim A. The relationships between university students’ chemistry laboratory anxiety, attitudes, and self-efficacy beliefs. Aust J Teach Educ 35: 48–59, 2010. doi:10.14221/ajte.2010v35n8.4.
8. Lin Y-G, McKeachie WJ, Kim YC. College student intrinsic and/or extrinsic motivation and learning. Learn Individ Differ 13: 251–258, 2003. doi:10.1016/S1041-6080(02)00092-4.
9. Modell HI, Michael JA, Adamson T, Horwitz B. Enhancing active learning in the student laboratory. Adv Physiol Educ 28: 107–111, 2004. doi:10.1152/advan.00049.2003.
10. Pajares F. Self-efficacy beliefs in academic settings. Rev Educ Res 66: 543–578, 1996. doi:10.3102/003465430660040543.
11. Pickering M. What goes on in students’ heads in lab? J Chem Educ 64: 521–523, 1987. doi:10.1021/ed064p521.
12. Pintrich PR, Groot EVD. Motivational and self-regulated learning components of classroom academic performance. J Educ Psychol 82: 33–40, 1990. doi:10.1037/0022-0663.82.1.33.
13. Pintrich PR, Smith DAF, Garcia T, Mckeachie WJ. Reliability and predictive validity of the motivated strategies for learning questionnaire (Mslq). Educ Meas 53: 801–813, 1993. doi:10.1177/0011164493053003024.
14. Schunk DH. Self-efficacy and academic motivation. Educ Psychol 26: 207–231, 1991. doi:10.1021/ed064p207.
15. Sha L, Looi C-K, Chen W, Seow P, Wong L-H. Recognizing and measuring self-regulated learning in a mobile learning environment. Comput Human Behav 28: 718–728, 2012. doi:10.1016/j.chb.2011.11.019.
16. Sun P-C, Tsai RJ, Finger G, Chen Y-Y, Yeh D. What drives a successful e-learning? An empirical investigation of the critical factors influencing learner satisfaction. Comput Educ 50: 1183–1202, 2008. doi:10.1016/j.compedu.2006.11.007.
17. Tsang A, Harris DM. Faculty and second-year medical student perceptions of active learning in an integrated curriculum. Adv Physiol Educ 40: 446–453, 2016. doi:10.1152/advan.00079.2016.
18. Zion M, Michalsky T, Mevarech ZR. The effects of metacognitive instruction embedded within an asynchronous learning network on scientific inquiry skills. Int J Sci Educ 27: 957–983, 2005. doi:10.1080/09500690500068626. 

Advances in Physiology Education • doi:10.1152/advan.00016.2019 • http://advan.physiology.org