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Efficacy of the Technological/Engineering Design Approach: Imposed Cognitive Demands Within Design-Based Biotechnology Instruction

John G. Wells

Abstract

Though not empirically established as an efficacious pedagogy for promoting higher order thinking skills, technological/engineering design-based learning in K–12 STEM education is increasingly embraced as a core instructional method for integrative STEM learning that promotes the development of student critical thinking skills (Honey, Pearson, & Schweingruber, 2014; Kolodner, 2002; NGSS Lead States, 2013). To demonstrate the efficacy of these practices for promoting student use of higher order thinking skills (schematic and strategic knowledge), a group of mixed-discipline (STEM) students enrolled in a 16-week Biotechnology by Design™ graduate course were immersed in a series of biotechnology design challenges developed to intentionally teach select content and practices of technology and engineering design concurrent with those of science and mathematics. A pre-experimental, one-group pretest–posttest design was used to assess student responses to the continuum of cognitive demands imposed by the biotechnology design challenges. Overall findings indicate strong connections between student gains in biotechnology content knowledge and practices and supports the conclusion that technological/engineering design-based learning strategies improve a student's capacity for responding to all four levels of imposed cognitive demand (declarative, procedural, schematic, strategic), lead to deeper learning of both content and practices, and promote student development of schematic and strategic (higher order) thinking skills.

Keywords: efficacy; imposed cognitive demands; higher order thinking skills; critical thinking skills; design-based biotechnology literacy; technological/engineering design-based learning.

The pedagogical intent that underpins technological/engineering (T/E) design-based learning (DBL) as an instructional approach is to (a) promote student understanding of the connections between disciplinary content and practices (schematic domain) and (b) foster the ability for making informed decisions (strategic domain) based on that understanding (National Assessment Governing Board [NAGB], 2008; NGSS Lead States, 2013). The integration of STEM content and practices employing T/E DBL approaches uniquely imposes cognitive demands that tomorrow's problem solvers must be prepared to address. A student's ability to respond to higher order cognitive demands provides the premise for bridging instructional strategies with the assessment of student performance expectations at basic, proficient, and advanced levels (Wells, 2010).

The research presented in this article was designed to address the need for demonstrating the efficacy of T/E design-based practices in promoting student use of higher order thinking skills (schematic and strategic knowledge). Specifically, this research was conducted to evidence the potential of Design-Based Biotechnology Learning (DBBL™) to improve a learner's response capacity to the higher order cognitive demands imposed by these unique T/E DBL challenges.

Background

Meeting the global challenges of the 21st century will require individuals who possess the capacity for integrating both the content and the practices requisite of specialists in the science, technology, engineering, and mathematics (STEM) disciplines (National Academy of Sciences, National Academy of Engineering, & Institute of Medicine, 2007, 2010). In anticipation of these challenges, the educational system in the United States is aggressively promoting the use of integrative approaches to STEM education (Honey, Pearson, & Schweingruber, 2014; Wells, 2008, 2010). As a result, STEM education disciplines are modifying their current national standards to incorporate the content and practices of disciplines other than their own, most notably those of T/E design (Burke, 2014; International Technology Education Association [ITEA], 2007; NGSS Lead States, 2013; Singer, Nielsen, & Schweingruber, 2012). Pedagogically, the underlying intent behind the incorporation of T/E design as an instructional strategy within the STEM education disciplines is to promote higher order learning skills by enhancing student understanding of the connections between disciplinary content and practices (schematic domain) and fostering their ability to make informed decisions (strategic domain) based on that understanding (NAGB, 2008; NGSS Lead States, 2013). Higher order cognitive abilities such as these are based on how cognitive theorists have come to distinguish between various types of knowledge. Beginning as early as 1949, the British philosopher Ryle envisioned knowledge that has been acquired to be demonstrated as declarative (knowing that) and procedural (knowing how), which was later supported empirically through Anderson's (1983) research. Utilization of acquired knowledge has more recently come to be recognized (Alexander, Schallert, & Hare, 1991) as a different type of knowledge (conditional) with two distinct forms (conceptual and metacognitive). Given that conditional knowledge is a subtype of metacognition, they could be collapsed into a single type (Li & Shavelson, 2001) that is referred to as strategic knowledge (knowing when and where). Recognition of relationships between multiple concepts or facts is referred to as schematic knowledge (knowing why) and is a precursor to development of strategic knowledge. This theoretical understanding of knowledge types underpins and is explicitly conveyed in the expected and observed performance outcomes as described in both the National Assessment of Educational Progress (NAEP) Science 2009 (NAGB, 2008, p. 83) and the NAEP Technology and Engineering 2014 (WestEd, 2012, p. A-38–A-40).

Performance expectations are generated by crossing the content to be learned with the practices that demonstrate understanding of that content (Wells, 2010). This approach to assessment provides, by design, the structure needed to obviate the connections between the instructional strategies employed by the educator and the performance outcomes (content and practice) demonstrated by the student. In the NAEP 2009 science framework (NAGB, 2008) and now in the *Next Generation Science Standards* (NGSS Lead States, 2013), science performance expectations are inclusive of a student's ability to employ T/E design in the pursuit of learning science content and practices. Theoretically, the basis for this inclusion is the belief that T/E DBL promotes and advances a student's ability to respond to the cognitive demands associated with the ill-structured, ill-defined challenges that they will undoubtedly be confronted with when meeting the challenges, both local and global, of the 21st century—that is, the knowledge and skills that they will need (Bybee, 2010; National Research Council [NRC], 2010; Partnership for 21st Century Skills, 2009) to compete in a global society (Engineering Challenges; National Academy of Engineering, 2008). Specifically, its incorporation is predicated on the pedagogical basis that the very nature of T/E DBL requires students to *utilize*,[1] and therefore demonstrate, their declarative *(knowing that)*, procedural *(knowing how)*, schematic *(knowing why)*, and strategic *(knowing when and where)* cognitive abilities.

Accepting this pedagogical basis as valid, student responses to the full spectrum of cognitive demands would therefore provide a mechanism for assessing their knowledge gains along the continuum from declarative to strategic and thus some evidence for the efficacy of T/E DBL as an instructional

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[1] The term *utilize* is intentional and is distinguished from the term *apply*, which is often the perspective taken in science education regarding the role of T/E DBL that views engineering as a tool "in the service of science" (Sneider, 2012).

strategy that achieves the goal of integrative STEM education (Wells, 2013). However, in spite of this embedded pedagogical basis in the recently published *Next Generation Science Standards* (NGSS Lead States, 2013), the content and practices of T/E design are not expressly targeted or assessed learning outcomes, nor is there sufficient empirical evidence that the pedagogical approach of T/E DBL actually does enhance the ability of students to respond to cognitive demands, specifically schematic and strategic (i.e., higher order thinking skills).

Empirical evidence resulting from prior research related to DBL concludes that T/E DBL is a better approach for teaching core science concepts and leads to higher gains in science knowledge achievement (Doppelt, Mehalik, Schunn, Silk, & Krysinski, 2008; Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004; Mehalik, Doppelt, & Schunn, 2008). Though such research has provided evidence of knowledge gains, concurrent gains in higher order thinking skills associated with the development of desired 21st century problem solving abilities were not addressed. Herein lies the need and potential for documenting the extent to which T/E DBL, as practiced in the secondary technology education classroom can and does place such cognitive demands on the learner and in so doing results in more well developed higher order thinking abilities required in responding to them.

Rationale

Although not empirically established as an efficacious pedagogy for promoting higher order thinking skills, K–12 STEM education engineering, and specifically engineering design, is increasingly embraced as a core instructional method and teaching tool for integrative STEM learning (Kolodner, 2002; NGSS Lead States, 2013). Furthermore, few if any effectiveness trials have been conducted to present empirical evidence of T/E DBL as an effective integrative STEM instructional method (Honey, Pearson, & Schweingruber, 2014). Although widely accepted as a necessary precondition for effectiveness trials (Sloane, 2008), efficacy research in education is often not presented as a precursor to effectiveness research on new interventions. For T/E DBL, this begs the question: Why invest resources into implementing an intervention that has yet to be demonstrated efficacious? The research presented here is an efficacy study designed to establish, within an ideal setting, the viability of T/E DBL as a pedagogical approach that through imposed cognitive demands supports student development of critical thinking skills.

Purpose

The purpose of this study was to evidence the potential of T/E DBL to improve the capacity of students to respond to higher order cognitive demands imposed by select engineering design challenges. Specifically, the biotechnical engineering design challenges used in this research are drawn from the T/E

Design-Based Biotechnology Learning teaching guide (Wells, 2015). The research was guided by the following questions:

To what extent can T/E Design-Based Biotechnology Learning design challenges:

1. Facilitate student gains in biotechnology content knowledge (declarative and procedural),
2. Enhance the ability of students to respond to embedded higher order cognitive demands (schematic and strategic), and
3. Provide evidence for the validity of T/E DBL as an instructional method?

In the United States, the contextual basis for studying technology education content is organized around three inclusive technological categories: physical, biological, and informational systems (ITEA, 1996, 2006). Biotechnology is a content area housed specifically within the context of biological systems. Within the *Standards for Technological Literacy: Content for the Study of Technology* (STL; ITEA, 2007) biotechnology is addressed directly in Standard 15 (pp. 149–157) and found naturally embedded across all five STL content standard categories as well (Wells & Kwon, 2009, p. 265). In the fields of both science and technology education the broadly accepted and employed operational definition of biotechnology is "'any technique that uses living organisms, or parts of organisms, to make or modify products, improve plants or animals, or to develop microorganisms for specific purposes' (OTA, 1988/1991, FCCSET, 1992/1993)" (ITEA, 2007, p. 149; e.g., Dunham, Wells, & White, 2002; FCCSET Committee on Life Sciences and Health, 1993; ITEA, 2007; Stotter, 2004; U.S. Congress, Office of Technological Assessment, 1984, 1988, 1991; Wells, 1994, 1999, 2012, 2015; Wells & Kwon, 2008, 2009). As operationally defined, educators from the classroom to preservice levels are provided with a set of explicit criteria for determining what is or is not recognized as biotechnology content or practices (Wells, 1995):

1. "Any technique": This first criterion specifies the full spectrum of practices, from micro to macro, involved in biotechnical processes.
2. "That uses living organisms": This criterion underscores the requirement that biotechnical processes must include living organisms (such as plants, microbes, fungi, and even macro scale organisms such as human beings).
3. "Or parts of organisms": As an extension of the living organisms, this criterion further specifies that components within the organism or its cellular elements (e.g., organelles, enzymes, proteins, DNA) can be isolated and used independently.
4. "To make or modify products, improve plants or animals, or to develop microorganisms for specific purposes": These final elements provide specificity for the range of potential biotechnical applications.

In technology education, biotechnology is one content area that naturally imposes cognitive demands when employing T/E DBL approaches to teach the content and practices of both science and technology. In the case of Design-Based Biotechnology Learning, which uses a T/E design approach to teach biotechnology content and practices (Wells, 1992, 1994), each cognitive demand is intentionally targeted within a series of authentic experiences that are integral to the design of instruction. The DBBL™ curriculum (Wells, 2015) uses biotechnology problem scenarios to present students with open-ended, T/E design-based biotechnology challenges that intentionally teach the content and practices of both science and technology concurrently.

Method

Participants

This research involved a mixed-discipline (STEM) group of graduate students enrolled in a 16-week Biotechnology by Design™ (BBD™) graduate course. The course is designed to immerse participants in a series of biotechnology design challenges in the same manner as it would be delivered to secondary-level students while concurrently reflecting on the educator's requirements for delivering such instruction. Of the 16 graduate students enrolled in the course, 75% (12) were female and 25% (4) were male, with the class composition representing each of the four primary (home) STEM disciplines (Table 1). All students were currently, or had been, practicing K–12 educators in their primary disciplines with classroom experience ranging from 2 to 30 years. The 50% of students representing the technology and engineering disciplines had prior experience in using the T/E DBL approach but only minimal formal biology content or practice preparation (i.e., high school only). None of the science or mathematics students had any prior experience using the T/E DBL approach.

Table 1

Student Disciplinary Demographics

	Number of students representing primary disciplines			
Gender	**Science**	**Technology**	**Engineering**	**Mathematics**
Female	5	2	3	2
Male	0	3	0	1

Specifically, the participants in this study, who were all licensed K–12 educators, were prepared to teach only one of the four STEM education subjects. Each participant possessed at least the minimal required level of classroom expertise (content and practice) to teach their respective disciplines, but they lacked that same level of expertise for teaching subjects other than their own. Therefore, from a preparation perspective, it is a fair assumption that the participants represent a replicable subsample. However, it is recognized that any duplication of this study might well produce different results, and as an efficacy study, there is no intent to generalize beyond this population.

The Biotechnology by Design™ course was delivered simultaneously to both on-campus and distance students, 10 and 6 respectively, using a synchronous audio–video platform. All students received the same instruction, materials, and course supplies with no appreciable differences in engagement during the regularly scheduled 3-hour class sessions. The overarching instructional objective of the course was to intentionally teach select content and practices of T/E design concurrent with those of science and mathematics using the T/E DBL approach.

Procedure

Graduate students in the course were engaged in a sequence of biotechnology design challenges. Problem Scenario 4A: Alternative Fuel Bioreactor (Bioreactor Scenario) was presented first, followed by Problem Scenario 4C: Microbial Fuel Cell (Fuel Cell Scenario), which is a more complex design challenge. The number of students in the course allowed for five design teams comprised of three to four on and off campus students. Multidisciplinary teams were purposefully assembled to include at least one student representing either technology or engineering and one representing science. Class composition allowed only two teams to include a student of mathematics. Different design teams of similar disciplinary composition were assembled for each of the two design challenges. Both problem scenarios provided the context, challenge, and constraints framing the challenge and asked student design teams to design, develop, and test a working prototype. The Bioreactor Scenario prototype calls for the design of a functioning bioreactor that harnesses *S. cerevisiae* (common yeast) immobilized in alginic beads to metabolize a dextrose substrate and produce ethanol and carbon dioxide byproducts. The Fuel Cell Scenario challenges students to design a functioning organic microbial fuel cell that exploits the electron production abilities of select benthic microorganisms to generate an electrical current sufficient enough to power a light emitting diode.

Teams were allotted 5 weeks to complete each problem scenario, at which point they would present their functional prototype, discuss performance results, and submit a detailed report documenting work performed in the form of a collaborative portfolio reflecting every phase of the T/E design process. As part of the course materials, students were provided with the PIRPOSAL blended pedagogy model (Wells, 2015) portfolio document used to detail the T/E design process and guide all students, both independently or collaboratively, in achieving plausible design solutions. Elements of the PIRPOSAL portfolio include **P**roblem identification, **I**deation, **R**esearch, **P**otential solutions, **O**ptimization, **S**olution evaluation, **A**lterations, and **L**earned outcomes. The

PIRPOSAL portfolio document structured student engagement in a sequence of predetermined investigations designed to highlight relationships between key technological and biological variables critical to making informed biotechnical design decisions. In this way, students were guided in their exploration and exposure to prerequisite biological and technological content and practices unique to each problem scenario and necessary for achieving viable biotechnology solutions. For the Bioreactor Scenario, an immersive strategy was used in which students acquired both biology and technology content and practice following the steps of the design process. These steps were presented in the PIRPOSAL document as a mechanism for both teaching and guiding students through the technology design process. No direct (didactic) instruction of content or practice was provided. In contrast, because of the more complex concepts involved with organic generation of free electrons and their capture for use in an electric circuit, a small degree of didactic instruction was necessary for initiating the Fuel Cell Scenario. Weekly class discussions were used to assist in further clarifying technological and biological concepts, processes, and practices, but design teams worked independently to design and develop their final biotechnology prototyped solutions.

This study followed a preexperimental, one-group pretest–posttest design (Creswell, 2014). The full spectrum of research that was conducted utilized a battery of data collection instruments (Biotechnology Stages of Concern, Awareness, General Content Knowledge, ProbScen Knowledge, Terminology, and Literacy) intended to assess student variables on multiple levels. However, the purpose of this article is to present evidence of the cognitive demands inherent within T/E DBL and, therefore, focuses only on the pre–post changes in ProbScen Knowledge and corresponding assessment of students responses to the continuum of cognitive demands (i.e., cognitive gains) imposed by select design-based biotechnology problem scenarios.

Instrumentation

Prior to introducing either problem scenario, students were asked to complete ProbScen Content and Practice Knowledge (CPK) questionnaires developed for each. CPK items had been developed to closely correspond with those included in the NAEP Science 2000–2011 twelfth grade sample questions (National Center for Educational Statistics, 2014) to ensure each assessed the specific biology and technology content and design-based practices intentionally targeted within the design of instruction. Every item was independently analyzed by an expert from engineering education and an expert from biological science education. The experts then met to discuss, arbitrate, and reach consensus on alignment of each with one of the four cognitive demands (declarative, procedural, schematic, and strategic) imposed by the design-based instructional approach. The same CPK questionnaires were administered again at the completion of each design challenge and following team presentations of final biotechnology prototypes. All pre- and post-CPK questionnaires were web-based instruments administered during class.

Findings

Data from the Bioreactor and Fuel Cell pre- and post-Knowledge questionnaires were analyzed to assess student knowledge gains and their ability to respond to questions aligned with imposed cognitive demands along a continuum from declarative to strategic. Of the 17 items comprising the Bioreactor questionnaire, roughly 54% targeted declarative knowledge, 5% procedural, 23% schematic, and 18% strategic. Of the 17 items used for the Fuel Cell questionnaire, roughly 43% targeted declarative knowledge, 11% procedural, 11% schematic, and 35% strategic. Pretest–posttest data analyses for the Bioreactor Scenario are displayed in Table 2, and data analyses for the Fuel Cell Scenario are shown in Table 3.

Table 2

Bioreactor Scenario: Pretest–Posttest Biotechnology Domain Knowledge

Domain		*M*	*SD*	*SEM*	*df*	*t*	*p*	†ES
Declarative								
	Pre	2.86	1.66	0.44	13	6.63	0.0001*	0.86
	Post	7.71	2.20	0.59				
Procedural								
	Pre	0.00	0.00	0.00	13	4.16	0.0001*	2.19
	Post	0.57	0.51	0.14				
Schematic								
	Pre	1.71	0.73	0.19	13	6.73	0.0001*	2.44
	Post	3.64	0.84	0.23				
Strategic								
	Pre	1.43	0.94	0.31	13	5.38	0.0001*	2.31
	Post	3.07	0.47	0.20				
Combined								
	Pre	27.64	10.59	2.93	13	11.15	0.0001*	3.61
	Post	70.62	13.21	3.66				

Note. $n = 14$

*$p < .05$, two-tailed, paired; †Effect Size

Table 3

Fuel Cell Scenario: Pretest–Posttest Biotechnology Domain Knowledge

Domain	*M*	*SD*	*SEM*	*df*	*t*	*p*	†ES
Declarative							
Pre	8.69	1.74	0.44	15	2.61	0.0197*	0.68
Post	9.93	1.02	0.26				
Procedural							
Pre	2.50	0.89	0.22	15	1.82	0.0891	0.77
Post	2.94	0.25	0.06				
Schematic							
Pre	2.31	0.87	0.22	15	2.76	0.0145*	0.94
Post	2.88	0.34	0.09				
Strategic							
Pre	7.50	2.83	0.71	15	2.30	0.0361*	0.61
Post	8.88	1.67	0.42				
Combined							
Pre	74.88	16.19	4.05	15	3.16	0.0064*	0.91
Post	85.88	8.08	2.02				

Note. $n = 16$

*$p < .05$, two-tailed, paired; †Effect Size

Data analysis for the Bioreactor Scenario shown in Table 1 indicates significance for pretest/posttest differences ($p < .05$) individually across all four levels of cognitive demand, and also for the aggregate analysis (Combined). The practical strength of these mean differences for all analyses is substantiated by large effect sizes, ranging from .86 to 3.61. The same series of analyses performed for data from the Fuel Cell Scenario (Table 3) similarly indicate significance ($p < .05$) across all cognitive demands except for procedural, which was not found to be significant. The practical strength of the mean differences displayed in Table 3 is substantiated by large effect sizes, ranging from 0.68 to 0.94.

Discussion

Design to Understand

As the signature pedagogy of technology education, technological design is privileged in the context of Integrative STEM Education (Wells, 2014) in which the teaching of discipline specific content and practice is intentional within the selected design-based instructional strategies. Such strategies are intent on positioning the students' achievement of understanding within the need-to-know learning context imposed by the challenge of designing a functional prototype solution. Design-Based Biotechnology Learning is built upon this pedagogical premise in which the instructional goal is intent on having students *design to understand* when working toward a viable biotechnology solution.

Problem Scenario Comparisons

Based on the combined (whole class) findings for the Bioreactor Scenario (Table 2), students clearly demonstrated a significantly better understanding of the technology, science, engineering, and mathematics content and practices following this immersive approach. These findings are supported by similar results from prior research into design-based learning (Calabrese-Barton, 1998; Doppelt, et al., 2008). However, due to the more complex nature of biology and technology content associated with the Fuel Cell Scenario, a more didactic approach was necessary for initiating this design challenge. As a result, students did receive some direct instruction in order to explain some of the more difficult to understand technology and biology concepts and processes. The remainder of the design challenge was guided by the same steps of the design process outlined in the PIRPOSAL document.

The comparison of combined results in Tables 2 and 3 (Bioreactor vs. Fuel Cell) reveal several interesting points. First, the average pretest combined scores for the Fuel Cell Scenario were significantly higher than those for the Bioreactor Scenario. This should be expected because students were provided direct instruction of content/practice prior to beginning the Fuel Cell Scenario. Furthermore, given that the biological elements were distinctly different in the second design challenge, the higher combined outcome scores would suggest that the T/E knowledge acquired in the first design challenged might well have been applied in the second challenge. Moreover, some content and practice covered in the completion of the Bioreactor Scenario was common and applicable to the design challenge in the Fuel Cell Scenario. The second interesting point was that strategic pretest and posttest scores were substantially higher for the Fuel Cell Scenario than for the Bioreactor Scenario. Recognizing the body of content and practice knowledge acquired in the completion of the Bioreactor Scenario, it is logical to consider that design-based decision-making (strategic) knowledge would be cumulative and therefore find application in the second biotechnology design challenge. Third, a significant difference was not observed in the pre–post procedural scores. This result provides some indication that the procedures repeatedly followed in the T/E design process were well engrained through completion of the problem scenarios.

Conclusions

This research examined the cognitive demands encountered by graduate students when engaged in developing T/E design solutions (functional biotechnical prototypes) to challenges presented in two select Design-Based

Biotechnology Learning problem scenarios. Specifically, the research was designed to investigate the extent to which these biotechnology scenarios facilitated student gains in biotechnology content knowledge (declarative and procedural), the extent to which these problem scenarios enhanced their ability to respond to embedded higher order cognitive demands (schematic and strategic), and whether these together with the pedagogical approaches provided sufficient evidence to validate the T/E DBL as an instructional method.

Overall findings indicate strong connections between student gains in biotechnology knowledge and the design-based biotechnology instructional strategies used to intentionally teach that content and practice, along with suggestions that the immersive approach is a viable strategy for facilitating those gains. As such, they support the conclusion that T/E DBL strategies improve a student's capacity for responding to all four levels of imposed cognitive demand, lead to deeper learning of both content and practices, and promote student development of schematic and strategic (higher order) thinking skills. Although this research offers valuable empirical support for T/E DBL as a viable pedagogical approach, one must acknowledge the research limitations and consider the extent to which they affect the applicability of the conclusions reached.

Implications

Demonstrating T/E DBL to be an efficacious instructional approach for enhancing student use of higher order thinking skills carries with it at least one significant implication that is noteworthy for the T/E education profession. Specifically, findings indicate that T/E DBL is a viable approach for achieving cognitive learning goals (higher order thinking skills) similar to those espoused to be targeted in other core K–12 STEM subjects. For decades, scholars in technology education have repeatedly called for just such validation of practice (Foster, 1996; Hoepfl, 2002; Lewis, 1999; Zuga, 1994) and credibility among core K–12 subjects. Collectively, these calls are poignantly mirrored by Lewis (1999) in his statement that "To take its place squarely in school curricula, technology education must establish itself not only in its own right, but crucially in relation to other subjects" (p. 49). The implications of evidencing the inherent value of T/E pedagogical practices within the educational enterprise and establishing its legitimacy among other school subjects have significant potential for advancing the profession.

Recommendations

Acknowledging that there are limitations to this research, caution must be exercised regarding the extent to which conclusions can be drawn and implications made. To establish the broad validity necessary for acceptance of T/E DBL as a viable approach that supports student development of higher order (critical) thinking skills, many more efficacy studies are needed. In addition to replicating the research presented here, similar efficacy studies should be conducted with different populations, larger populations, across geographic locations, and using various disciplinary team configurations. Further research is needed for improving the alignment of cognitive demands imposed by T/E DBL with content and practice assessment items. A replication efficacy study is currently underway with modifications addressing item construction and alignment with cognitive demands, alignment of cognitive demands with the PIRPOSAL blended pedagogy model (Wells, 2015) of integrative STEM education, as well as longitudinal assessment of knowledge retention. Efficacy studies of this type will be a necessary precondition and precursor to any effectiveness studies that might follow.

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About the Author

John G. Wells (jgwells@vt.edu) is Associate Professor in the Integrative STEM Education Program at Virginia Polytechnic Institute and State University.