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Review Article

E-Learning in Orthodontic Education: Assessment of a Virtual Case-Based (eCBL) Treatment Planning Course Using SOLO and BLOOM's Taxonomy

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Abstract

This study investigates the effectiveness and learning outcomes of a virtual Case Based Learning (eCBL) Orthodontic Treatment Planning Course at the UT Health San Antonio Orthodontic and Dentofacial Orthopaedics Residency Program. The course was established in March 2020 due to the COVID-19 outbreak to preserve academic continuity through distance-leaning modules. The assessment tools used were a) Structure of Observed Learning Outcome (SOLO) taxonomy, b) Bloom's Taxonomy of Educational Objectives, and c) American Board of Orthodontists (ABO) Domains of Assessment and were completed in 6 sessions. Participants in the study were post- graduate orthodontic residents in the Fall Semester of 2020 enrolled in the eCBL course "Treatment Review and Progress," and their performance was recorded through a post-course written exam, which was evaluated by three experienced educators and ABO Certified Orthodontists. The results indicated that students performed significantly better on levels associated with higher-order cognitive skills and a deeper understanding of the diagnostic and treatment concepts. We conclude that the proposed Case Based Learning Virtual Seminar is an effective teaching method to promote learning at a cognitively complex level appropriate for advanced postgraduate dental curriculum.

Keywords: E-Learning; Orthodontic; eCBL; SOLO; BLOOM's Taxonomy

Introduction

In March 2020, worldwide regulations aiming to prevent the spread of the COVID-19 virus necessitated the limitation of in-person instruction to the minimum. The global healthcare crisis profoundly impacted dental education and forced most, if not all, educational institutions to implement virtual education modalities or cease educational activities completely [1]. According to Association for Dental Education in Europe (ADEE), in 153 European dental schools, non-clinical teaching was performed online in 90% of the schools [2].

During mandated social distancing, UT Health San Antonio Orthodontic and Dentofacial Orthopaedics Residency Program utilized distance education modalities to preserve academic continuity per federal and institutional regulations. Since traditional Lecture Based Learning (LBL) formats have been proven to be less effective in virtual education due to the lack of physical presence in a classroom and limited student engagement and attendance [3], an alternative approach was required to preserve the educational standards of the curriculum [4].

The academic administration maximized using Problem Based Learning (PBL) and Case Based Learning (CBL) methods while using digital distance education modules. Research indicates that these interactive teaching approaches, when utilized in computer-based learning, enabled increased student focus, enhanced attention, and immediate feedback that has demonstrated improvements in long-term knowledge retention [5].

The UT Health San Antonio Orthodontics Residency Program has implemented in the curriculum several CBL and PBL teaching methodologies in the past, with robust positive results in students'

performance and cognitive skills. Established in 2012, the weekly course "Treatment Review and Progress" (TRAP) has been one of the most prominent examples of a structured CBL course. This study aims to evaluate this course's learning outcomes in a virtual educational setting (eCBL).

The assessment method includes using SOLO Taxonomy [6]. and BLOOM'S Taxonomy [7,8] to evaluate the level of structural complexity achieved by students, both in quantity (increase in knowledge) as well as in quality (more profound understanding of learning objectives). Additionally, students' performance was assessed using the American Board of Orthodontists Scenario Based Examination (ABO SBE) Domains [9,10].

Anticipated outcomes

According to current literature, a CBL course cultivates skills related to treatment planning decisions, case management, and in-depth understanding and application of complex treatment concepts. Compared to LBL methodologies, CBL courses do not emphasize memorizing facts and developing recollection skills [11,12].

Therefore, it is anticipated that residents will have improved performance in higher levels of SOLO and BLOOM's taxonomy, indicating that the skills developed by this teaching methodology involve interpretation, analysis, justification, synthesis, creation of treatment planning, and diagnostic decisions. (Table 1), There are no anticipated outcomes regarding residents' performance in each ABO SBE Domains since there is no prior research evidence correlating it with the CBL teaching methodology.

Materials and Methods

Permission was granted by the UT Health San Antonio Institutional Review Board to conduct this study. (Protocol Number: HSC20200892E).

Educational setting

Course description

The eCBL course is titled "Treatment Review and Progress" (TRAP), and the participants were the 13 post-graduate orthodontic residents enrolled in the program for the Fall Semester of

SOLO Taxonomy	BLOOM'S Taxonomy	ABO Domain
1st level (Unistructural) Fact memorization and simple concept recollection 2nd level: (Multiscriptual) Combine diagnostic facts to define etiology, interpret multi-faceted concepts 3rd level: (Relational) Synthesize and formulate treatment plans, justify treatment selections, predict therapeutic outcomes 4th level: (Extended Abstract) Apply seminar concept and principles in hypothetical scenarios	1st level Remember facts 2nd level Understand a concept 3rd level Apply a concept on the case 4th level Analyze and diagnose 5th level Evaluate and justify a decision 6th level Create a new perspective/point of view	DOMAIN A: Data Gathering and Diagnosis DOMAIN B: Treatment Objectives and Planning DOMAIN C: Treatment Implementation and Management DOMAIN D: Critical Analysis and Outcomes Assessment

Table 1: Methods of assessment of learning outcomes.

Level descriptions have been adapted by the authors to better reflect the anticipated learning outcomes in orthodontic education

SOLO Taxonomy: (Structure of Observed Learning Outcomes): A classification developed by Biggs and Collis is a way of evaluating responses of students.6 Research indicates a strong correlation between competency at higher levels of SOLO Taxonomy and a deep approach in leaning and more complex cognitive skills [14,15]

BLOOM's Taxonomy: A framework to classify educational goals and objectives proposed in the year 1956 by Benjamin Bloom, leading a team of educators.7 Cognitive skills range from skills that require less processing to higher order skills, associated with deeper learning and greater degree of cognitive processing [16,17].

ABO Scenario Based Examination Domains of Assessment: Established by the American Board of Orthodontics in 2019 9 as the domains in which examinees have to demonstrate sufficient clinical competency, in order to become ABO Certified.

2020. The course was conducted virtually, using the Zoom Platform (Zoom Video Communications, Inc.) and the Qualtrics Survey Software (©2020 Qualtrics®).

Course Structure

Using the modified PBL tutorial, modeled on the Maastricht "seven jump" process and then adapted by Wood [13], the course was designed as follows (Figure 1, Table 2)

Figure 1

		Participants' roles	Anticipated learning outcomes
Phase	Diagnostic review answers submission	Facilitator: Collects, assesses and categorizes responses Tutors: Assist facilitator in answer evaluation Presenter: Provides diagnostic information Group members: Submit their treatment plan	Assess diagnostic records Formulate treatment plan and select treatment modality Select appropriate treatment sequencing and mechanics Anticipate tx progress and provide alternative plans
	Discussion	Facilitator: Directs discussion by asking specific questions on the submitted answers, emphasizing on contradicting opinions and different treatment modalities. Tutors: Observe discussion and assess students' understanding and performance. Conclude the discussion with their expert opinion and underline points with high educational value Presenter: Observe discussion Group members: Discuss treatment plans and selected treatment modality, present their thought process, ask questions to other members	Present a treatment option and justify their selection Critically assess all the treatment modalities discussed and recognize the diagnostic criteria leading to each option Recognize and evaluate anticipated outcomes, expected progress and challenges with each treatment selection Formulate alternative treatment plans and critically assess diagnostic data for multiple points of view Discuss treatment planning with colleagues and constructively resolve critical diagnostic dilemmas Assess their performance based on faculty feedback
	Case presentation	Facilitator: Observes Presentation Tutors: Observe Presentation Presenter: Presents case progress, explains rationale for selected treatment, critically assess progress and outcomes and references to current literature pertinent to the case Group members: Observe Presentation	Assess treatment progress, applied clinical and biomechanical concepts Critically assess treatment outcomes, consider alternative treatment options Justify clinical decisions Recognize and appropriately use a variety of treatment mechanisms and modalities Recognize, consider and prepare for contributing factors (growth, compliance etc) Make evidence-based clinical decisions, considering current literature.
	Conclusion	Facilitator: Summarizes important points from previous discussion and correlates them to presentation and treatment outcomes Tutors: Comments on treatment outcomes Presenter: Answers questions on presentation Group members: Ask questions, provide feedback and comments	

Table 2: Structure of the course and anticipated learning outcomes.

- **Attendance:** All participants log in to the Zoom Platform using a link and password e-mailed to their institutional e-mail accounts. They were required to have their video streaming on at all times. The presenter is responsible for recording and monitoring attendance throughout the course.
- **Records Review:** A Qualtrics Survey link is shared to the course chat (accessible only by participants), where all the initial case records are presented in a standard form. Participants are free to ask and clarify unfamiliar terms presented in the scenario.
- Treatment Plan Submission: All residents must submit a summarized treatment plan within 10 minutes.
- **Treatment Plan Evaluation:** The chair and tutors review the submitted plans and structure discussion points.
- **Discussion:** Students discuss their selected treatment plant and debate their preferred treatment modalities (extraction patterns, appliances, diagnostic details). The chair and the tutors monitor the discussion. The students' discussion follows the tutors' opinions on the case and their selected treatment plan.
- **Case Progress Presentation:** The presenter (resident who treated the patient) presents the treatment progress of the case, summarizes treatment outcomes, and correlates them with existing evidence in the current orthodontic literature
- **Conclusion:** All participants (students/faculty/director) comment on the case and discuss the treatment outcome and selected treatment modality.

Learning outcomes assessment

After each session (6), the residents were requested to complete a written test anonymously. Each of the questions was classified according to the SOLO and Bloom's Taxonomy as well as the four domains of assessments established by the American Board of Orthodontists Scenario Based Examination.

Students' performance was assessed by three experienced clinical faculty that participated in the session as tutors. The evaluators were calibrated by an answer key that was prepared for each question and graded each answer on a rank scale from 1-5.

Statistical analysis

A Kruskal-Wallis test was conducted to determine if scores differed between four SOLO levels, six Bloom levels, and 4 ABO domains. The distribution of scores was not similar for all levels as assessed by visual inspection of a boxplot. Scores were statistically significantly different between the levels, $\chi2(3) = 36.245$, $p < 0.001$. Pairwise comparisons were performed using Dunn's (1964) procedure. A Bonferroni correction for multiple comparisons was made with statistical significance accepted at the $p < .0083$ level.

Figure 2

ICC estimates and their 95% confidence intervals were calculated using SPSS statistical package version 23 (SPSS Inc, Chicago, IL) based on a mean-rating (k = 3), absolute-agreement, 2-way mixed-effects model.

Results

All postgraduate orthodontic residents enrolled in the course (n = 13) completed the questionnaire for all three sessions. (Response rate: 100%). The inter-examiner reliability analysis revealed an ICC of .942 CI (.932, .951), which is excellent reliability or high agreement between the three raters.

Overall performance in all sessions was satisfactory, with an average performance of 72.9% (SD: 16.3%) with the lowest overall scores in Session 2 (M: 52.5%, SD: 16.9%) and highest in Session 4 (M: 92.8%, SD: 7.1%).

SOLO taxonomy

Students achieved significantly higher scores on Level 4 (M: 83.64%) compared to all three other levels of cognitive complexity. No significant difference was observed between Level 2 and Level 3. The lowest average score was kept in Level 1 (M: 60.56%)

BLOOM's taxonomy

Results indicated statistically significant differences in scores between all levels. Residents performed significantly better in Lev-

Pairwise Comparisons of SOLO Levels

	Test Statistic	SE	Std. Test Statistic	*p*	Adj. *p*.[a]
Level 1-Level 3	-32.186	27.704	-1.162	0.245	1.000
Level 1-Level 2	-77.889	30.518	-2.552	0.011	0.064
Level 1-Level 4	-159.896	29.287	-5.460	0.000	0.000
Level 3-Level 2	45.702	27.471	1.664	0.096	0.577
Level 3-Level 4	-127.709	26.097	-4.894	0.000	0.000
Level 2-Level 4	-82.007	29.067	-2.821	0.005	0.029

NOTES: Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same. Asymptotic significances (2-sided tests) are displayed. The significance level is .050.

Pairwise Comparisons of ABO Levels

	Test Statistic	SE	Std. Test Statistic	*p*	Adj. *p*.[a]
C-B	31.256	35.934	0.870	0.384	1.000
C-A	49.036	29.539	1.660	0.097	0.581
C-D	-146.199	34.769	-4.205	0.000	0.000
B-A	17.780	28.259	0.629	0.529	1.000
B-D	-114.944	33.687	-3.412	0.001	0.004
A-D	-97.163	26.760	-3.631	0.000	0.002

NOTES: Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .050.

Pairwise Comparisons of Bloom Levels

	Test Statistic	SE	Std. Test Statistic	*p*	Adj. *p*.[a]
Level 3-Level 2	34.207	37.463	0.913	0.361	1.000
Level 3-Level 1	104.232	33.992	3.066	0.002	0.033
Level 3-Level 5	-142.673	39.166	-3.643	0.000	0.004
Level 3-Level 4	-183.032	34.825	-5.256	0.000	0.000
Level 3-Level 6	-210.577	33.992	-6.195	0.000	0.000
Level 2-Level 1	70.025	34.278	2.043	0.041	0.616
Level 2-Level 5	-108.466	39.414	-2.752	0.006	0.089
Level 2-Level 4	-148.825	35.104	-4.240	0.000	0.000
Level 2-Level 6	-176.371	34.278	-5.145	0.000	0.000
Level 1-Level 5	-38.441	36.130	-1.064	0.287	1.000
Level 1-Level 4	-78.800	31.373	-2.512	0.012	0.180
Level 1-Level 6	-106.346	30.445	-3.493	0.000	0.007
Level 5-Level 4	40.359	36.915	1.093	0.274	1.000
Level 5-Level 6	-67.905	36.130	-1.879	0.060	0.903
Level 4-Level 6	-27.545	31.373	-0.878	0.380	1.000

NOTES: Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.

Table 3

Figure 3

els 5 (M:96.02%) and Level 6 (M: 94.61%), and the lowest scores were observed in Level 2 (M:53.04%)

ABO domains

Students' performance in Domain D (Critical Analysis and Outcomes Assessment) was significantly better than all three levels (M:81.21%). No significant differences were observed between all other three Domains.

Discussion

Since its dawn in the early twentieth century, advanced dental education in Orthodontics has evolved, adapting to the ever-changing nature of orthodontic science and the rapid development of diagnostic tools, treatment modalities, and orthodontic appliances [18], The primary focus of orthodontic residency training is to teach students how to adapt to new therapeutic concepts, assess contemporary literature, and develop advanced critical skills and sound clinical judgment rather than absorbing already existing knowledge and pre-defined sets of orthodontic evidence and treatment protocols [19] Several teaching methodologies have been proposed to achieve such cognitive skills. As early as the 1920s, William Gies emphasized the need to change the learning approach in advanced dental education [20] However, to this day, the training techniques and learning methodology employed by each orthodontic residency program vary greatly, while the literature to assess their effectiveness in orthodontic education is limited [21].

During the initial outbreak COVID-19 pandemic in early 2020, social distancing and quarantine policies necessitated the temporary cessation of in-person education to mitigate the public health crisis and limit the spread of the virus. This incident and its heavy impact on all aspects of clinical education emphasized the need for alternative, more progressive teaching methods, offering an equally fruitful and engaging educational experience through distance-learning modules [22] Virtual education in orthodontic residency training is less effective when the learning process is passive and observational, and residents' satisfaction is negatively impacted [23]. Interactive teaching approaches, using technology and communication media, were crucial to preserve academic continuity and maintaining education standards [24,25].

In this study, we investigated interactive teaching methodologies' quantitative and qualitative learning outcomes in virtual education based on Problem Based Learning (PBL) principles and Case Based Learning (CBL). Through CBL, postgraduate students learn to relate content learning to professional practice and improve their ability to collaborate in studying, critical thinking, and clinical problem-solving [26-28]. There have been reports of CBL implementation in postgraduate orthodontic education, with various conclusions regarding its efficiency [29]. The main limitation is the small size of each resident class and the inherent difficulty in quantitatively assessing educational value in advanced dental education since competency is usually evaluated by everyday clinical and academic performance rather than standardized tests [30].

The evaluation of expected outcomes after implementing a PBL curriculum at Harvard School of Dental Medicine revealed improvement in NDBE Part I scores, graduation rates, and percentage of graduates entering postgraduate education programs, as well as decreasing attrition rates [31] The results of the present study also indicate that the students participating in this eCBL course achieved a deep understanding of the clinical concepts discussed. Students' performance was considered overall satisfactory (72.9%), with significantly improved performance in the highest

levels of structural complexity. Students performed exceptionally well (>90%) in Bloom's levels 5-6, demonstrating a thorough understanding of complex cognitive concepts and a remarkable ability to hypothesize, reflect and justify their clinical decisions.

Additionally, our results indicate that the lower scores were recorded on the first levels of cognitive complexity, relevant to memorizing and recalling facts (SOLO level 1 and Bloom's Level 1-3) and the ABO Domain C (Treatment Implementation and Management). The educational material examined in these levels was derived exclusively from the third phase of the eCBL course, where the presenter gives a lecture on the treatment progress and relevant literature references. This further affirms the belief that the traditional teacher-centric approaches (lecture, presentations), where an educational concept is delivered to the students are not suitable for virtual environments since the ability of the students to memorize and recall the information provided is limited.

It is important to emphasize this eCBL course's psychosocial impact on all participants. In their study, Bednar., *et al*. observed that the acceptability of online orthodontic seminars was significantly affected by the ability of the participants to interact with each other [32] In this study, students responded with highly positive feedback and commented on their overall satisfaction with the educational outcomes of the course. Additionally, the virtual educational setting allowed for a significant increase in participation by faculty/tutors in all sessions since their physical presence was not required. As a result, residents were exposed to a greater variety of treatment philosophies and could observe them elaborate and discuss advanced diagnostic and therapeutic dilemmas. Finally, in several eCBL sessions, third-party observers were invited to participate, including residents and faculty from international orthodontic programs, alums, and experienced orthodontists, initiating a new portal of scholarly communication of our department with the orthodontic community.

Limitations

As a consequence of the sudden COVID-19 outbreak, the rapid changes in our life and the immediate implement physical distancing left little to no time to prepare, design, standardize and assess every aspect of the eCBL course "TRAP." Therefore, the following limitations in this study may impact the interpretation of the work

- The small number of participants and their variable level of experience (all three years of residents)
- The lack of a control group due to the inability to establish any in-person educational modalities
- The limited and variable number of question items for each class of learning outcomes

Conclusions

This study suggests the following regarding the proposed eCBL teaching approach

- It is an efficient method to achieve higher levels of understanding of complex clinical concepts and acquire advanced cognitive skills.
- Students were successful in analyzing problem etiology, comparing and evaluating alternative approaches, providing rationales for plans of action, and predicting outcomes.
- The interactive teaching approach appears more efficient than the uni-directional, teacher-to-student educational model in stimulating deep learning in virtual environments.
- Implementing virtual education modalities did not compromise the quality and quantity of learning outcomes. Students' performance was satisfactory (>60%) in all ABO SBE domains.

Data Availability Statement

The corresponding author's data supporting this study's findings are available upon reasonable request.

Conflict of Interest Statement

The authors declare that there is no conflict of interest.

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