Research Article

JMBE Journal of Microbiology & Biology Education

Student Perceptions of a Framework for Facilitating Transfer from Lessons to Exams, and the Relevance of This Framework to Published Lessons

Dilan P. Evans,[a] Lekelia D. Jenkins,[b] and Gregory J. Crowther[c,d]

[a]Ira A. Fulton Schools of Engineering, Arizona State University, Tempe, Arizona, USA

[b]School for the Future of Innovation in Society, Arizona State University, Tempe, Arizona, USA

[c]Life Sciences Department, Everett Community College, Everett, Washington, USA

[d]Division of Biological Sciences, University of Washington Bothell, Bothell, Washington, USA

A main goal of academic courses is to help students acquire knowledge and skills that they can transfer to multiple contexts. In this article, we (i) examine students' responses to test question templates (TQTs), a framework intended to facilitate transfer, and (ii) determine whether similar transfer-promoting strategies are commonly embedded in published biology lessons. In study 1, in surveys administered over several academic quarters, students consistently reported that TQTs helped them transfer course content to exams and the real world; that multiple (two to five) examples were generally needed to understand a given TQT, leading >40% students to create their own additional examples; and that TQTs would be helpful in other science courses. In study 2, among 100 peer-reviewed lessons published by CourseSource or the National Center for Case Study Teaching in Science (NCCSTS), less than 5% of lessons gave students advice about exams or helped students create additional practice problems. The latter finding is not meant as criticism of these excellent lessons, which are a boon to the biology education community. However, with TQT-like prescriptions generally absent from peer-reviewed lessons, biology instructors may wish to supplement the lessons with TQT-like strategies to explicitly connect the material to subsequent exams.

KEYWORDS transparent alignment, formative assessment, summative assessment, analogical thinking

INTRODUCTION

Quality education involves not only the memorization and retention of specific knowledge, but also the application and broadening of that knowledge (1, 2). Transfer has been defined as "the ability to generalize knowledge across contexts" (3). For example, students may solve worksheet problems as an in-class activity and then, days later, transfer that knowledge to a midterm exam (immediate or short-term transfer) or, years later, to related problems in a professional setting (long-term transfer).

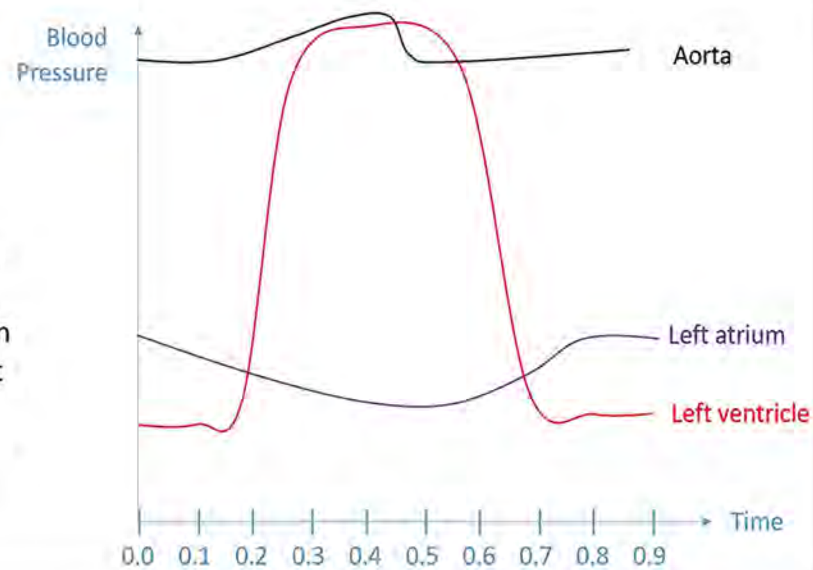
Barnett and Ceci (4) have defined several dimensions to transfer, which can occur across different knowledge domains, different modalities, and different physical, temporal, social, and functional contexts. For each dimension, transfer could be placed somewhere on a continuum ranging from near transfer to far transfer. In the example above, transfer from the worksheet to the midterm would be near transfer in the physical domain if both were done in the same location (e.g., a particular classroom) but would be moderately far in the social domain if one were done in a large group and the other were done by oneself.

Numerous research studies have indicated that, in the knowledge domain, even near-to-moderate-range transfer is often very challenging for students. For instance, many of the undergraduates interviewed by Kohn et al. (5) were unable to reconcile views on energy and ATP acquired from their chemistry and biology courses, respectively. Kaminske et al. (3) partly attributed transfer's difficulty to its dependence on three challenging steps: recognizing the relevance of previous knowledge, correctly recalling that previous knowledge, and applying the knowledge to the new situation. A complementary explanation is that students' study methods are often not optimal for transfer. For example, retrieval practice, in which students try to recall previously delivered information, can dramatically boost comprehension and retention (6–8), but many students opt for the inferior strategy of simply rereading their textbook or notes (9, 10).

As students strive to get better at transfer, instructors can support them with various strategies (2, 3). One validated approach is to give students multiple problems with different

Editor Samantha T. Parks, Georgia State University
Address correspondence to Life Sciences Department, Everett Community College, Everett, Washington, USA. E-mail: gcrowther@everettcc.edu.
The authors declare no conflict of interest.
Received: 31 October 2022, Accepted: 14 January 2023,
Published: 6 February 2023

TABLE 1
Example of a test question template

Lesson Learning Objective (LLO)	Given information about relevant pressures, answer questions about the sound or status (open or closed) of a cardiac valve.
Example A	At a given moment, the blood pressure is 80 mm Hg in the aorta, 20 mm Hg in the left atrium, and 15 mm Hg in the left ventricle. Is the mitral valve open or closed? Is the aortic valve open or closed?
Example B	An alien (with cardiovascular anatomy like ours but somewhat different physiology) has the blood pressures shown at right. At what time will the "lub" sound be heard? 
Example C	Make up an example and ask your classmates!

surface features but common underlying patterns (3), perhaps explicitly asking students to identify the underlying patterns (2). The process of noticing common features in distinct examples is referenced in the cognitive psychology literature as analogical abstraction (11) and case comparison (12), among other terms. The value of this analogical thinking has been demonstrated in a series of classic studies on how MBA students learn to negotiate contracts. In classroom negotiation exercises, individuals and teams were more likely to form contingent contracts (an elusive but desirable outcome) if they had previously received analogy training, as opposed to separate case training or no training (13–15).

Recognition of patterns (or analogies), therefore, is central to the enterprise of transfer. Transfer could be defined as the ability to apply patterns to new situations, and the above-mentioned challenges of transfer (3) could be recast as the challenges of learning a pattern, recognizing when the pattern is relevant, and applying the pattern correctly.

The need for biology students to identify patterns among related problems has been recognized by biology education researchers and practitioners (e.g., references 16 and 17). Such pattern recognition should help students transfer knowledge to novel problems, such as those that appear on exams (18). However, to our knowledge, the biology education community has not widely adopted any framework that explicitly teaches students about patterns of likely exam problems.

One possible remedy is the use of test question templates (TQTs) (19, 20). As originally formulated, a given TQT has four components: an input, an output, one or more examples, and a key (19). Alternatively, a TQT can be summarized as a lesson learning objective (LLO; i.e., the input and output) directly paired with specific examples of questions assessing that LLO (Table 1). TQTs thus represent a highly structured kind of study guide. A typical study guide or practice exam offers practice questions related to the actual exam questions; for example, a study guide for an undergraduate physiology course might include either example A or example B of Table 1. The difficulty for students, as previously noted (19), is that they are not usually told how the practice problems relate to the actual exam questions. If students are given example A of Table 1 on a study guide, but are not given the LLO or example B, they may get a general sense that cardiac valves are important, but they will not really know which kinds of cardiac valve questions are and are not within the scope of the exam. In contrast, each TQT, in bundling a clear LLO with multiple example questions carefully matched to that LLO, reveals the patterns underlying the examples and thus defines expectations more clearly.

We believe that the explicit student-facing delineation of the relationship between practice problems and actual exam problems is a unique and powerful feature of TQTs. However, TQTs have not been formally evaluated aside from an analysis of student comments from one academic quarter (19). Therefore, study 1 of this paper offers a more extensive characterization of anatomy and physiology students' perceptions of TQTs. Study 1's findings then lead us to ask, in Study 2, whether TQT-like strategies are commonly included in peer-reviewed biology lessons from two leading sources (CourseSource and NCCSTS).

METHODS

Study 1

(i) Overview. In a typical academic quarter, author G. Crowther teaches separate courses in Human Anatomy (Biology 231) and Human Physiology (Biology 232). These 11-week courses have prerequisites of one-quarter courses in general chemistry and cell biology and are typically taken by sophomore-level students as prerequisites for nursing programs and other health science professional programs. Demographic information on these students is presented in Appendix S1 in the supplemental material.

The present study spanned six academic quarters, from Spring 2020 to Fall 2021, with the first quarter (Spring 2020) serving as a pilot study that informed subsequent quarters. TQT-related artifacts were collected as summarized in Appendix S1 and as described below. This work was approved by the Everett Community College Institutional Review Board.

(ii) Do students understand the TQT framework? We determined whether students understood the TQT framework—and thus whether they were well-positioned to answer survey questions about this framework—with two nondisruptive assessments based on regular course activities: post a practice question and identify the TQT sources of old test questions (see Appendix S2).

Starting in Fall 2020, before each of the six tests (Fall 2020 to Winter 2021) or before tests 2 to 6 (Spring 2021 to Fall 2021), students were required to post a practice question based on a TQT to an online discussion board, or to answer a classmate's question (see Appendix S2). To assess understanding of TQTs, students' practice questions were rated either as consistent or as not consistent with the TQT format. A majority of students posted at least one practice question each quarter (range, 57 to 86%; mean, 70%) (see Appendix S1).

Starting in Spring 2021, before test 1, students were required to access the previous quarter's test 1 short-answer questions and identify the specific TQT on which each old test question was based (see Appendix S2). To assess students' understanding of TQTs, each of the 10 to 15 identifications was graded for correctness. A majority of students participated in this activity each quarter (range, 55 to 90%; mean, 72%) (see Appendix S1).

(iii) Survey administration. Human Anatomy and Human Physiology students were surveyed about their perceptions of TQTs. Students received small amounts of extra credit (0.2 to 0.3% of their final grade) for completing the survey online (as a Google Form), outside of class time. To protect students' privacy and minimize the invasiveness of the survey, all responses were collected anonymously. A majority of students in each class participated in the survey each quarter (range, 67 to 90%, mean, 81%) (see Appendix S1).

The survey was mostly exploratory in nature, i.e., questions were designed to gather general feedback rather than to test specific hypotheses. Therefore, rather than using or developing a formally validated instrument, we created an *ad hoc* survey, including both fixed-choice and free-response questions, that evolved over several quarters (see Appendix S3). In part because the survey was created *ad hoc* and was changed slightly from quarter to quarter, detailed statistical analyses were not performed.

(iv) Analysis of survey structure. As summarized in Table 2, we determined *post hoc* that the survey covered three main topic areas:

- Do students find TQTs helpful in Human Anatomy and Human Physiology?
- Do TQTs help students work on multiple related examples?
- Could TQT-like frameworks help students in other science courses?

The second topic area involved only fixed-response questions, while the first and third topic areas used a mix of fixed-response and open-ended questions. Answers to those open-ended questions and a final optional question ("Please share any other thoughts you have about test question templates") were then used to consider a final overarching topic: "Do students perceive TQTs as facilitating transfer?"

(v) Analysis of free responses to survey questions. Students' answers to the free-response survey questions (Table 3) were analyzed for transfer-related themes in a manner informed by pilot study work on an earlier, different version of the survey from Spring 2020 (see Appendix S3). In that pilot study, author Dilan P. Evans performed open coding of free-form survey responses with MAXQDA software, applying a grounded theory approach to text analysis, an iterative inductive process of coding concepts that emerged from the text, and linking these concepts into themes (21). Among the themes arising from the Spring 2020 comments were three themes that concerned transfer (Table 3): (1) TQTs indicate test content, (2) TQTs indicate test format, and (3) TQTs show applications to the real world. For the remaining quarters (Fall 2020 through Fall 2021), we focused on the issue of transfer by conducting a content analysis using the codebook developed from the grounded theory analysis. Authors D. P. Evans and G. Crowther independently looked for the three transfer-related themes (Table 3) in students' free responses. Agreement of the two coders was checked by the calculation of Cohen's kappa values (22). This agreement was generally strong, as indicated by kappa values of ≥0.6 (23). The overall kappa values (covering all quarters, Fall 2020 through Fall 2021) for themes 1, 2, and 3 were 0.60, 0.60, and 0.86, respectively. For reporting final theme

TABLE 2
Overview of survey structure (Fall 2020 through Fall 2021)

Survey topic area and questions[a]		
Do students find TQTs helpful in Human Anatomy and Human Physiology?	**Do TQTs help students work on multiple related examples?**	**Could TQT-like frameworks help students in other science courses?**
• Did TQTs affect your learning of the course material? [#1 for Fall 2020 through Fall 2021] • Briefly explain your answer to the previous question. [#2 for Fall 2020 through Fall 2021] • Did the pre-exam online discussion boards about TQTs affect your learning? [#5 for Fall 2020, #3 for Winter 2021 through Fall 2021] • Briefly explain your answer to the previous question. [#6 for Fall 2020; #4 for Winter 2021 through Fall 2021]	• In your studying outside of class assignments, did you make up and solve any of your own additional examples based on the TQTs? [#3 for Fall 2020, #5 for Winter 2021 through Fall 2021] • To understand a TQT well, I would normally need to do about _____ practice examples. [#6 for Winter 2021 through Fall 2021]	• If you had your choice, would you want instructors in your other science courses to provide you with TQTs (or something similar)? [#7 for Fall 2020 through Fall 2021] • Briefly explain your answer to the previous question. [#8 for Fall 2020 through Fall 2021]
Optional: Please share any other thoughts you have about test question templates. [#9 for Fall 2020 through Fall 2021]		

[a]Question numbers are reported in brackets; see Appendix S3 for details.

counts (Table 4), the coders used discussion to reach consensus on all comments that they had initially categorized differently.

Study 2

(i) Sources of lessons. Among many useful sources of peer-reviewed undergraduate biology lessons (e.g., HHMI Biointeractive, LifeSciTRC.org, HAPSweb.org, various journals), we focused on two: *CourseSource* (coursesource.org) and the National Center for Case Study Teaching in Science, recently transferred from the University at Buffalo to the National Science Teaching Association (NSTA.org). These sources were chosen because they met the following criteria: a thorough and transparent peer-review process, a standardized publication format, and a collection representing numerous instructors from diverse academic institutions.

From each source, 50 lessons were randomly selected for analysis (Table 5; see also Appendix S4). These lessons nearly always yielded "no" responses to coding questions Q3 and Q4 (see below), so, with this trend already clear after 100 lessons,

TABLE 3
Code book for students' survey comments about TQTs and transfer

Category	Test content	Test format	Application to real world
Definition of theme	TQTs helped the student have reasonable expectations for what content would be present on an exam.	TQTs helped the student understand how future exam questions would be formatted.	Students were able to apply their lecture knowledge in real life scenarios through TQTs.
Inclusion criteria	To fit this theme, a comment would refer both to TQTs and to knowing what content to study for an exam, or to having expectations of exam content.	To fit this theme, a comment would refer both to TQTs and to exam properties such as "formatting," "wording," "question style," etc.	To fit this theme, a comment would refer both to TQTs and to "real-world," "real-life," "clinical," or "medical" applications or scenarios.
Examples of student comments illustrating this theme	"It clearly defined expectations of what I should be able to comprehend by the test by highlighting what the teacher thought was the most pertinent information." [Fall 2020] "It really showed me what was going to be expected of me on tests. Especially by describing the main focus in detail at the beginning of the TQT, and then provide question examples of how knowledge of the focus can be asked in different ways." [Summer 2021]	"Loved how that was how the tests were based on and written based off instead of having random questions you don't understand and have never seen a format to." [Fall 2020] "TQTs allowed me to become familiar with the content in the way it would be presented during testing." [Fall 2021]	"The TQT helped me apply the knowledge I had learnt from the lectures and apply it to real life situations." [Fall 2020] ". . .It also helps in terms of condensing information into what I really need to know and helps apply concepts we learned in real life situations. It makes what we're learning feel important." [Spring 2021]

TABLE 4
Percentages of students bringing up transfer-related themes[a] in free responses to questions about TQTs

Student category	Human Anatomy	Human Physiology
Total students surveyed (Fall 2020 through Fall 2021)	88	137
Themes brought up by indicated % of respondents		
TQTs indicate test content	26%	20%
TQTs indicate test format	13%	10%
TQTs show applications to the real world	10%	15%

[a]Full definitions of transfer-related themes are given in Table 3.

we deemed the sample size adequate. That is, we saw 100 lessons as an adequate sample size to demonstrate that very few of these lessons provide exam-related advice to students or facilitate students' creation of additional practice problems.

(ii) Coding of lessons. We asked four transfer-related questions, Q1 to Q4, about each published lesson (Table 6). Of these, Q1 ("Do any of the lesson's LOs promote transfer?") was the most subjective, and thus may merit more explanation than Table 6 provides. We acknowledge that any LO can be applied to a context different from that of the lesson itself, so any LO can contribute to transfer. However, some LOs inherently extend beyond the details of the lesson itself, and thus may be seen as promoting transfer, while others do not extend in this way and thus might or might not contribute to transfer. We sought to distinguish between these "transfer-promoting" LOs and other LOs in Q1.

Q3 and Q4 were designed to compare these diverse published biology lessons to the TQT framework. Q3 asked whether the lessons explicitly coached students on transferring the lesson's content or skills to exams, as TQTs were perceived to do in study 1. Similarly, Q4 asked whether the lessons promoted students' creation of additional related practice problems, as TQTs were found to do in study 1.

We attempted internal validation of our coding of Q1 to Q4 by comparing two coders' independent coding of the same lessons. Author D. P. Evans coded all 50 CourseSource lessons and 10 of the NCCSTS lessons, while author G. J. Crowther coded all 50 NCCSTS lessons and 10 of the CourseSource lessons. For the purpose of reporting consensus values, rare disagreements between our two authors were resolved by L. D. Jenkins.

Once the code book was finalized (Table 6), agreement between the two coders was strong, with Cohen's kappas of 1.0 for Q1, 0.89 for Q2, and 1.0 for Q4. The Cohen's kappa for Q3 was undefined, because Q3 was answered "no" by both coders for all 20 jointly coded lessons.

RESULTS

Study 1

(i) Do students understand the TQT framework? In each of the nine classes for which data were available, most of the posted practice questions were in the requested TQT format (data not shown), and a majority of students posted at

TABLE 5
Sources of biology lessons analyzed in study 2

Criterion or category	CourseSource	NCCSTS
Published lessons at the time of the study (Spring 2021)	171	950
Subject matter	171 (all lessons concerned biology)	Subject heading of "Biology (General)" or a biological subfield
Grade level	Course level of "Introductory"	Educational level of "Undergraduate lower division"
Subject matter and grade level	∼120	∼800
No. of lessons selected for coding	50	50
No. of authors represented in selected lessons	196	83
No. of institutions represented in selected lessons	106 colleges or universities	60 colleges or universities, 1 high school, 3 nonacademic institutions
No. of published pages of materials per lesson (mean ± SD)[a]	22 ± 18	15 ± 6

[a]Page counts do not include videos, PowerPoint slides, or previously published articles used as resources.

TABLE 6
Questions and code book used to analyze biology lessons in study 2

Category	Question 1	Question 2	Question 3	Question 4
Full question [answer options]	Do any of the lesson's learning objectives (LOs) promote transfer? If yes, do they promote far transfer or near transfer? [Yes-far transfer/Yes-near transfer/No]	Does the lesson (including associated teaching notes and supplementary materials) discuss exams or provide possible exam questions (not counting questions that were part of the activity itself)? [Yes/No]	Does the lesson provide advice to students on preparing for future exams? [Yes/No]	Does the lesson encourage students to create additional practice problems related to the lesson? [Yes/No]
Criterion for a yes answer	Near transfer: LOs require students to apply knowledge or skills in slightly different contexts. This can be different types of knowledge, locations, times, social contexts, etc. These LOs will stay within the scope of the course and subject but will still require the student to apply material in a different (but similar) context. Far transfer: LOs require students to apply knowledge or skills in more different contexts. This can be different types of knowledge, locations, times, social contexts, etc. These LOs will be widely applicable outside of the lesson.	The authors explicitly state that a related test is coming in the future (after the lesson), and/or they attach a supporting file with exam details.	The lesson advises students on how to prepare for a postlesson exam.	The lesson encourages students to devise their own practice problems, whether for homework, studying, or exams.
Examples of yes answers (reference)	Near transfer: "Predict ionization state of a molecule at a particular pH based on its pKa." (41) Far transfer: "Apply this knowledge [pH chemistry] in a medical context." (41).	"Student understanding of spatial and temporal summation was also assessed on a lecture exam with both multiple choice and short answer questions (supporting files: Leaky Neuron, sample test questions)." (42)	"I end by telling students to review the details of this case for their upcoming exam." (26)	"After the tutorial, students brainstorm questions about air quality/pollution that they can answer using the data. . .. Some students may find that exploring these tools may spark some ideas for questions that they want to explore further." (28)

least one question in the correct TQT format (Fig. 1). Similarly, most students were able to correctly identify most links between TQTs and previous test questions, with class success rates ranging from 67% to 85% (mean, 76%). These results suggested that most students understood the TQT framework and could thus offer informed answers to survey questions about TQTs.

(ii) Do students find TQTs helpful in Human Anatomy and Human Physiology? Of the 88 Human Anatomy students and 137 Human Physiology students surveyed, most gave positive responses to the question, "Did TQTs affect your learning of the course material?" Of the 88 Human Anatomy students surveyed, 73% chose "definitely helped," 27% chose "somewhat/moderately helped," and 0% chose "did not help." Of the 137 Human Physiology students surveyed, 77% chose "definitely helped," 22% chose "somewhat/moderately helped," and 1% chose "did not help."

Opinions of the TQT discussion boards were more mixed. Of the Human Anatomy students, 49% chose "definitely helped,"

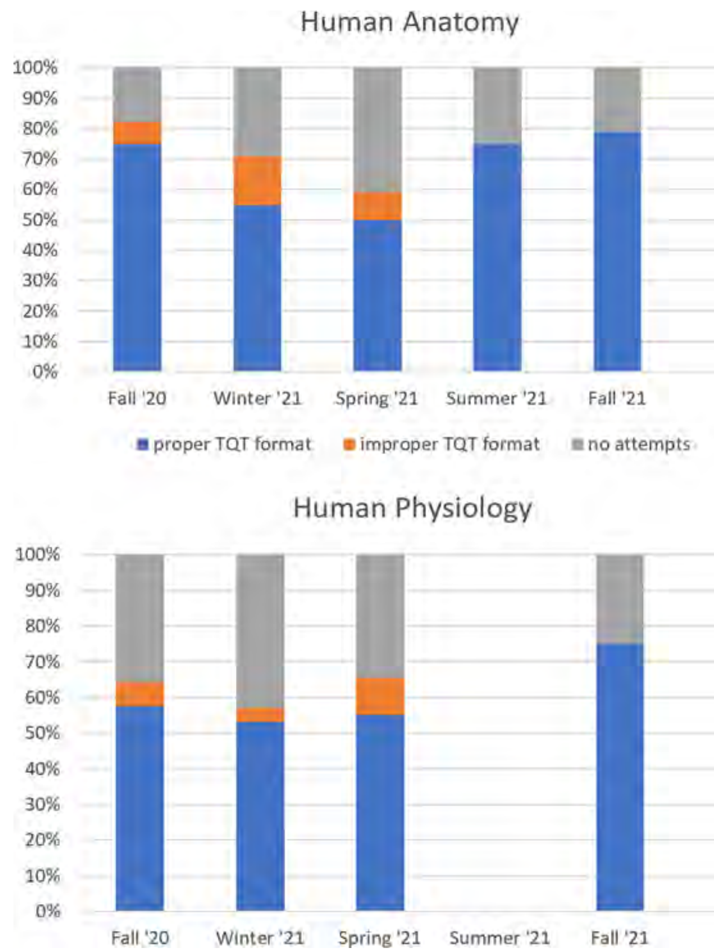


FIG 1. Percentage of students in Human Anatomy (upper panel) and Human Physiology (lower panel) who wrote at least one discussion board example in proper TQT format (bottom, blue), whose attempts were never in proper TQT format (middle, orange), or who did not make any attempts (top, gray). Human Physiology was not taught in Summer 2021.

38% chose "somewhat/moderately helped," and 14% chose "did not help." Of the Human Physiology students, 49% chose "definitely helped," 42% chose "somewhat/moderately helped," and 9% chose "did not help."

(iii) Do TQTs help students work on multiple related examples? Two survey questions explored whether TQTs' emphasis on multiple related examples was noticed and perhaps valued by students. In response to the survey question, "To understand a TQT well, I would normally need to do about ____ practice examples," very few students found 0 or 1 examples sufficient; a majority were satisfied by 2 to 3 examples, but at least 25% of students in both courses felt that they needed 4 or more examples (Fig. 2).

In response to the question, "In your studying outside of class assignments, did you make up and solve any of your own additional examples based on the TQTs?" a substantial minority of students (>40%) in Human Anatomy and in Human Physiology answered yes, i.e., they created additional nonrequired questions. For Human Anatomy, 46 out of 108 students (43%) made up extra examples; for Human Physiology, 71 out of 171 students (42%) did so.

(iv) Could TQT-like frameworks help students in other science courses? The positive views of TQTs expressed by Human Anatomy and Human Physiology students of author G. Crowther did not address the question of whether TQTs (or

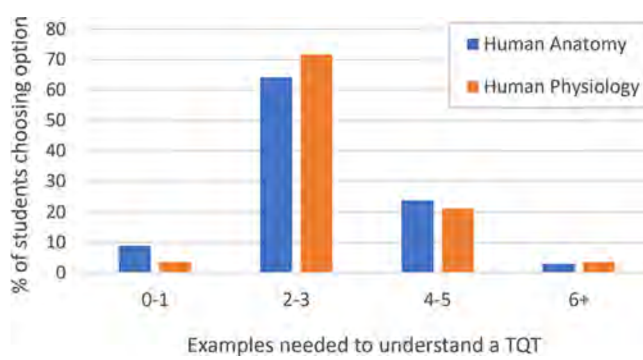


FIG 2. Students' responses to the question of how many example questions are needed to understand a TQT well. For this figure, the *y* axis represents the percentage of students that chose each option. Data are compiled from all quarters of 2021. (This question was not asked in 2020.) Total respondents: 67 for Human Anatomy and 85 for Human Physiology.

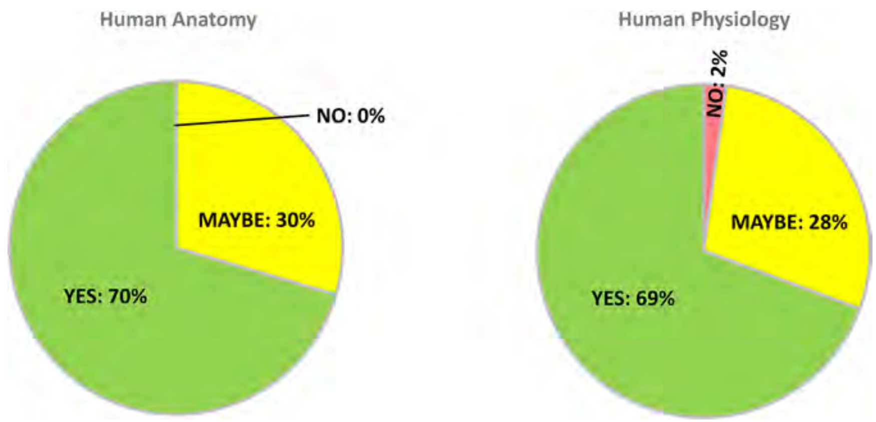


FIG 3. Students' responses to the question of whether they would want TQTs (or something similar) in their other science courses. Choices were "Yes, definitely," "Maybe/Somewhat" and "No, definitely not." Data are from Fall 2020 through Fall 2021. (This question was not asked in Winter 2020 or Spring 2020.) Total respondents: 88 for Human Anatomy, 137 for Human Physiology.

similar frameworks) would be helpful in other science courses taught by other instructors. Therefore, these students were also asked, "If you had your choice, would you want instructors in your other science courses to provide you with TQTs (or something similar)?" Figure 3 indicates that ∼70% of students answered "yes, definitely" to this question, with almost all others answering "maybe/somewhat."

A subsequent survey question asked students to explain their yes/maybe/no answer, and many responses mentioned transfer issues (thus contributing to Table 4). Of the 230 students who received this survey question, 8 compared TQTs to similar approaches (e.g., study guides, practice exams) in other courses, but only 1 student suggested that they had previously experienced a framework equivalent to TQTs. Overall, these survey answers implied that TQTs are quite distinct from study frameworks in other science courses, yet they are quite applicable to those other courses.

(v) Do students perceive TQTs as facilitating transfer? Our Spring 2020 pilot study suggested three transfer-related themes in students' open-ended responses: (1) TQTs indicate test content, (2) TQTs indicate test format, and (3) TQTs show applications to the real world. We then looked for these themes in open-ended responses from Fall 2020 through Fall 2021. Examples of student comments fitting each theme are shown in Table 3, and percentages of students judged to mention each transfer-related theme are shown in Table 4. Overall, 44% of Human Anatomy students (39 of 88) and 39% of Human Physiology students (54 of 137) gave comments judged to address transfer via one or more of the three themes.

Connections between study 1 and study 2

While conducting study 1, we learned that Deborah Donovan of Western Washington University had independently created a TQT-like framework based on learning targets and success criteria (D. A. Donovan, personal communication). We wondered whether other biology instructors might also promote transfer with TQT-like approaches (called by other names, as in Donovan's case, or perhaps unnamed), and we looked for evidence of such approaches in published biology lessons. Since two of the three transfer-related themes in study 1 concerned high-stakes exams, and since these exams are presumably a common feature of most introductory biology courses, study 2 focused mostly on transfer in the context of exams.

Since transfer involves switching contexts (e.g., from one day to another, or from one course to another), it is fair to ask whether transfer can be fruitfully studied by analyzing individual (often single-day) lessons, as we have done here, instead of analyzing whole courses or multicourse curricula. We believe there are at least three reasons why individual lessons are an appropriate level at which to study transfer. First, some of the strategies recommended for facilitating transfer, e.g., including multiple examples with different surface features, discussing underlying patterns (2, 3), can easily be implemented within individual lessons. Second, since final grades in many introductory biology courses are determined mainly by performance on high-stakes exams (24), it is reasonable to see whether individual lessons support the transfer of knowledge from the lessons to the corresponding exam questions. Third, connecting course content to students' personal interests is a best practice of engagement (25), so one could ask whether individual lessons promote engagement by enabling transfer into domains of personal interest, though this is mostly beyond the scope of our study.

Thus, believing that transfer could indeed be studied via examination of individual lessons, our research question for study 2 was, "To what extent do published lessons facilitate transfer to exams?" We explored this broad question by asking four more specific transfer-related questions about each lesson (Table 6).

Study 2

(i) Evidence of transfer-promoting LOs. By our criteria, 82% of CourseSource lessons had at least one transfer-promoting

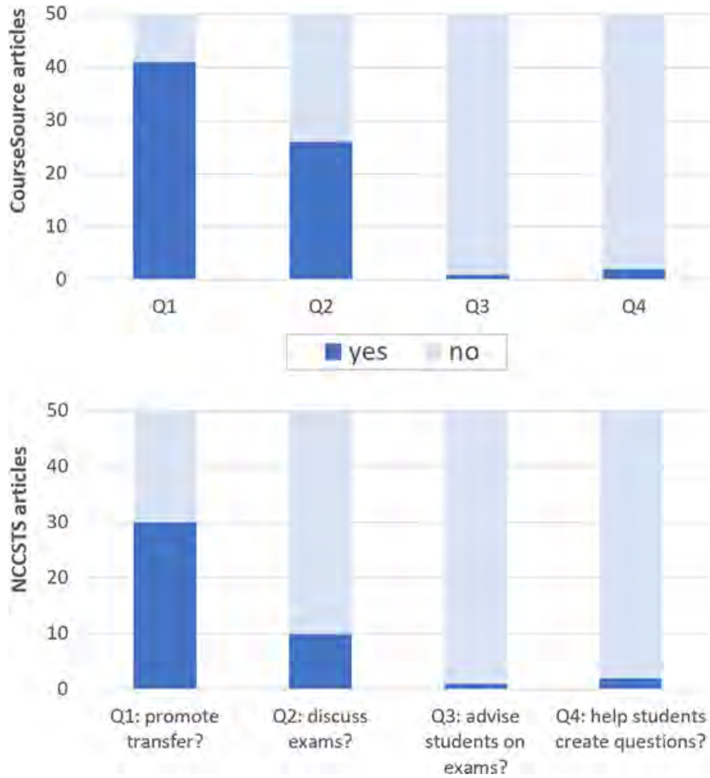


FIG 4. Results of coding introductory biology lessons from CourseSource (top) and NCCSTS (bottom). For full descriptions of questions Q1 to Q4, see Table 6. For Q1, CourseSource lessons included 28 lessons with far-transfer LOs and 13 lessons with near-transfer LOs, while NCCSTS lessons included 19 lessons with far-transfer LOs and 11 lessons with near-transfer LOs.

LO; the corresponding percentage for NCCSTS lessons was 60% (Q1 of Fig. 4). These percentages represent a conservative lower bound on interest in transfer among lesson authors, since (i) even LOs not rated as "transfer-promoting" could facilitate transfer (as noted above) and (ii) lessons' implementation might promote transfer in ways not visible in the published LOs.

(ii) Foreshadowing of exams. We found that 52% of CourseSource lessons referred to postlesson exams (Q2 of Fig. 4). The 52% is likely a conservative lower bound on lesson authors who use high-stakes exams, since CourseSource's assessment subsection does not require authors to discuss exams. (The journal instructs authors to "List and/or explain the kinds of assessment tools used to measure how well students achieved the learning objectives. For example, assessments might be clicker questions, forced choice questions, exams, posters, etc.") In contrast, only 20% of NCCSTS lessons received a "yes" answer to Q2, perhaps reflecting the fact that most NCCSTS lessons lacked an assessment section.

(iii) Promotion of transfer. Among the 36 lessons that mentioned exams somewhere in their materials ("yes" answers to Q2), only two earned "yes" answers to Q3 (Fig. 4). Mossman (26) recommends that professors "...end by telling students to review the details of [the] case for their upcoming exam." Freeman et al. (27) provided an optional homework assignment in which the students generate their own practice questions to study from, which might also be considered (indirect) advice on exam preparation. None of the 100 lessons directed students' exam preparation toward specific topics or skills in the manner of the test content and test format themes of study 1 (Table 3).

For Q4, only 2 of the 100 lessons were coded as "yes" (Fig. 4). In addition to the just-mentioned example of Freeman et al. (27), Williams et al. (28) asked students to come to class with their own questions about the lesson. No other lesson explicitly encourages students to create their own practice questions on the material.

To be clear, our Q3 and Q4 data (Fig. 4) do not mean that the lessons' authors and users failed to help students with transfer to exams, or that they failed to help students create practice problems. Our data simply show that these practices are not explicitly written into the lessons themselves.

DISCUSSION

Given the TQT framework's potential to help students with lessons-to-exams transfer (19, 20), study 1 reports on student artifacts concerning this framework over several academic quarters (Spring 2020 through Fall 2021), a period spanning the transition from online teaching back to in-person teaching. Our main findings were that most students demonstrated an understanding of the TQT format (Fig. 1); most could imagine TQTs being useful in other science courses besides anatomy and physiology (Fig. 3); many (∼40%) suggested without prompting that TQTs facilitate transfer (Table 4); and many (∼40%) created additional TQT-based example problems beyond those required by homework assignments, suggesting that they found the TQT framework useful.

We acknowledge that changes in survey questions from quarter to quarter could have affected the results obtained. To minimize this impact, we limited our analyses to spans of quarters where survey changes were small. The data reported in Table 4 and Fig. 3 are for the surveys from Fall 2020 through Fall 2021, all of which had very similar questions.

We also acknowledge that, since less than half of students (39 to 44%) gave comments coded as covering transfer via TQTs, we cannot be sure that most or all students perceived TQTs to address transfer. Nevertheless, this relatively high percentage of 39 to 44% suggests relatively pervasive attitudes, given the broadness of the survey prompts (which did not mention transfer) and our adherence to strict coding criteria (Table 3), which demanded that, to be counted as exemplifying a theme, a comment had to explicitly mention TQTs. If we had assumed that all comments concerned TQTs (based on the fact that the questions were about TQTs), the theme counts would have been even higher.

The abundant pro-TQT feedback amassed in study 1 then led us to ask (in study 2) whether biology lessons published by others include TQT-like support for students creating additional sample problems or otherwise preparing for exams. The main result of study 2 was that less than 5% of published lessons helped students create their own practice problems or otherwise prepare for exams (Q3 and Q4 of Fig. 4). In principle, these absences could indicate publisher-imposed constraints, rather than authors choosing not to address student exam needs, but this possibility seems unlikely. Neither CourseSource nor NCCSTS imposes length limits on its authors, as neither publishes its lessons in a print journal. Moreover, most aspects of each lesson are documented in great detail (materials averaged 22 pages for CourseSource and 15 pages for NCCSTS) (Table 5), suggesting that exam-related guidance could have been included if the authors had wanted to provide it.

The Q3 and Q4 results of Fig. 4 were not especially surprising to us. For one thing, student problem-writing (the focus of Q4) is often thought of and presented as a discrete review activity (29–31), rather than as an integral component of a lesson covering new content. Moreover, the published lessons may lack student-facing exam guidance because the lessons' authors are agnostic about other instructors' longer-term assessment strategies. We would agree that it is ultimately the job of the instructors using a lesson to integrate that lesson into the rest of the course, including any exams; study 2, being limited to published materials, does not address how these lessons are actually implemented in the classroom. With all of that said, we remain struck by the fact that of the 36 lessons mentioning exams in instructor-facing materials (Q2), only 2 (or 5.6%) said anything to students about these exams (Q3). Thus, students' strong desires to transfer lessons to exams will go unaddressed unless connections are made by instructor interventions and/or student questions.

To see how a published lesson itself could connect more explicitly with exams, consider the CourseSource lesson in reference 20 (by the corresponding author of the present study, and therefore not a lesson examined in study 2). Each of this lesson's three modules include one or two TQTs, each of which contains two study questions along with an invitation to create an additional related question. Each individual study question is much like those found in other CourseSource and NCCSTS lessons, but with the key difference that, in the TQT framework, each question is explicitly grouped with both a related question and a well-matched LO. These groupings should help students notice patterns among related problems with distinct surface features, a key prescription of Ambrose et al. (2) for promoting transfer.

Of course, TQTs are not the only way to forge strong connections between lessons and exams. In another emerging strategy, known as public exams, students are given portions of the exam in advance (32, 33); for example, students might receive an exam figure but not the corresponding question, or vice versa. The lead-up to a public exam itself becomes a kind of lesson in which students work collaboratively to make sense of the exam pieces that they have and to imagine how they might answer various possible forms of the final, full questions.

Some educators might object to approaches like TQTs and public exams out of concern that, if we are extratransparent about lesson-exam connections, students will only study the exam content while ignoring everything else. (This concern has given negative connotations to the phrase "teaching to the test" [34].) We would counter that, if a test reliably assesses the knowledge and skills we care about most, teaching to the test is actually commendable (35). For example, if a top priority is to assess and reward students' critical thinking skills, prespecifying certain aspects of the test limits the breadth of what students need to study, allowing them to cover the remaining material in greater depth, with more critical thinking. More transparent assessments should also improve students' trust in the instructor and their satisfaction with the fairness of exams (36).

The present study therefore leads to our recommendation that excellent innovative lessons (e.g., those found at CourseSource and NCCSTS) continue to be used, but that instructors explicitly relate these lessons to subsequent exams, perhaps using a framework like TQTs (19, 20), learning targets and success criteria (D. A. Donovan, personal communication), public exams (32, 33), or exam blueprints (36). For example, one could use a published lesson more or less as written, but then, as a final add-on, one could ask students (either in class or as homework) questions like, "Now that you've been through this lesson, how do you think I will test you on this material? Can you imagine questions that cover the same concepts, but that have different details? How might these questions be structured on the exam, when time is more limited than it was today?" Such questions should help students to notice the common patterns underlying similar problems (2), and to envision exam questions that fit these patterns despite superficial differences. Promoting this kind of cognition is a major goal of the example C component of each TQT, which asks students to create an additional example question based on the pattern of the template. Students who understand how to create additional examples can then generate as many as they need (Fig. 2), even if the instructor has only provided one or two.

Our belief that instructors should clearly foreshadow upcoming exams applies to most if not all courses using high-stakes exams. However, this foreshadowing may be less critical in classes where students can recover from poor exam performances with further studying and additional chances to demonstrate competence. Giving students multiple tries is a pillar of various related grading methods like mastery grading (37), specifications (spec) grading (38), and standards-based grading (39). We endorse such methods, and we will explore their overlap with TQTs in a future manuscript (in preparation).

Conclusion

A primary goal of teaching is to provide students with knowledge they can transfer to novel contexts. Transfer has many dimensions (4); the present study focused mostly on "near" transfer from lessons to exams within a given course. This focus was adopted in part because transfer to exam situations is of great concern to many students whose chances for far transfer (e.g., in advanced courses and jobs) become limited if struggles with near transfer lead to low grades.

According to our compilation of student feedback (study 1), the TQT framework seems to promote transfer to exams (Table 4) and seems broadly applicable to other science courses (Fig. 3). We also observed an apparent desire for multiple examples of challenging types of problems (e.g., Fig. 2). However, others' published biology lessons (study 2), while excellent in many respects, did not include TQT-like support for students creating additional sample problems or otherwise preparing for exams (Fig. 4). Therefore, TQT-like approaches may usefully augment such lessons by connecting the lessons more directly to subsequent exams.

Since students' perceptions of their learning (e.g., in study 1) may not reflect their actual learning (40), future research should aim in part to determine whether TQTs empirically improve exam performance on application and higher Bloom-level questions, as we hypothesize. A future manuscript (in preparation) will present the empirical evidence that we have amassed to date.

SUPPLEMENTAL MATERIAL

Supplemental material is available online only.

SUPPLEMENTAL FILE 1, DOCX file, 0.03 MB.

ACKNOWLEDGMENTS

D.P.E.'s effort on this study were supported in part by a PALM-FRONDS grant awarded via the PALM Network (NSF RCN-UBE grant 1624200; Principal Investigator, Susan Wick, University of Minnesota) and by the SURF Scholars Program at Arizona State University's School for the Future of Innovation in Society. Publication charges were covered by a Teaching Career Enhancement Award to G.J.C. from the American Physiological Society. In addition, we thank Neal Parker (Everett Community College) for demographic information and Crystal Uminski (University of Nebraska—Lincoln) and anonymous reviewers for helpful suggestions.

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