Adapting Mixed-Mode Instructional Delivery to Thrive within STEM Curricula

Dr. Ronald F. DeMara P.E., University of Central Florida

Ronald F. DeMara is a Professor in the Department of Electrical and Computer Engineering at the University of Central Florida (UCF), where he has been a full-time faculty member since 1993. His educational research interests focus on classroom instructional technologies and the digitization of STEM assessments. He is Principal Investigator of the NSF Workshop on Digitally-Mediated Team Learning and the organizer of faculty development workshops on Assessment Digitization Innovation and also on Virtualized Active Learning. He has completed over 275 technical and educational publications, 47 funded projects as PI/Co-I, and 22 Ph.D. graduates. He serves as the founding Director of the Evaluation and Proficiency Center (EPC), is an iSTEM Fellow, and the Digital Learning Faculty Fellow at UCF. He received the UCF university-level Scholarship of Teaching and Learning Award twice, Teaching Initiative Program Award four times, Research Initiative Award twice, Excellence in Undergraduate Teaching Award, Advisor of the Year, Distinguished Research Lecturer, Marchioli Collective Impact Award, the Effective Practice Award from Online Learning Consortium, and the Joseph M. Biedenbach Outstanding Engineering Educator Award from IEEE.

Dr. Tian Tian, University of Central Florida

Tian Tian is an Associate Lecturer of Mechanical and Aerospace Engineering at the UCF, which she joined in 2013. She has been frequently teaching undergraduate lecture and laboratory components of Heat Transfer, Thermodynamics and Fluid Mechanics. Her educational research interests focus on project-based learning, online learning, and the digitization of STEM assessments. She received the Teaching Incentive Award, Excellence in Undergraduate Teaching Award, the Dean's Advisory Board Faculty Fellow Award, Professor of the Year Award and Advisor of the Year Award.

Ms. Shadi Sheikhfaal, University of Central Florida

Shadi Sheikhfaal received her B.Sc. degree in computer engineering from Azad University, Ardebil, Iran, in 2012 and her M.Sc. degree in computer engineering, computer systems architecture from Science and Research Branch of Azad University, Tehran, Iran, in 2014. She is currently pursuing her Ph.D. degree in computer engineering at the University of Central Florida, Orlando, FL, USA. Her current research interests include brain-inspired computing, spin-based computing, and educational research involving digitally-mediated team learning.

Dr. Wendy Howard, University of Central Florida

Dr. Wendy Howard is the Program Director of the Pegasus Innovation Lab at the University of Central Florida, which is an incubator of experimental projects focused on digital learning innovations that can be developed and refined through rapid prototyping and then promoted throughout the university to maximize collective impact on student success at scale. With over twenty years of experience in both instructional design and teaching, her current research is focused on blended learning, collaborative online learning and internationalizing the curriculum through technology.

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Ronald F. DeMara[1], Tian Tian[2], Shadi Sheikhfaal[1] and Wendy Howard[3]
{[1]Department of Electrical and Computer Engineering, [2]Department of Mechanical and Aerospace Engineering, [3]Pegasus Digital Learning Innovation Lab}
University of Central Florida, Orlando, FL 32816-2362

Abstract
Given increasing enrollments within STEM curricula, it is sought to overcome challenges of conventional lecture-only delivery in high-enrollment courses. Mixed-mode delivery, which is also known as *Blended Delivery*, utilizes a combination of online and traditional face-to-face methods. Herein, a novel eight-step phased instructional flow with several targeted adaptations is used to accommodate the mixed-mode delivery of STEM curricula. It is formalized as the *STEM Blended Delivery Protocol (STEM-BDP)* with a special emphasis on the scaffolding of analytical procedures along with hands-on problem solving in both online and face-to-face components of the delivery. Methods used, learning outcomes, instructor perceptions, and students' perceptions of courses using STEM-BDP over multiple semesters at a large state university are described. Two high enrollment course case studies utilizing STEM-BDP are examined herein, including an Electrical and Computer Engineering required core undergraduate course and a Mechanical and Aerospace Engineering undergraduate course. The details of the STEM-BDP delivery strategies, learning activities, and student perceptions surveys are presented. Results indicated very positive feedback whereby 90% of students agreed that video content offers valuable convenience compared to live lecture and 76% of students, agreed that opportunities for questions and interaction with the instructor have increased versus traditional lecture. Finally, the paper will discuss the evidence of transportability of STEM-BDP from ECE courses to large-enrollment Mechanical Engineering courses, associated challenges, tools, and suggestions for successful transport to other courses and institutions.

1. Introduction

'*Blended learning*,' '*mixed-mode delivery*,' '*flipped classroom*,' and '*hybrid online and face-to-face instruction*' are terms which are frequently used to refer to the interwoven conveyance of electronically-delivered and in-class learning modalities [1-3]. Whereas there is considerable information in the literature on various flipped classroom approaches, this paper begins by identifying some open issues with respect to the use of blended delivery more specifically within STEM. Those are used to identify how the described approach fits into the larger body of work and the subsequent sections describe in detail what is novel about this approach. Case studies are elicited from both a required core undergraduate Electrical and Computer Engineering course (*EEL3801: Computer Organization*) and a core Mechanical Engineering course (*EML4142: Heat Transfer I*) in which the techniques of STEM-BDP were applied for multiple semesters.

Conventional instructional delivery relying upon live lecture, homework assignments, and synchronous in-class exams remains as the predominant delivery mode within undergraduate Science, Technology, Engineering, and Mathematics (STEM) programs [4]. Conventional lecture can offer advantages of simplicity of a low-tech broadcast mechanism for large class sizes and matches the expectation of some students to be lectured on the material, thus

maintaining their status quo bias [5]. However, as enrollments grow, students in large classes may tend to lose concentration due to the crowded environment, and thus may hesitate to ask questions during class. This has motivated research to sustain content engagement [6] and overcome live lecture's challenges at engaging critical thinking and soft skills within its classroom setting [7]. As a means to enable mastery learning, it is sought to utilize instructional technologies with alternative modes of delivery embracing active learning [8] and other pathways identified herein.

At the other extreme, Massive Open Online Courses (MOOCs) exclusively utilize online delivery methods with a high reliance on self-paced learning via an asynchronous delivery mechanism and often at the expense of reduced engagement [9]. Strengths of MOOCs include very high instructor productivity, which can reach thousands of students and some peer-assessment is feasible albeit via asynchronous discussion mechanisms [10]. Challenges of MOOCs for teaching STEM include reduced retention [11], few opportunities for active engagement, and challenges with assessment arising from the lack of authentication wherein online-only grading may be difficult to realize meaningful assessments [12, 13]. Mixed-Mode delivery hybridizes these to utilize online knowledge acquisition followed by classroom-based instructional activities. Videos improve comprehension and student enjoyment [14], and the in-class time is reallocated to active learning and productive activities [15, 16]. This can assist with struggles with engagement of millennials acclimated to learning from on-demand interactions, such as Internet searches and YouTube videos [6]. Blended learning has been successful in many disciplines outside of engineering as a means of combining the desirable attributes of both modes in stages of an online component and face-to-face instruction.

However, relative to other disciplines, the adoption of blended delivery has lagged in STEM especially in engineering disciplines, which can be due in-part to some additional demands of their curricula. Some challenges codified in the literature that have proven challenging are addressed herein with specific interventions include:

1) students may be unprepared when they arrive to conduct the face-to-face component [15],
2) homework must be tailored to be effective [15], and
3) students may lack appropriate feedback [2, 14, 17].

Each of these is addressed herein with the pedagogical and/or instructional technology advances described in the subsequent sections. The overall objective of the manuscript is to explore how Mixed-Mode delivery can be adapted in several aspects to accommodate STEM curricula and to discuss the results of those adaptations on core undergraduate courses at a large state university. Herein, an adaptation of mixed-mode delivery is formalized as a multi-stage phased delivery approach called the *STEM Blended Delivery Protocol (STEM-BDP)*. Results will be presented to provide the evidence of applicability of STEM-BDP to large-enrollment Electrical/Computer Engineering and Mechanical Engineering courses, associated challenges, tools, and suggestions for success.

2. Challenges facing Blended Delivery of STEM Curricula

2.1 Need to Convey Complex Systems in STEM Curricula

Often in the STEM fields, instructors are challenged by the need to explain complex and intricate material. In the classroom, it is important to annotate static content electronically while

explaining a concept or stepping through a problem. Similarly, when delivering content online, static text or images may not be sufficient. Animations, screen capture recordings, and narrated interactive notations may be used to explain complex concepts or procedures. Furthermore, traditional classroom teaching is often limited to information transfer, thus limiting students' engagement with the content, particularly in larger class sizes [18]. When information transfer is moved to the online environment, students can engage with the content at their own pace, which then frees up in-class time for more instructor interaction and problem-solving activities. For example, instructor generated videos allow instructors to provide their own explanation of complex topics just as they would have in lecture, but by providing them online students have the added benefit of pausing, rewinding, and replaying the initial delivery [19, 20]. Then classroom time may be used more efficiently for clarifying complex concepts and implementing active learning strategies, which are widely supported in STEM education [8, 21-23]. Engineering education is largely problem-based and project oriented [24-26] and student engagement is often attributed to success [27].

2.2 Diminished Feasibility of Online Discussion Groups

Another common challenge that blended learning may improve is building the students' sense of community [28]. The same challenge is amplified in the STEM fields where students have reported that collaborating with peers is a common success strategy [19]. Online discussion forums may be used to foster student-student interaction. While Tibi [29]found that students who participated in structured online discussions in a computer science course reported more positive attitudes than their peers who participated in unstructured discussion forums, others have experienced mixed results. For example, in a five-year study of blended learning courses in computer and information sciences, Dringus and Seagull [30] found that instructors who used discussion forums to encourage student conversations around a topic did not see the results they had hoped for, but over time they adopted other forms of interaction strategies with better results. In a review of 29 studies, Hosam Al-Samarraie and Noria Saeed found that social networking tools can be used to promote interpersonal communication for sharing and discussing ideas while synchronous cloud computing tools may be used to engage students in active learning experiences [31]. The traditional online discussion feature offered in most learning management systems allows for student-to-student interaction but often falls short in providing an effective environment for collaborative problem solving.

2.3 Towards Attaining an Optimal Modality Blending for STEM Curricula

Graham and Allen talked about finding the "right blend" that maximize the affordances of each modality to meet the contextual student needs [32]. Ultimately, the challenge is strategically connecting the online and face-to-face components in a comprehensive way that maximizes the benefits of each modality while providing a cohesive student experience. One approach that links the two is online content delivery followed by in-class concept clarification and practice. A successful blended design also requires a balanced assessment strategy within the integration of online and face-to-face modalities. For example, if students are expected to prepare online prior to each class meeting, the online activities should be assessed as well as the in-class participation so that class time does not slip back into traditional lecture to compensate for poor student preparation. Given these challenges, the authors explored the following guiding questions:

1. Which technology-enhanced learning methods can address these challenges effectively?
2. What is the best way to properly structure a blended course design for STEM courses?

This exploration has led to a set of vetted best practices for blended instruction in STEM courses which are identified in detail herein.

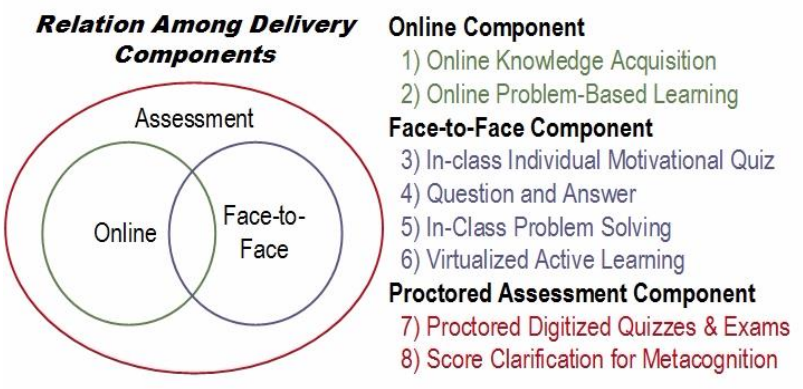

Figure 3.1: Components of STEM-BDP Protocol. The rightmost image shows hierarchical coverage relationship. The leftmost indented lists identify the student-facing activities within each of the three components

3. STEM Blended Delivery Protocol (STEM-BDP)

An overview of the delivery mechanisms utilized in STEM-BDP is shown in Figure 3.1. The three main steps of this delivery method are Online Components, Face-to-Face Components and Assessment Components, respectively. The Assessment Component covers content of both the Online Component and the Face-to-Face Component. There is also overlap between them. Namely, two Face-to-Face activities which are the Motivational Quiz and the GLASS (Group Learning and Assessment at Significant Scale) Digitally-Mediated Team Learning Activity. These occur in-class using online participation mechanisms as described below within the context of the weekly sequence of activities listed.

3.1 Activity 1: Online Knowledge Acquisition

As consistent with mixed-mode delivery, each course module begins with an online activity to facilitate the knowledge acquisition phase. Consider a typical Engineering course which is enrolled as 4 credits, namely "4(3,3)" credit hour format whereby there are 3 hours of instruction and one 3-hour laboratory session each week, which follow an *eight-activity sequence* in STEM-BDP. First, students conduct approximately 1-hour of knowledge acquisition online, which substitutes for one of the three hours of classroom meetings. STEM-BDP advocates for the first pass of knowledge acquisition to occur outside of the classroom through *fortified video* content with dynamic highlighting, callouts, electronic pen, hotlinks and online activities as illustrated in detail in Section 4. Slides of the video content are also provided verbatim that match those used in the video, which are made available as a .pdf file. Students are assigned to annotate them with questions while viewing the fortified video to ask during face-to-face meeting as detailed below.

3.2 Activity 2: Online Mechanisms to Engage Problem-Based Learning (PBL)

To reinforce the material presented in the fortified videos, problem-based learning is engaged next. The three modalities evaluated include Assigned Homework, Automated Systems, and the Study Set approach. Assigned homework is a conventional problem set which is collected and graded manually, but subject to collaboration, authentication, and integrity challenges. Automated PBL systems include online problem solving through publisher web-based systems such as McGraw Hill Connect, Adaptive Learning Systems such as RealizeIt!, or other Intelligent Tutoring System. For instance, homework assignments in EML4142 are delivered through McGraw-Hill Connect, which allows students to perform at their own pace during a specified window with unlimited attempts. Students can also revisit assignments throughout the semester to further reinforce their mastery of concepts. These unsupervised preliminary formative assignments help students acquire foundational knowledge while requiring minimal

workload from faculty since these assignments are automatically graded. The third option, which is a hallmark novel activity in STEM-BDP, is the use of *Study Sets* in lieu of homework. Study Sets consist of five to seven worked problems relating to the content of each module. Each problem provides a clear statement of givens and soughts along with a detailed solution. Students will then obtain credit for demonstrating the skill via a lockdown proctored biweekly quiz/exam.

3.3 Activity 3: In-class Individual Motivational Quiz

When students meet for the face-to-face component, they receive a quiz in the first 5 minutes of class. This fosters accountability to complete the online component prior to class. The authors and others using STEM-BDP at their large state university utilize Individual Motivational Quizzes to afford extra credit of 1 point on the upcoming exam which is out of 100 points. This helps students to be positively motivated through autograded quizzes disbursed via the LMS, or by *i*Clickers.

3.4 Activity 4: Face-to-Face Question-and-Answer

After completing the Motivational Quiz, a Question-and-Answer session based on annotations of pdf slides is conducted. The instructor allows students to ask any questions for 40 minutes which reduces the visitation load during office hours. Namely, students' concerns are addressed via the use of a broadcast mode to address common questions, as described in detail in Section 4.

3.5 Activity 5: In-Class Problem Solving of Selected Study Set Questions

After answering questions led by student inquiries, the instructor solves some archetypical Study Set questions in real-time to impart authentic problem-solving experience during face-to-face class-time. Supportive instructional technologies such as electronic pen are vital to annotate the previously disbursed problems and solutions, while solving them from scratch. Several examples are illustrated in Section 4 of this paper.

3.6 Activity 6: Virtualized Active Learning

Sixth, active learning is engaged via a Team Challenge problem during the last 40 minutes of each 2-hour class. Students are assigned automatically to virtual teams randomly via the LMS to solve Team Challenge questions together which are problem-based learning. The virtual collaboration tools allow students to participate in teams in-situ without requiring special furniture or moving chairs. Color-coding and Most Valuable Peer strategies have been developed by the authors to attain scalable, traceable, autograded quizzes for large enrollment of STEM curricula.

3.7 Activity 7: Proctored Digitized Quizzes and Exams

Basing the course points on the proctored assessment avoids integrity vulnerabilities in classes with online components. It uses lockdown proctored biweekly quiz/exam which avoids integrity vulnerabilities common to online delivery methods. Since multiple choice can be restrictive, students' hand-written scratch worksheets composed during assessment are scanned-in. This is further explained herein within the *Proctored Assessment Component* in Section 6 of this paper.

3.8 Activity 8: Score Clarification to Foster Metacognition

Score Clarification is a technique that motivates learners in a quest for partial credit to explain the problem-solving flow that they used in their formative assessment submissions from scanned-in scratch sheets. These elicit an explanation of the solution in their own words with first-line remediation by student tutors, with student follow-up to the instructor. This is further explained herein within the *Proctored Assessment Component* in Section 6 of this paper.

4. Online Components

Online components evidently play a significant role in blended delivery. This section presents the method the authors have developed and applied to two pilot courses *EEL3801: Computer Organization* and *EML4142: Heat Transfer 1*, which span two disciplines of Computer Science and Mechanical Engineering, respectively. Multiple anonymous surveys have been administered each semester in both courses to collect student perceptions of the mixed-mode delivery mode. Over the years, the authors have continuously refined the method based on student feedback and put forth the practice which was widely praised by students and regarded as effective.

4.1 Course Home Page on LMS

Figure 4.1 shows the course "Home" page on Canvas LMS, as the default page students see while logging into the course, features the following components:

1) "Course Overview & Site Map" provides instructions for navigating around the course site; insights about how course content is organized into Modules; instructor's Background and Its Relation to Course Content; and Course Resources. This page educates students to utilize the various learning resources made available on the course site at the very beginning of the semester.

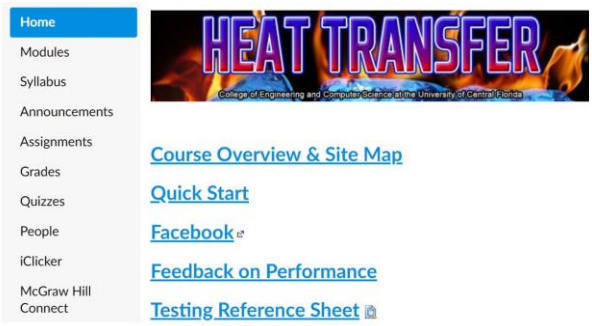

Figure 4.1: Course "home" page on LMS featuring "Quick start" etc. in EML4142

2) "Quick Start" contains all of the course's PDF files within the Modules as a .zip file, which students can download via a single click. These include Slides and Study Sets organized into folders for convenience. This page helps students to overview and organize course content from the start of the semester. It also clarifies course expectations by listing important hints students may follow for the semester.

3) "Facebook" links to the course Facebook page created by the instructors. The purpose is to set up a platform where students feel welcome and invited to share ideas and ask questions about the course. Students' feedback has indicated that they are more at ease posting on Facebook than on the LMS discussion board.

4) “Feedback on Performance” provides a histogram of scores, plus additional post-testing assistance, after each assessment, so students can be aware of their own performance relative to the class average as a whole. This will be elaborated in the Assessment Component.

5) “Testing Reference Sheet” links the equation sheets for each test of the semester, which will be provided in the testing center during quizzes and exams. Students are instructed to use the equation sheets to solve assigned problems so that they can become familiar with them while finding information quickly during tests. In the meantime, students also practice a needed career skill of referring to data sheets.

4.2 Content Authoring and Importance of Video and Lightboard-based Technical Material

The idea of blended delivery is to utilize substantial online activities to substitute for reduced classroom meetings. The quality of online lectures essentially decides the success of the blended delivery. While exploring effective approaches to conduct online activities in their courses in both Mechanical Engineering and Computer Sciences, the authors learnt that some common practice in other disciplines may not apply to STEM curriculum. For instance, face-to-face lectures may be sufficiently replaced by reading materials and discussion assignments in some other disciplines, but video lectures may still be highly beneficial in STEM due to the complex nature of subjects considering that videos may communicate with more clarity and impact than written words alone. Ideally, the shortest amount of time to explain the concept can be advantageous. Mini-videos of less than 5 minutes are usually recommended in other disciplines. However short videos are unlikely to be adequate to cover engineering contents that are equivalent to face-to-face lecturers. Based on the authors’ observation over the years, longer videos of half to an hour seem to be acceptable for engineering students in general as well. The authors learned that a well-defined clarification between online and face-to-face activities in structure help students set expectations and minimize confusion. In the two pilot courses, video lectures focus on concept and theoretical knowledge, and face-to-face classes are dedicated to problem solving, with an emphasis on collaborative problem solving. For rather challenging topics, videos were also created on extra practice questions as supplemental resources.

4.2.1 Lightboard lecture videos

Figure 4.2 shows a screenshot of a video for extra practice questions where the instructor works through the problem to thoroughly explain the process. Lightboard also suits well for recording problem solving videos as it allows easy writing with colorful fluorescent marker that glows brightly on the board. Moreover, at the author’s institution, the lightboard is facilitated by the Faculty Multimedia Center with all relevant devices such as camera and microphone ready to use, and hence requires zero setup work from the instructor. The instructor just needs to make an appointment, walk in, and start or stop the recording by pressing one button, which makes Lightboard an efficient tool for making short videos that requires more handwriting than PowerPoint slides.

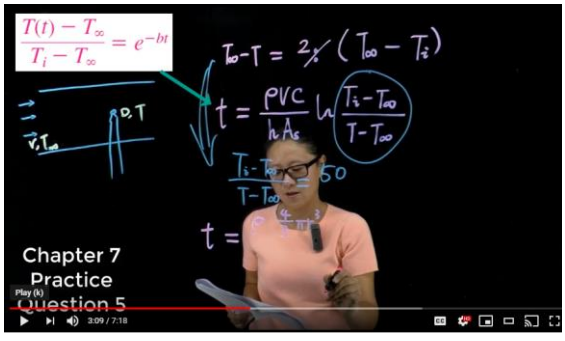

Figure 4.2: A snapshot of a video on extra practice questions created by Lightboard and Camtasia

4.2.2 Screencast Videos

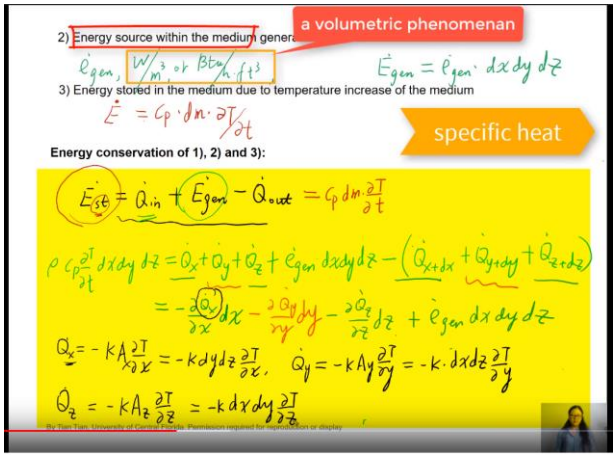

Figure 4.3: Screencast video created by Camtasia.

Besides Lightboard, the authors in both pilot courses created the majority of their lecture videos using screencasting, which is a digital video and audio recording of what occurs on a presenter's computer screen. Screencasts can be made with a number of software products available, ranging from free downloadable programs with limited features to fee-based products offering more advanced options. The authors have used a rather affordable and user-friendly software "Camtasia" produced by TechSmith for recording screen and editing videos and they find it rather effective. Comparing screencast and lightboard videos, screencast allows displaying more content on each screen since writing on a board with a marker naturally results in large fonts and the size of the lightboard is very limited. Frequent change of screen may disturb the lecture flow and negatively affect viewer experience and learning effectiveness. In contrast, screencast allows pre-prepared printed text and images as shown in Figure 4.3 and with the development of tablet technology nowadays, writing on a Tablet with a quality stylus could feel akin to their paper-and-pen counterpart. For most problem-based STEM content, high quality screencast videos perceived as most useful by students depended not only on thorough planning of the recorded content, but upon careful post-editing with callouts. Of course, any awkward pauses, misspoken words, or other unwanted portions should be removed to craft a focused video that uses students' time efficiently and sustains their retention. Furthermore, it is important to stress that rich annotations created by instructors during pre- and post-editing can help grab students' attention, significantly enhance video quality, result in deep impact, and make it a more fun experience. As shown in Figure 4.3, various annotation formats can be provided depending on the topic, including electronic pen annotation of equation derivation or problem being solved during recording, and text and graphic callouts, such as "text balloons" that provide hints, links, notes or typed-out questions.

5. Face-to-Face Components Vital to STEM-BDP

5.1 Motivational Quiz Submitted as Individual Work

As mentioned in Section 3, individual motivational quizzes are utilized to encourage students to complete the online component prior to face-to-face classes. For instance, the EEL3801 class meets weekly for 2 hours of face-to-face instruction, which begins with a 5-minute long motivational quiz delivered by the LMS using the students' own laptop or tablet PCs. Clones of question are used to decrease the impact of information sharing among students whereas lockdown browsers are not feasible. Moreover, questions asked are those not easily obtained via search engines, but rather refer to artifacts developed within the video content that is specific to the video itself. In EML4142, the motivational quiz is delivered by *i*Clicker Classroom Response System, which does not allow internet access and inherently avoids the needs to create clones of questions for faculty. In an anonymous survey 81%, 162 out of 199 students, Agreed or Strongly Agreed that the *i*Clicker quizzes offered motivation for them to watch the course videos prior to attending classes.

5.2 Virtualized Active Learning with Team Challenge Problems

Active learning can be especially effective within STEM curricula. It is ubiquitous in the case of three hours per week labs as separate meetings, and fundamental to building STEM practical skills from the theory covered in the course. With the availability of mixed-mode which moves lecturing to video, it is also possible to add more active learning exercises during the face-to-face component. Moreover, active learning is highly-synergistic with mixed-mode delivery because it is complimentary to online activities. Active learning during in-class meeting time can be vital for STEM problem solving, design, and team-based activities, which in the past the student had to undertake on their own. In fact, accreditation requirements for these skills have had little room in the curriculum for "functioning on multi-disciplinary teams" except for senior design capstone projects, so until arrival mixed-mode we have had little spare time nor opportunity to add it to the classroom. Now, the challenge becomes which pedagogies and technologies can best assist to deliver active learning effectively within face-to-face time of mixed mode courses. STEM-BDP attempts to address that need. To thrive, the foci need to include scalability within existing instructor and physical resources while achieving student traceability and authentic interaction mechanisms sufficient to guide and assist the activity. In the case of large enrollment STEM courses, this mandates observability by the instructor despite large class sizes and limited GTA availability. Here, automation is essential to make active learning feasible in UCF classrooms. This includes some level of auto-grading and good integration with the LMS.

The novelty of STEM-BDP is to apply Virtualized Active Learning weekly in the case of EEL3801 or biweekly in the case of EML4142. Namely, the authors developed the Group Learning and Assessment at Significant Scale (GLASS) approach to increase the scalability and efficacy of student design teams during group sessions [33]. GLASS allows the instructor to manage multiple design teams to conduct a weekly Challenge Problem during in-class time. Students are first randomized by the Learning Management System into small groups. A challenge problem is delivered via Wi-Fi-enabled laptops, tablets, or smart phones, forming virtual design teams, regardless of where students are seated. Students utilize their Wi-Fi enabled devices to discuss the challenge question via chatroom-style dialog channels alongside a solution whiteboard and/or figure drawing space, while utilizing open resources on the Internet to postulate a solution. Once the design team concurs that their results are complete, they submit their answers to the Learning Management System (LMS) for auto-grading and score-recording in the grade book. Credit is earned by correctly answering each designated question sub-part, which provides partial credit.

Throughout the team design activity, the instructor monitors the assignment progress online in real-time, including windows for each design team showing a solution draft as it is constructed, and providing feedback via each group's designated chat channel. LMS statistics are available in real-time for the autograded answer of the first design team having a correct solution, dubbed the Pioneer Group, which receives a bonus after its group leader presents

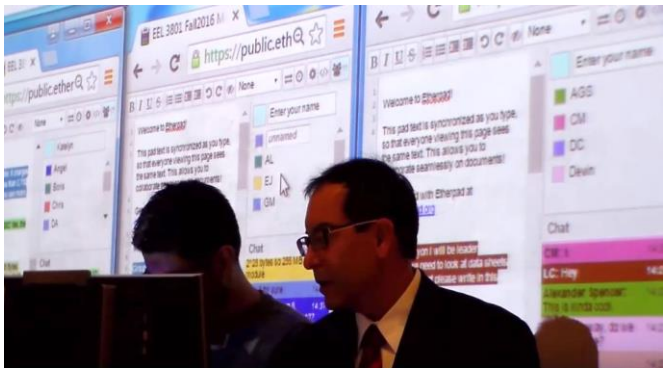

Figure 5.1: Design team windows projected on auditorium screen during observation and guidance by Instructor or GTA.

their solution to the class. Simultaneously, as shown in Figure 5.1, the instructor is able to view the whiteboard windows of each design team, which can be displayed on a private screen or broadcast to the entire room. Here, the instructor can provide real-time guidance for a group via their chat channel, and then moving on to observe and assist the next group. Thus, GLASS makes problem-based learning tractable for groups of design teams in F2F sessions, while helping to coordinate and automate the logistic mechanisms, as well as providing new means for observing and guiding learning. Finally, the selected Pioneer Group is invited to present and defend their design to the rest of the class, while earning bonus credit for its group members. This further engages the technical communication soft-skills of the presenting design team and critical thinking skills of the other design teams, who comprise the audience. Overall, GLASS assists the instructor by increasing the observability of the solution process, providing instructional technology to guide learning while it is occurring, and providing traceability of student interactions that are valuable for after-action review to refine the content or pace of the course, and for review with individual students. After completion of the design team activity, an optional post-class activity to elicit follow-up at significant scale is afforded to students through an opportunity to create a discussion post or video blog [34], in order to elaborate on technical aspects outside of F2F time.

6. Proctored Assessment Component

This component utilizes the college-level Evaluation and Proficiency Center (EPC) which is depicted in Figure 6.1 [4, 35-37]. The EPC targets *value-based instructional harvesting* using a novel cost-saving educational infrastructure for both students and faculty. It recasts GTA and faculty roles of labor-intensive tasks towards high-gain learning activities such as:

- *exam preparation and secure exam delivery*,
- *GTA-guided content tutoring*, and
- *Score Clarification which is a post-test remediation based on scanned-in scratch sheets*.

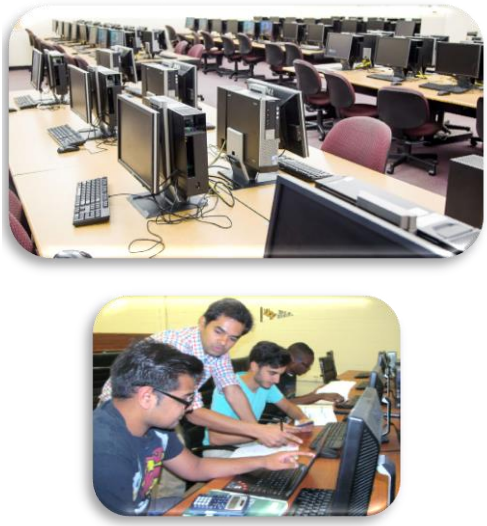

Fig. 6.1: 140-Seat Testing Area (above) and 20-Seat & Untethered Tutoring Area (below).

Thus, the well-cited "Testing Effect" engages learners with retrieval practice through closed-book proctored quizzes interwoven with rapid tutored remediation. It pools together instructional and human resources (GTAs) from 29 courses across seven degree programs to achieve higher learning impact at reduced cost, via rapid student feedback and detailed statistics for instructors to tune their delivery. It has achieved learning benefits as depicted in Figure 6.2. It realizes new efficiencies of paperless delivery of 20,000+ exams using auto-grading, followed by 2,500+ tutoring sessions via existing GTA resources which are freed from grading to facilitate increased enrollments. Figure 6.2 shows student perceptions of EPC within a Computer Engineering course (N=53 responding of 68 enrolled). The majority agreed that EPC-based delivery was beneficial, e.g. 90% deemed that Study Sets followed by a computerized quiz in the EPC were more effective than traditional homework. Additionally, for *STEM-BDP Activity 8: Score Clarification*, 81% of respondents assessed the efficacy of Score Clarification to be favorable in the post-survey at the end of the course. Score Clarification is a cornerstone of post-test review

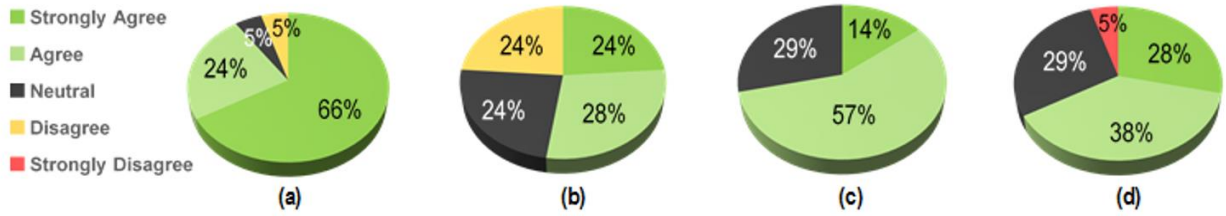

Fig. 6.2: **(a) Study Sets followed by computerized assessment are more effective for learning than Homework.**
(b) In this course, computerized questions were adequate to evaluate engineering design skills.
(c) Graduate assistant guided access to quiz results enhanced my comprehension of material.
(d) The use of a testing center provided an adequate testing environment compared to in-class exams.

in STEM-BDP that self-motivates students via partial credit to explain the problem-solving flow they used on scanned-in handwritten scratch worksheets with the pooled GTA tutors and the instructor's office hours gained. Thus, substantiating an improvement in efficacy while also raising efficiency.

In both case study courses, the significant assessments including quizzes, midterm exams, and the final exam were delivered via the LMS Canvas in the EPC. Test Proctors in the EPC provide a turnkey service in a secure environment to prevent cheating/Googling solutions using IP restriction, camera/phone checks, and lockdown browsers. Various question type such as *Multiple Choice*, *Multiple Answer*, *Multiple Dropdown*, *Formula Format*, and *Incremental Solution* assessments were adapted to the assessment design [4]. The proctored formative and summative tests contribute to 76% of course grade. The authors carried out a crossover study that randomly-partitioned all enrolled students in a class into control and intervention cohorts to examine the effectiveness of computer-based assessment relative to paper-based assessment. It was found that well-formed and well-delivered CBAs can determine scores differing as little as 0.6% compared to paper-based assessment. This strong consistency demonstrated that CBA could result in scoring comparable to PBA and thus validated the feasibility of CBA [37]. Moreover, if the paper-based grading time which was eliminated is then reallocated for tutoring and Score Clarification, then higher learning outcomes than paper-based assessment are attainable without additional instructor resource. DeMara et al. discussed strategies they developed while applying computer-based assessment in a large enrollment engineering course [36]. Due to space constraints in this manuscript, the reader is referred to those references for supporting details.

7. Results

To gather student perceptions of STEM-BDP and the effectiveness of STEM-BDP, anonymous surveys were administered both mid-semester and upon exit of *EEL-3801: Computer Organization* and *EML-4142: Heat Transfer I* courses. These surveys provide detailed information regarding student's view towards STEM-BDP. Throughout these semesters using STEM-BDP, we have updated several aspects of the initial version of this method.

For instance, survey questions asked at the end of EEL-3801 in Fall 2018 semester are shown in Figure 7.1. It shows the results for the 99 respondents out of the 126 students who were enrolled. According to these results, the majority of the students have a positive outlook towards different phases of STEM-BDP. As shown in Figure 7.1 (b), 72% of the students wished that more

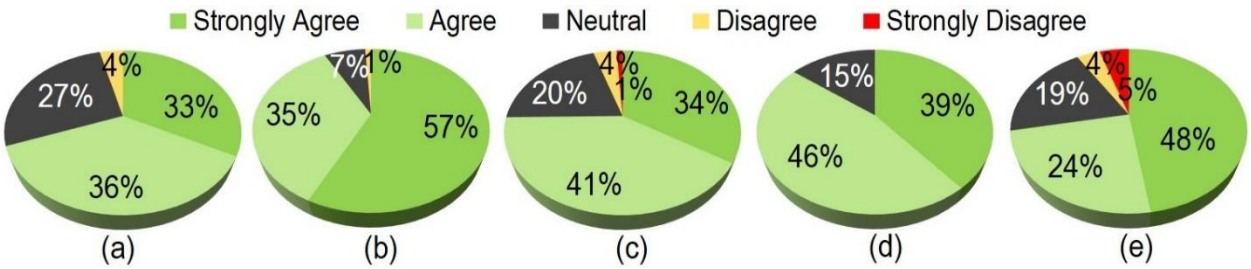

Figure 7.1: Survey Results for EEL3801 using STEM-BDP techniques during Fall 2018 semester:

(a) "Screencast" format video of professor explaining one-on-one is preferable to "Classroom Movie" format video of lecture.
(b) Highlights / Callouts / Electronic annotations assist in following technical material on video presentations.
(c) My ability to apply engineering skills, design components, and function on multidisciplinary teams has been increased more so than via traditional lecture-based format.
(d) Electronically-mediated groups can be beneficial in large enrollment classes.
(e) I wish additional courses offered mixed-mode delivery options besides lecture-only format.

courses offered Mixed-Mode delivery options besides lecture-only format. Results indicated that 75% of students Agreed or Strongly Agreed that "My ability to apply engineering skills, design components, and function on multidisciplinary teams has been increased more so than via traditional lecture-based format", while only 5% Disagreed. Similarly, in Figure 7.1 (d), 85% of the students Strongly Agreed/Agreed that electronically-mediated groups can be beneficial in large enrollment classes. This number is especially encouraging as no student disagreed with the statement. Similar results from EML4142 were obtained with a larger enrollment.

8. Conclusion

STEM-BDP provides STEM-specific tailoring of mixed-mode delivery with a special emphasis on scaffolding of analytical procedures in the online component and active learning in face-to-face component. Within the online component, fortified video delivery, Study Sets, and student annotations are emphasized. Within the face-to-face component of the delivery, motivational quizzes at the start of class plus virtualized active learning in the last 30 minutes are emphasized along with a traditional question-and-answer session and solving of worked examples. STEM-BDP delivery strategies, learning activities, and student perceptions surveys have been overwhelmingly favorable from both instructors and students.

As with any technology-enhanced delivery, time and effort is required to conduct the initial conversion. In the case of STEM-BDP, modularizing and splitting the online and F2F roles, drafting course weekly schedule, and creating website layout for the entire course may take a solid week of work. The time required to convert each module's content varies by topic, but screencasting slides with minimal edits/retakes can be completed in a couple of days per module. However, the most useful features such as callouts, links, highlights, and animations bring that number to one week or more. Motivational quizzes may be composed quickly in under an hour each. Active learning with GLASS may take a day initially to create the problems and solutions. The authors' institution offers a course release to convert a traditional face-to-face class to mixed-mode to facilitate above efforts. Digitized exams for an entire course can be quite time consuming, so the authors' institution offers another course release to do so, and in some case the publisher's test banks provide a useful start. At the Authors' university, it was found that with two semester course release to give the faculty sufficient time, then conversion could be ready to

deliver after that. So, a two semester course release can roughly quantify the minimum expectation as more updates will be made during the offering and subsequent semesters. Assessment digitization and mixed-mode delivery could occur in separate semesters.

With regards to inclusion of virtualized active learning, research is on-going with an NSF grant for a Workshop in Digitally-Mediated Team Learning (https://www.digital-learning-teams.com/) by the authors. It is significant to note that in utilizing virtualized active learning as a weekly activity in STEM-BDP, two important factors are the instructor and student perspectives. Instructors report enjoying having a 30-minute active learning exercise at the end of every face-to-face meeting. It is rewarding for instructors to be able resolve their students' questions before they get too far off track while helping them solve the problem at-hand. Students overwhelmingly agree that the active learning exercises were worthwhile, conducted more effective use of class time, and were even fun. Nonetheless, it is some additional work to prepare authentic, new, and perpetually-fresh active learning exercises. Some automation could manage the complexity of running that weekly while handling the grading load and sustaining the significant coordination and team grading challenges which may otherwise burden faculty. These are being addressed as on-going and future work.

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