Effects of Course Structure on Student Engagement and Learning Performance in an Electronics Course

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Abstract

Many educational strategies have been proposed to improve students' learning motivation and outcomes. This paper reports the student learning outcome results of a three-year study centered on the Electronics course at the Department of Physics of National Taiwan University. In the first year, peer instruction (PI) with in-class lectures was implemented. In the second year, in-class lectures were replaced with online lectures in a flipped classroom (FC) approach, and PI in class was maintained. In the third year, PI-based conceptual questions (CQs) were scored as part of in-class homework to enhance motivation for online lecture preview. Learning performance was evaluated based on cumulative percentage of correct answers to CQs and summative assessment. The results revealed improved student performance on summative assessment with PI and FC approaches combined. Furthermore, when CQs were scored, overall learning outcomes were significantly enhanced. In addition, an advantage of using a PI plus FC approach over using PI alone is that more course materials can be covered in online videos, which prevents a loss of lecture content to the time-consuming, in-class discussions involved in PI. Our study indicates that when students' motivations to prepare before class are reinforced using graded CQs, the learning outcome enhancement of PI plus FC is even more significant.

Keywords: blended learning, peer instruction, flipped classroom, conceptual question grading, learning motivation.

INTRODUCTION

The comparative effectiveness of student engagement versus content transmission as teaching approaches in physics education has been discussed for a long time. Instructors of introductory physics courses usually spend the majority of class time lecturing. With traditional instructional methods, students might rely on rote memorization to understand key concepts in physics yet obtain superficial knowledge (Mazur, 2008). The use of interactive engagement methods in the classroom can enhance students' problem-solving abilities and increase teaching effectiveness well beyond that obtained using traditional practices (Mazur, 2008). Although numerous studies have indicated that interactive engagement methods enhance students' performance more than traditional lecture-based teaching does (Hake, 1998), the time-consuming nature of such interactions and limited in-class time prevent instructors from adopting these teaching approaches (Freeman et. al., 2014). In addition, discipline-based education researchers claim that many instructors often adapt rather than adopt interactive practices, and subtle variations may unwittingly reduce the effectiveness of a particular interactive practice (Henderson & Dancy, 2007). Therefore, it is critical to understand practical and detailed adaptations made in real classrooms and develop more effective implementation protocols for interactive engagement practices.

The peer instruction (PI) approach, an interactive engagement technique, has been promoted in and influenced many university and college science, technology, engineering, and mathematics (STEM) courses (Vickrey et. al., 2015; Crouch & Mazur, 2001; Lasry et. al., 2008; Zhang et. al., 2017a; Cortright et. al., 2005; Zhang et. al., 2017b; Smith et. al., 2009). The original PI model includes the following instructional steps (Crouch & Mazur, 2001). First, the instructor gives a brief lecture at the beginning of the class. Next, students are asked to answer a series of conceptual questions (CQs) using an (online) electronic instant response system. If the proportion of correct answers selected falls below a certain threshold, students discuss their answers with peers and explain their reasoning. After peer discussion, students answer the same question again. Each cycle typically takes 13–15 minutes (Crouch & Mazur, 2001). Numerous studies have demonstrated that students enrolled in PI-based classes achieved significant improvements in both their conceptual reasoning and quantitative problem-solving abilities (Vickrey et. al., 2015; Lasry et. al., 2008; Cortright et. al., 2005; Zhang et. al., 2017b; Smith et. al., 2009).

In 2014, a course instructor at the Department of Physics of National Taiwan University (DPNTU) began implementing the PI approach in an introductory electronics course and integrated the use of a multimedia online interactive system named Zuvio (Lee & Shih, 2015), which was developed in 2012 by NTU electrical engineering alumni. Electronics is a course that exposes physics students to some of the foundational topics in experimental physics, such as the basic properties of nonlinear components, concepts related to electronic circuits, and the fundamentals of semiconductor characteristics. Students in the 2014 Electronics class spent a considerable part of their in-class time discussing and solving CQs and solutions with their peers. However, the course instructor found that guiding students through peer discussions and explanations in the classroom often detracted from the lecture time required to cover the content of each subject unit, leaving students insufficiently prepared to take tests. As a result, the 2014 Electronics class covered fewer key knowledge points than classes in previous academic years that used the traditional instructional approach. Some researchers expressed concern that implementing the PI approach would require a reduction of the physics content covered within a course, deterring instructors from implementing the PI model in their introductory physics courses (Freeman et. al., 2014).

To save valuable in-class time without sacrificing either students' higher-level cognitive development or course content covered, the 2015 Electronics course combined the flipped classroom (FC) approach and the original PI model. In the FC approach, students watch lecture content videos before class and then collaborate with each other in class, under the supervision of instructors to complete assignments (Chen et. al., 2014; Prunuske et. al., 2012; Lage et. al., 2000). Related studies suggest that watching instructional videos before class helps instructors cover essential lecture material and complete activities without sacrificing time for student engagement. Watching videos before class also improves student performance in answering CQs designed to test lower-order cognitive skills (Prunuske et. al., 2012). The instructor of the 2015 Electronics course did not consider CQs as part of student assignments or grade CQ answers. However, the DPNTU instructor found that students' overall performance on conceptual tests did not significantly improve in the 2015 course over results in the 2014 class, possibly because some students may not have devoted adequate time and attention to watching the videos. To motivate students to diligently preview instructional videos, the 2016 course included the CQs as part of in-class assignments, and students' answers, which they submitted on Zuvio, were scored every week and treated as an assessment item.

To identify an effective PI course structure for physics education reform, the authors examined and compared student performance in DPNTU's Electronics course from 2014 to 2016. This study evaluated the evolution of the PI instruction structure over these three years (Year 1, Year 2, and Year 3), compared students' summative assessments (SAs) and number of correct CQs answered in class among the three years, and discussed the practical implications of the PI approach for physics education.

METHOD

General course information

The Electronics course was an elective course offered as part of the bachelor's degree program at DPNTU. Most students took this course in their sophomore year. The course content analyzed in this study covered 14 units that focused on general concepts in Electronics, applications, and electrical components. The course first introduced the fundamentals of linear and nonlinear components and explored the conductive mechanism of nonlinear components, including diodes, bipolar junction transistors (BJTs), and metal–oxide–semiconductor field-effect transistors (MOSFETs). Afterward, DC and AC circuit models with BJTs and MOSFETs were introduced, followed by an analysis of amplifiers based on BJT and MOSFET circuits. If time allowed, advanced analog topics in Electronics were introduced, including two units on operational amplifiers and frequency responses. 14 units were divided into 5 domains (i.e., nonlinear, diode, BJT, MOSFET, and advanced analog concept domains). For each unit, the instructor designed three to six multiple-choice CQs. Students' responses helped identify their level of understanding of each unit's core topic. Table 1 presents the number of content units and instructional weeks spent in each domain throughout each year's courses.

Two learning outcome evaluation activities were integrated into the instructional schedule. The summative written exam was conducted after teaching MOSFET domain instruction. Each year's course concluded with a final project consisting of student presentations. This served to reinforce learning outcomes and as course review to reemphasize the curriculum structure.

Table 1. *TeachingaAnd Learning Content and Teaching Progress for Each of The Course Years*

Teaching & Learning Content	Teaching Weeks for each course		
	Year 1	Year 2	Year 3
Nonlinear domain (2 units: Linear & active, Semiconductor material & pn junction)	2	2	2
Diode domain (2 units: Diode introduction, Diode circuits)	2	2	2
BJT domain (4 units: Introduction, DC model, AC model, Amplifiers)	5	3	3
MOSFET domain (4 units: Introduction, DC analysis & biasing, AC model, Amplifier)	4	4	3
Summative written exam	1	1	1
Advanced-analog-concept domain (2 units : Operational amplifier, Filters & frequency analysis)	0	1	2
Final project presentation & course review	2	2	2

The instructional structure and assessment design for each class are shown in Table 2. In the Year 1 course, students were taught using the original PI model, which included a brief lecture followed by CQ peer discussion in class. In the Year 2 course, PI and FC approaches were adopted, wherein students previewed video lectures before class and then participated in a CQ activity and discussed calculation exercises in class. In the Year 3 course, in addition to PI and FC approaches, students' CQ responses were scored to evaluate their level of understanding of video previews.

As shown in Table 2, the common items in assessment designs throughout the three years were class participation in opinion expression (all years, 10%), summative written exam (Year 1: 20%, Year 2 and Year 3: 30%), and a final hands-on project focused on analog electronic circuits (Year 1: 30%, Year 2 and Year 3: 40%). Each year's assessment design included a preview report assignment, exercise calculation, and CQ scoring. The Year 1 preview report assignment encouraged students to read the textbook units before each class. Year 1 students completed and submitted exercises after classes, whereas Year 2 and Year 3 students completed them in class**.** To reinforce students' motivation to watch the preview lecture video, students' performance on CQ responses was evaluated only in Year 3.

Table 2. *Instructional Methods and Assessment Design of the Three Courses*

Instruction Assessment	Year 1	Year 2	Year 3
Instructional approach	PI (brief lecturing + CQ discussion)	PI + FC (videos preview + CQ & exercises discussion)	PI + FC+ CQ scoring (videos preview + CQ scoring & exercises discussion)
Assessment design	1. Class activeness 10% 2. Calculation exercises (at home) 20% 3. Preview report 20% 4. Summative written exam 20% 5. Final project 30%	1. Class activeness 10% 2. Calculation exercises (in class) 20% 3. Summative written exam 30% 4. Final project 40%	1. Class activeness 10% 2. CQ scoring 10% 3. Calculation exercises (in class) 10% 4. Summative written exam 30% 5. Final project 40%

Study participants

The students enrolled in the Electronics courses in each of the three years were mainly from the Physics department, and a few were from other science departments as well as engineering and medicine departments. Year 1, 2, and 3 had 62, 44, and 54 students, respectively.

Students planning to participate in the college admission process in Taiwan must take the General Scholastic Ability Test (GSAT). The average GSAT Science scores of students who entered the DPNTU from 2014 to 2016 were 14.75–14.91 (scale: 0 to 15), meaning that students enrolled possessed similar physics understanding and problem-solving skills before they entered college.

Data Collection

Data on all CQ activities in the three class types were collected using Zuvio (https://www.zuvio.com.tw/). In each class, the instructor would announce the CQs and immediately receive all students' responses and results from the Zuvio system. If the answers were diverse (e.g., less than 80% correct), the instructor asked the students to discuss their answers with peers, explain their reasoning, and answer the CQs again. For this study, we selected the same sets of students' CQ answers throughout each of the three years and analyzed the first run of Zuvio responses to quantify students' understanding of the course material prior to peer discussion. We also collected the average scores of the SAs from each of the three courses. The SA was given approximately two-thirds of the way through the course and covered content from ten units, including linear and active to MOSFET DC analysis. All three years' SAs contained similar exam items and were composed of 50% CQs and 50% calculation problems.

Data Analysis

We used a descriptive analysis and *t* test to understand students' overall performance and differences across the three years studied. The average rate of correct answer (ARCA) and standard error demonstrated students' understanding of the Electronic course's knowledge domains. The ARCA value on CQs was calculated using the sum of the correct rate divided by the number of total CQs answered in class. Standard errors were obtained by dividing standard deviations by the square root of the number of students in each year. SA scores were used to provide an overview of students' acquired knowledge.

We used independent-sample *t* tests to examine the effectiveness of the three PI teaching structures on students' physics knowledge. The criterion for significant differences was a *p* value of <0.05. For significantly different sets of data, we further reported the effect size (ES) of individual knowledge domains and SA based on Cohen's d method (Cohen, 1992), in which ES is categorized into small (0.2–0.5), medium (0.5–0.8), and large (0.8–1).

RESULTS

Learning Outcome Analysis of CQs Answered in Class

In Fig. 1, we illustrate the ARCA, with standard errors, for the CQs answered in class for each domain from Year 1 to Year 3 courses. In Year 1, the ARCA in the CQs on knowledge domains was 51% ± 5%, 62% ± 5%, 55% ± 5%, and 56% ± 5% for the nonlinear, diode, BJT, and MOSFET domains, respectively. In Year 2, the ARCAs of the five domains were 69% ± 5% (nonlinear), 55% ± 6% (diode), 61% ± 7% (BJT), 62% ± 7% (MOSFET), and 47% ± 6% (advanced analog concept). In Year 3, the ARCAs were 76% ± 3% (nonlinear), 87% ± 4% (diode), 78% ± 4% (BJT), 78% ± 4% (MOSFET), and 74 ± 5% (advanced analog concept).

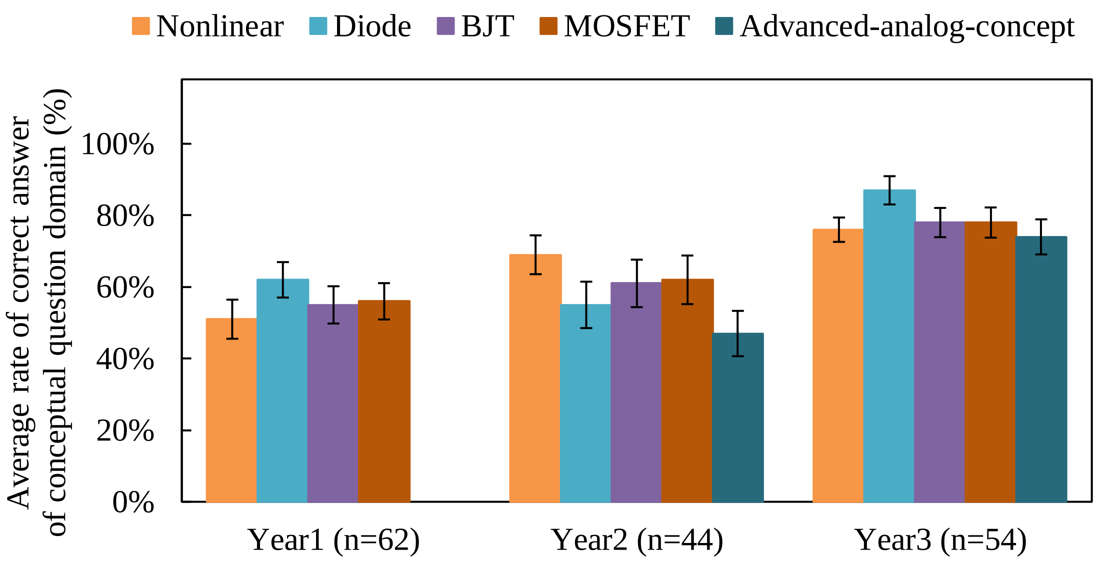

Figure 1. *ARCA Of Each CQ Domain For The Three Years. The Error Bar Shows The Standard Error. "N" Is The Number Of Participants In Each Course.*

Two valuable observations are highlighted in Figure 1. First, the ARCAs of most domains slightly improved from Year 1 to Year 2, except in the diode knowledge domain. More impressively, the ARCAs of Year 3 were significantly higher than those of both Year 1 and Year 2.

Second, the course content in Year 1 terminates at the MOSFET domain, but extends to the advanced analog concept in Year 2 and Year 3. This shows that a combination of PI and FC not only allows for more efficient learning and discussion in class but also enables the inclusion of more content than that from PI model alone. The increase in the amount of content covered was also apparent in the increased number of slide pages. In Year 1, the average number of slide pages per unit was approximately 30–40, including 5–6 pages of CQs. In Year 2 and Year 3, each online course unit contained 50–60 slide pages, without CQs (in a separate slide for in-class homework), thus illustrating an improved depth of content.

Table 3 shows the independent-sample *t* test results obtained from a comparison of students' performance levels in CQ responses among the three class years. In the Year 2–Year 1 *t* test results, which reveal the effectiveness of video previews in an FC approach, only the nonlinear domain had significant differences with a small ES, whereas the results from the other three domains did not differ significantly. In the Year 3–Year 2 comparison, the nonlinear domain was the only one in which significant differences were not observed; results from the other three domains all indicated significant differences, with at least small ESs obtained. Notably, when Year 3 was compared with Year 1 to determine the compound improvement of the FC approach with CQ-scored, significant improvements were observed in all four domains, with medium ESs.

Table 3. *Independent-sample t tests (including t statistics, p values, and ESs) of four CQ domains for Year 2–Year 1, Year 3–Year 2, and Year 3–Year 1 comparisons, related to the effects of the FC approach, CQ-scored, and the FC approach with CQ-scored, respectively*.

	Year 2-Year 1 *t* test (FC)			Year 3-Year 2 *t* test (CQ-scored)			Year 3-Year 1 *t* test (FC with CQ-scored)		
domain	t	p	ES	t	p	ES	t	p	ES
nonlinear	2.396	.018	0.45	1.159	0.250	----	3.828	.000	0.71
Diode	-.882	.380	----	4.224	0.000	0.90	3.902	.000	0.70
BJT	.704	.483	----	2.226	0.029	0.47	3.891	.000	0.73
MOSFET	.732	.466	----	2.082	0.041	0.43	3.508	.000	0.64

Learning Outcome Analysis Based on the SA

Figure 2 presents the adjusted SA score average from Year 1 to Year 3, with error bars representing standard errors. Students' performance levels improved with time (Year 1: 47 ± 2, Year 2: 56 ± 3, Year 3: 65 ± 3). The corresponding *t* test results are given in Table 4. Both the Year 2–Year 1 and the Year 3–Year 2 comparisons revealed significant differences with small ESs. Notably, the Year 3–Year 1 comparison revealed significant differences as well as a large ES. The analyses jointly demonstrated that the most effective teaching structure used was a combined approach that included the in-class discussion of the PI method, the lecture video preview of the FC approach, and CQ scoring.

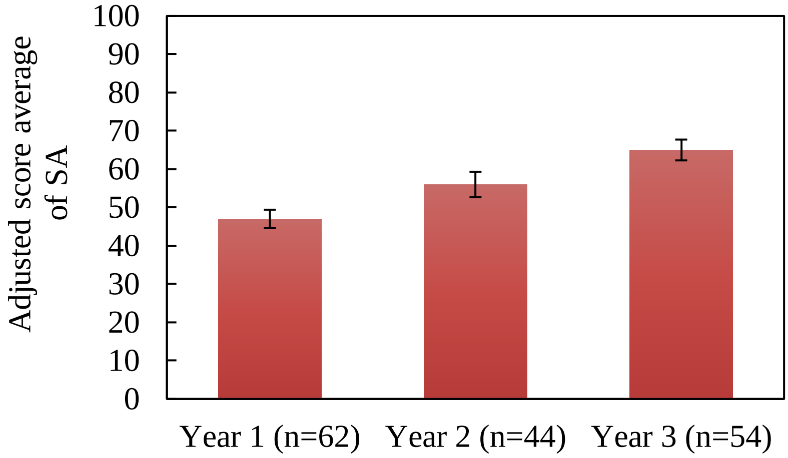

Figure 2. *Adjusted SA Score Average for Each of the Three Courses. The Error Bar Shows the Standard Error. "n" Is The Number Of Participants In Each Course.*

Table 4. *Independent-sample t tests (including t statistics, p values, and ES) of SA scores for comparisons of Year 2–Year 1, Year 3–Year 2, and Year 3–Year 1; such comparisons can determine the effect of the FC approach, CQ-scored, and the FC approach with CQ-scored, respectively.*

	Year 2−Year 1 t test (FC)			Year 3−Year 2 t test (CQ-scored)			Year 3−Year 1 t test (FC with CQ-scored)		
	t	p	ES	t	p	ES	t	p	ES
SA	2.351	0.021	0.45	2.086	0.040	0.43	5.005	0.000	0.93

DISCUSSION

The present study examined the effectiveness of different PI teaching structures used in the Electronics courses at the DPNTU from Year 1 to Year 3. Over the three years, the same instructors taught the same content to students with similar levels of general scholastic ability; instruction involved mostly the same set of CQs and similar SA compositions. The main difference was in the instructional structure. In the Year 1 course, the instructor gave brief knowledge-based lectures at the beginning of each unit section, followed by CQs and peer discussion in class, as well as written assignments to be completed after class. In the Year 2 course, students were requested to preview the instructor's lecture videos online before each class, and they concentrated on CQ-based PI and completing written assignments in class. The

Year 3 course maintained the same combination of PI and FC approaches, but scoring of the students' CQ answers on the Zuvio system was added.

A comparison of learning outcomes between Year 1 and Year 2 revealed the positive effect of lecture video previews prescribed by the FC approach, and a comparison between Year 2 and Year 3 revealed the enhancement of learning outcomes from scoring CQs answered in class. A comparison of Year 1 and Year 3 demonstrated improvements in overall learning outcomes resulting from combining video previews, as used in the FC approach, and CQ scoring in class. Our study results demonstrated that the most effective teaching structure is the Year 3 approach.

According to the analyses of the learning outcome improvements of the three approaches, three implications were noted. First, it is well accepted that lecture-based teaching is less effective than interactive teaching. Nevertheless, the original PI approach with both lectures and CQ peer discussions in class is time consuming; this limits the amount of content that can be covered in class. Combining PI with video lecture preview, as prescribed in the FC approach, extends the amount of knowledge covered without sacrificing students' time for valuable active engagement in class.

Second, adaption of the FC approach with PI did not significantly increase the number of CQs correctly answered (Table 3, first column), but an FC approach combined with PI significantly enhanced SA grades (Fig. 2 and Table 4), which typically represent students' lower-order cognitive learning outcomes. The underlying reason may be that pre-class video lectures provide an effective platform for students to review course content before the summative exam, preferably at their convenience and pace (Prunuske et. al., 2012; Cardall et. al., 2008). However, studies have suggested that some students are unable to effectively schedule their time to watch instructional videos or comprehended basic content by themselves before class, thus resulting in ineffective learning during group activities in class (Lai & Hwang, 2016). For these students in our study, their ARCA for CQs in class may not have been ideal, but the video lecture review helped them to succeed in the SA.

Third, to reinforce students' motivation to watch video lecture previews, we added CQ scoring, assisted by the Zuvio system, as part of the in-class-homework in Year 3. Our study shows that the most effective instructional structure was the combination of PI and FC plus CQ scoring approaches; this combination substantially improved comprehensive performance on both CQs and SAs across all four content domains of the Electronics course (Figure 1 and 2, Table 3 and 4). Our findings are consisted with other research results (Freeman et. al., 2011; Gross et. al., 2015; Heiner et. al., 2014). Without pre-reading quizzes or other structured exercises that focus on fundamental knowledge acquisition, student engagement activities in class or peer instruction with clickers will not be maximally effective. It is not possible to work at the application or analytic level without knowledge of the requisite basic facts and concepts. Realistically, the CQ assessments motivated students to view the lecture videos before class more diligently.

Although this study examined these pedagogical approaches within the context of a physics course, the approaches are expected to have the same quality–quantity conflict, and difficulty motivating students to have a willingness to preview lecture materials is expected to apply across disciplines. We provide a plausible approach to balancing the quality and quantity of students' depth of learning by using in-class peer discussion in combination with teaching content through online video lectures prior to class time. The scoring of peer-discussion CQs in class encourages students to preview videos before class and add meaningful feedback to in-class discussions, thus further enhancing the preview motivation through a virtuous cycle.

Before COVID-19, many courses already offered online videos, such as through OpenCourseWare (OCW) or Massive Open Online Courses (MOOCs). Now, during the COVID-19 pandemic, almost every course and every professor in higher education has one or more online video courses. With these online resources, we foresee that students will be relieved of ineffective lecture-based learning in classroom, and professors will be relieved of repetitive teaching, especially in introductory courses, such as introductory physics, which is typically offered to interdisciplinary undergraduate students.

Students' valuable time can be used more effectively, allowing them to learn at their own pace and explore more projects that solve real-world problems. Professors' equally valuable, if not more valuable, time can then be directed toward designing CQs, problem sets, and projects specifically targeted toward each discipline. For example, those designing introductory physics courses for medicine and biology students should consider problems dealing with mechanical forces in muscles and bones, electric waves in neurons, and other topics in biophysics. Discipline-specific course customizations could allow students in non-physics fields to better appreciate the value of enrolling in fundamental physics courses, toward the goal of personalized study and customized higher education.

CONCLUSION

An effective course structure in physics education based on the PI method was identified. The combined PI and FC approach with CQ scoring in class provided the highest improvement in student performance in content-based understanding and peer discussions. The FC approach facilitates the maintenance of a sufficient pace to cover all lesson content, and CQ scoring increases students' preview motivation. Therefore, the instructor is able to dedicate sufficient time in the classroom for students to discuss and analyze information with each other and ascertain students' understanding of the material. The combined PI model offers benefits not achievable with traditional lecture approaches and helps students achieve the higher-order cognitive learning objectives of STEM education more effectively.

However, several research limitations should be noted. Our study did not assess the students' higher-order cognitive development using their group presentations in class and written reports of final projects. The analyses reported in this paper were not designed to control for the effects of instructor, student, and assessment variations. Further studies are necessary to develop techniques for evaluating higher-order cognitive performance, exam equivalence, and student equivalence.

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