

# BLUESHIFT: Rebalancing Engineering Engagement, Integrity, and Learning Outcomes across an Electronically-Enabled Remediation Hierarchy

Ronald F. DeMara, Shadi Sheikhfaal, Paul J. Wilder, Baiyun Chen, and Richard Hartshorne

## Abstract

With a growing number of enrollments in engineering programs, more time and energy for tutoring and grading exams/quizzes is necessary. The *BLUESHIFT* framework utilizes a synergistic combination of faculty, Graduate Teaching Assistants, and educational technologies to provide reliable approaches to not only meet the increased time, cost, and energy efficiency needed for increasing numbers of engineering students, but also to focus on improving the quality of education, skills, and employability of our graduates in computing-related fields. An *Evaluation and Proficiency Center (EPC)* has been piloted at a large state university, where key elements of the *BLUESHIFT* learning flow have been integrated into selected undergraduate engineering courses. The EPC integrates computer-based evaluation with a close-knit review and learning cycle based on directed and open tutoring. This approach has received overwhelmingly positive responses from students regarding the effectiveness of pedagogical approaches (i.e., Exemplar Vignettes, content tutoring), assessment models (i.e., electronically delivered quizzes, flexible scheduling, use of testing center), and tutoring strategies (i.e., self-paced, exam results review). Survey results have been positive with respect to student perceptions across a variety of perspectives compared to paper-based delivery. In this manuscript, the *BLUESHIFT* framework and process, as well as results collected from student performance and perceptions of the initial implementation, will be addressed.

## Index Terms

Computer-Based Assessment, Lock-Down Testing, Peer Tutoring, Asynchronous Testing, High Enrollment Curricula.

## I. INTRODUCTION

A STEM-educated (Science, Technology, Engineering and Mathematics) workforce is increasingly essential to meeting the current and future demands of the United States' technology interests [1], [2]. These needs are exacerbated by increasing losses to this workforce, both from the current population of aging engineers and scientists in the baby-boomer generation moving into retirement, and from decreased numbers of American youth showing interest in pursuing STEM careers. While enrollments have increased in engineering programs across the country, workforce decreases, along with an overall increase in need for STEM-educated staff has resulted in a net flow decrease in the STEM workforce pipeline. Further, cultivating engagement within diverse populations in order to drive interest in engineering remains challenging [3]–[6]. One factor contributing to the lower percentage of interested youth is that students often perceive a lack of excitement, personal relevance, and stimulation in today's K–16 STEM programs, not to mention the perceived difficulty of being successful in achieving an engineering education. Commonly, efforts have been made to reduce student malaise, including developing broad-based introductory engineering and science courses in an attempt to further engage undergraduates. While these efforts have provided some gains in retention, they remain inadequate to mitigate the attrition typically seen in STEM programs [7]–[12].

Importantly, engineering enrollment has been on the rise since 2005 in U.S. universities [13]. Yet, without further efforts to improve throughput, future needs will continue to outpace the pipeline's flow. Student success in engineering programs is complex, and is driven by multiple factors, which is typical in complex relationships. In order to improve student persistence, as well as address the additional stress on faculty resources associated with enrollment growth, the *BLUESHIFT* approach was developed to convert traditional paper-based testing into a digital format that accommodates the creative design of engineering problems. It is evaluated herein as a transportable approach to significantly increase student success through interweaving digitized assessments with rapid remediation. Akin to astronomy where a blueshifted spectrum occurs when distant stars move closer to the observer, the *BLUESHIFT* learning flow brings various high-gain learning activities and instructional technologies closer in the perspective of the learner.

R. F. DeMara and S. Sheikhfaal are with the Department of Electrical Engineering and Computer Science, University of Central Florida, Orlando, FL, 32816 USA (e-mail: ronald.demara@ucf.edu; shadi@knights.ucf.edu)

P. Wilder is the Division Dean for Engineering, Computer Program and Technology, Valencia College, Orlando, FL 32811 USA (e-mail: pwilder1@valenciacollege.edu).

B. Chen is with the Center for Distributed Learning, University of Central Florida, Orlando, FL 32816 USA (e-mail: baiyun.chen@ucf.edu).

R. Hartshorne is with the Department of Learning Sciences Educational Research, University of Central Florida, Orlando, FL 32816 USA (e-mail: richard.hartshorne@ucf.edu).

BLUESHIFT was developed and delivered in a state university for high-enrollment, required introductory engineering courses, where frequent challenges arise in course logistics and management. More specifically, the BLUESHIFT approach innovatively focuses on the challenges of engaging students in a high-enrollment, flipped model that enforces rigorous skill demonstration through both the use of electronically-based testing facilities and the practice of scaffolding activities between knowledgeable Graduate Teaching Assistants (GTAs) and students. Positioned within an active learning model, BLUESHIFT increases student engagement through the replacement of all homework assignments with solutions to worked problems on odd weeks and corresponding electronic formative assessments on even weeks, to assess learners at their personal time preference within a one-week evaluation window at a GTA-managed *Evaluation and Proficiency Center (EPC)*. The model capitalizes on both Vygotsky's *Zone of Proximal Development* and Bruner's *Scaffolding Theory* [14], to create the BLUESHIFT framework.

BLUESHIFT solves one of the most challenging obstacles to high-enrollment flipped courses, by enabling technological solutions to support active learning within the students' zone of proximal development. It has a beneficial remediation hierarchy that resolves two main issues related to using electronic evaluation within STEM curricula: 1) The online assessment instruments facilitate design problems where STEM learners require extensive guidance to hone their abilities on different design aspects, and 2) Problems with available partial credit are easily delivered electronically with the caveat that handwritten image files of the students' work are retained to provide a resource for students to review their evaluation results with GTAs and professors for additional grading credit and further explanations through the *Learner Electronic Workspace (LEW)*. These work together, to provide the strong side benefit of strengthening the soft skills of learners. Soft skills become practiced inherently within the assessments and remediation flow. Lastly, a hierarchy of expertise facilitates these processes using a rapid feedback loop.

Traditionally, adding any learning value to the curriculum comes at the expense of increased human and financial resources. As enrollments build, the number of GTAs and the time allocated to grading scale linearly with class size. The financial cost model developed herein demonstrates that additional tutoring can be developed at no cost through attainment of a breakeven point between a reduction in hours spent both proctoring and grading assignments and a commensurate increase in tutoring hours. Thus, BLUESHIFT reinvests instructor and GTA time to significantly focus on student learning. In summary, BLUESHIFT improves learning quality and shifts faculty/GTA focus toward curriculum tuning and development, and away from assignment preparation and grading tasks.

Preliminary results of this work, published in [15], highlight the strategies developed for constructing digitized assessment for STEM curricula that are suitable for replacing traditional paper-based assessments. The approach taken focuses on the reallocation of time and effort from grading, test management, and academic integrity workloads to high-gain learning activities, such as a novel post-test remediation strategy called Score Clarification. In this paper, we evaluate student perceptions of BLUESHIFT, and identify a monetary break-even threshold in terms of student credit hours. The remainder of the paper is organized as follows. Section II argues the need for *Computer-Based Assessment (CBA)*, introduces noteworthy approaches developed to address its challenges, and then compares and contrasts them with the BLUESHIFT framework. Section III addresses BLUESHIFT as a process and provides the benefits of using it for both students and faculty. Section IV describes the BLUESHIFT operational flow. Section V is dedicated to the progress achieved by using this approach and the instructor participation. Section VI explores the evaluations and perceptions of the approach and presents student survey results. Section VII provides suggestions for future work and presents conclusions.

## II. LITERATURE REVIEW

### A. Computerized Testing in Engineering

As previously mentioned, full-time enrollment in undergraduate engineering programs increased by 7.4 percent over 2014, which continued a growth trend evident since 2005 [13]. To manage challenges due to this substantial enrollment increase, new suitable and scalable means of assessing student achievement are urgently sought. Two challenges, assessment delivery and grading tasks, impose significant workloads in these high-enrollment situations. Unfortunately, diligent efforts to realize accurate paper-based assessment contributes little transferable progress to those same tasks in subsequent semesters when delivering the same course. These ongoing logistical challenges have motivated research into CBA, which has demonstrated some important advantages [16], resulting in CBA approaches being sought to support increased enrollments within engineering programs. One advantage of CBA is the streamlining of logistical overhead for exam delivery, while eliminating time-consuming manual grading and gradebook entry tasks. Other benefits of CBA include user-authenticated, consistent, and fair testing, along with detailed statistical assessment analysis and auto-grading. Ideally, CBA should increase the frequency and value of formative feedback, relative to conventional paper-based exams, which has significant potential to positively influence student achievement. Unlike traditional paper-based testing, the effort invested to create adaptable digitized assessments is a one-time burden, which carries its benefits forward into subsequent offerings. This promotes the incremental improvement of question content as a means to tune assessments, engage learners, and elevate learning outcomes.

The feasibility of digitized exams within engineering disciplines has received increasing attention in recent years [17]–[19]. However, since multiple-choice question formats are inherently restrictive, an open challenge facing CBA is how to fully assess skills within engineering disciplines. Challenges for digitized assessment include partial credit, solution composability/traceability including handwritten work, and assessment of problem solving aspects within the constraints of contemporary *Learning Management Systems (LMSs)* [15]. Herein, lockdown proctored computer-based testing was evaluated as an instruc-

TABLE I: Contemporary approaches for hierarchical technology enabled STEM delivery whereby each {✓,-} indicates relative {strength, limitation}.

		Service	Content	Exam	Exam	Score
		Approach	Tutoring	Preparation	Delivery	Clarification
Academic	BLUESHIFT	✓✓	✓✓	✓✓	✓✓	✓✓
	Open Tutoring Center	✓✓	✓	-	-	-
	ECE Clinic	✓✓	--	--	-	-
	OCM	✓✓	-	-	-	✓✓
Commercial	MyLab & Mastering	-	✓	✓	✓	--
	McGraw-Hill Connect	✓✓	✓	✓	✓	✓✓
	Udacity	✓	✓	✓	✓	-

tional technology to realize: 1) auto-grading for formative and summative assessments, 2) secure self-paced review of solutions by students, and 3) a *Score Clarification* approach to rapid remediation, utilizing a hierarchy of expertise from GTAs as tutors, with the instructor providing deeper guidance and follow-up.

### B. Increasing Degree of Production in STEM Disciplines

Varying approaches to address the challenges of CBA implementation have been proposed, and some have been piloted recently within various STEM curricula. Contemporary methods of hierarchical, technology-enabled STEM delivery are listed in Table I. The *Open Tutoring Center* utilizes the flipped classroom concept, with the addition of open tutoring facilities led by GTAs. This option affords students opportunities to obtain guided assistance from tutors to clarify challenging content [20]. One study found that students' perceptions of the flipped classroom are generally positive, but poor implementation of interactions and scope of pre-class material may result in diminished student achievement [21].

To mitigate potential limiting factors to student achievement, the authors have proposed to complement previous pedagogical approaches with selected aspects of an *Electrical and Computer Engineering (ECE) clinic* [21], which provides project-based experiences within the undergraduate curriculum. The ECE Clinic approach improves the problem-solving skills of students by motivating them to continuously engage in self-paced assignments, as well as adapt themselves to recent ECE technology. In order to evaluate the outcome of the ECE clinic approach, faculty are required to monitor specific outcomes and identify issues of concern using a *course-outcomes tracking sheet*. Another study addressed potential ECE limitations by enabling a novel assessment method, called *X-File*, to tighten the course adjustment cycle through the creation of a shared repository of course improvement tasks based on near real-time student performance data [22]. BLUESHIFT extends the positive aspects of digitized assessment, authenticated testing, and auto-grading while fostering metacognition via the score clarification process.

Another approach for hierarchical technology-enabled STEM delivery is the *Online Classroom Model (OCM)*. The purpose of the OCM is to provide guidance for the design, development, and assessment of online education systems utilizing four learning-theory oriented components and three human-computer interaction principles. This model promotes augmented face-to-face interaction by offering several features, such as collaborative multimedia presentations, virtual laboratories, a social and collaborative Q&A community, and a robust communication framework within the online classroom [23]. While acknowledging the potential of these services individually, and developing and elaborating an innovative approach to feedback and tutoring activities in online course delivery, the challenges posed by assessment in online formats, such as user authentication, individual contribution, and control of unauthorized material, were not a focus. As such, a significant need remains for a hierarchy of services using an integrated framework. This concern is addressed within the BLUESHIFT approach statement in section III.

Reduced seat time course formats, which deliver a portion of the course content online, can be a cost-effective approach to increasing degree production while maintaining quality. Nonetheless, such formats typically require increased self-discipline to succeed and may reduce the level of student engagement. To bridge the gap from academic organizations, commercial tools such as MyLab & Mastering and McGraw-Hill Connect have emerged and offer advanced learning environments designed to reduce the time that students and instructors allocate to the instructional process, while improving student outcomes. In particular, MyLab & Mastering created by Pearson Education Company offers instructors the ability to 1) automatically grade online homework assignments, quizzes, and tests, 2) easily add, remove, or modify existing instructional material, 3) quickly track students' results and 4) simply scale and maintain course content. Additionally, learning analytics has recently been integrated into the MyLab & Mastering framework, increasing student engagement in class discussions through the use of interactive student response tools. Similarly, McGraw-Hill Connect provides sophisticated data analysis, which allows instructors to determine the quality and clearness of the assessments, as well as make assignments more successful.

## III. BLUESHIFT APPROACH

The BLUESHIFT approach leverages the *Testing Effect* [24] to maintain student engagement at regular intervals within a reduced seat time course format. The *Testing Effect* refers to the benefit of retrieval practice through closed-book recall instructional

events. Namely, increased formative assessment involving recall of concepts and use of skills has been shown to be more effective than open-book assessments [25], [26], even for complex materials [27].

To leverage the Testing Effect, the EPC provides a flexible, dynamic, secure assessment environment. Complementing this, the BLUESHIFT framework enhances the testing effect in two additional ways. First, BLUESHIFT increases the frequency of assessments, decreasing the high stakes nature of individual assessments. Second, BLUESHIFT utilizes peer mentoring through GTAs to reach the student in his or her Zone of Proximal Development to facilitate the movement of content into the known category. The creative nature of engineering curricula requires a discipline-specific approach to provide a comprehensive learning assessment in each area for offering Socratic guiding principles. Thus, BLUESHIFT uses a layered remediation hierarchy to resolve two fundamental hurdles to integrating electronic evaluation within STEM curricula. First, the online assessment instruments facilitate design problems beyond rote multiple choice. Thus, the BLUESHIFT model supports various aspects of conceptual design problems with partial credit that are isomorphic to skills assessment using conventional pencil-and-paper based exams, but are deliverable electronically. Second, STEM learners require extensive guidance and student-specific coaching to hone their proficiency on subtle design aspects. A hierarchy of expertise facilitates these roles within a rapid feedback loop. Thus, the BLUESHIFT approach shifts instructor and GTA roles away from low-value repetitive tasks towards those having more significant impacts on learning outcomes. Focusing on the quality of education, skills, and employability of graduates in computing-related fields, this work proposes a cost-effective approach to integrate computer-based assessment with a close-knit review and learning cycle, based on directed and open tutoring, collectively forming the EPC.

#### A. Need for Online Evaluation

As enrollments increase, the EPC helps to maintain and increase learning quality for current and future Engineering students. For example, at the authors' institution, undergraduate Engineering enrollment has increased by 76.1% from 5,375 in the fall of 2010 to 9,468 in fall of 2017, with further similar increases anticipated for the foreseeable future. Such increases in enrollment significantly expand the logistical burden of assignment preparation, administration, and grading tasks for all faculty and course GTAs. Thus, a high quality approach is sought to manage the formative/summative assessment activities, and to re-focus faculty and GTA efforts from low impact activities, such as grading, to high impact activities, such as targeted content tutoring. The EPC was designed and implemented to address this need. However, due to the creative design nature of work found in engineering curricula, a discipline-specific approach is needed to address two fundamental hurdles to using electronic evaluation in an engineering curriculum. First, a mechanism is needed to administer creative design problems beyond rote multiple choice. Second, lengthy engineering questions require partial credit. Thus, novel approaches are needed to create electronically-deliverable design problems with partial credit that are isomorphic to skill assessments using conventional pencil-and-paper based exams.

#### B. Need for Proficiency Enrichment

Engineering students require extensive guidance and student-specific coaching to learn from subtle mistakes in their designs, referred to as proficiency activities. However, more so than ever, previous exams, homework assignments, and projects are being uploaded to websites such as *coursehero.com*, compromising the evaluation structure as students simply memorize previous exams and quizzes instead of rigorously learning the material through study. Thus, it is necessary to secure evaluation materials from redistribution. Instructors cannot simply withhold students' exams and quizzes, though, as an important aspect of learning engineering materials is to understand one's mistakes and how to correct them. To address this issue, the EPC allows students to review their previous evaluation materials on secured computers under the guidance of GTAs. The goal is to allow students the opportunity to review their evaluations in a self-paced format, or with the guidance of accessible GTAs, in an effort to develop a more comprehensive understanding of the material, while gaining a deep confidence in their technical skills.

#### C. Integrating Open Internet Resources with Proctored Assessment

In reduced seat time delivery modalities such as mixed-mode and online course delivery, achieving uniform engagement and meaningful participation in assessments by all students can present significant challenges. BLUESHIFT utilizes the relatively recent pedagogical approach of a flipped classroom model, in which pre-recorded lectures are viewed by students prior to a class session and are followed by in-class exercises, which can be particularly effective within STEM disciplines. First, knowledge acquisition occurs asynchronously using online resources, such as the video lectures, which can be either created by the instructor or selected from a repository. The online lectures allow students to move self-paced through the course material outside of class time, freeing the instructor to use in-class time to facilitate active learning in which students inquire about course material, apply obtained knowledge to a problem, and/or interact with other students in hands-on activities. Later, students meet for face-to-face instruction, which may consist of problem solving, clarification of questions, and team design activities as collaborative efforts. The EPC is especially synergistic with flipped classroom delivery for a couple of reasons. First, students become engaged to participate in a uniform, trackable, and intense assessment environment. This is in stark contrast to at-home, web-based assessment, which may elicit low levels of engagement and compliance. Second, students are

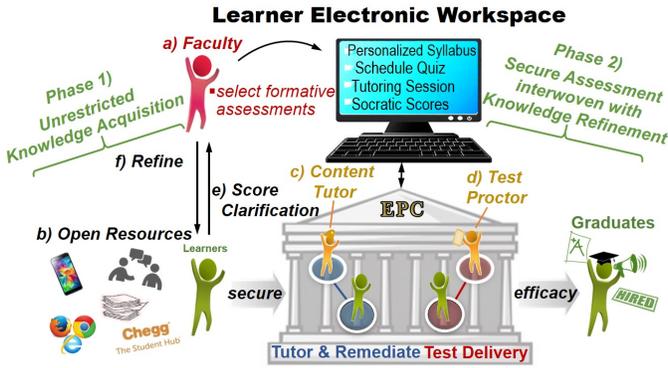


Fig. 1: BLUESHIFT infrastructure. Open-access digital resources are leveraged during Phase 1) in anticipation of secure in-person assessment during Phase 2) that is interwoven with remediation for rapid feedback and integrity gains.

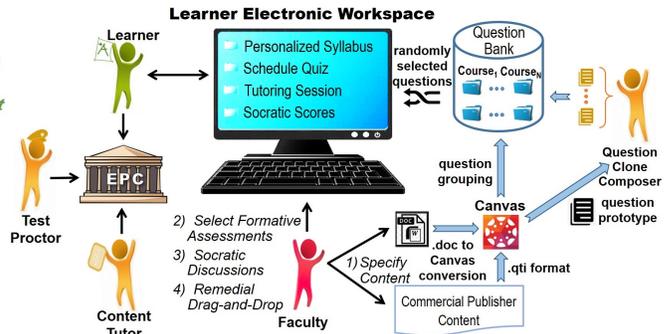


Fig. 2: Recasting conventional teaching roles around a LEW.

authenticated and substantial barriers to the use of unauthorized resources are enabled, which results in a turnkey, service-level infrastructure for securely maintaining the academic integrity of the assessments.

First, students complete computer-based assessments in a secure testing facility during a designated testing window, and may only review their submission after the testing window closes. Second, students can review their evaluation submission in a secure facility with on-site GTAs, who are available to provide structured and targeted content tutoring based on student reviews. Finally, students requiring additional explanations may visit their instructor with specific questions and issues resulting from preliminary discussions with the GTA, thus maximizing learning and teaching efficiency.

Figure 1 depicts the BLUESHIFT realignment of educational and human resources without a net personnel increase [28] by reallocating low-gain grading tasks to high-gain activities such as tutoring, remediation, and syllabus personalization. BLUESHIFT utilizes an iterative flow of 1) unrestricted access to open learning resources, followed by 2) secure assessment and knowledge refinement within a tightly-integrated testing and tutoring center, referred to as the EPC. As shown in Figure 1, the BLUESHIFT learning flow is initiated in step a) whereby the faculty member specifies formative assessments in order to instantiate a personalized syllabus within each learner’s LEW. In step b), the utilization of open resources is encouraged including prepared solutions, internet research, and group problem solving sessions, along with the availability in step c) of content tutoring within the EPC. Regardless of live or flipped delivery, the formative and summative assessments are conducted in-person as overseen, in step d), by test proctors in a secure computer-based testing facility. In step e), referred to as score clarification, students are afforded a two-week interval to clarify their scores based on handwritten work via scanned scratch-paper sheets, either with the content tutors or faculty who may, in step f), refine assessment scores or adjust the student’s personalized syllabus of pre-formed quizzes in the LEW, to be delivered at the EPC.

Learner interactions involving the LEW are depicted in Figure 2. The LEW contains the current working model of the learner’s progress, available via a web-enabled application. It maintains each student’s Personalized Syllabus along with historical records and performance information that are exchanged between the learner, GTAs, and faculty. The LEW was developed as a *Canvas LMS* plugin to integrate all information flows ranging from a Personalized Syllabus to computerized testing with tutoring in the EPC, and a replay-enabled record of Socratic discussions. The instructor specifies content either via the *Respondus* converter or from a commercial publisher, so that the question prototype becomes loaded into Canvas. Second, these are grouped by topic and then cloned by the Question Clone Composer GTA. Third, after being afforded the opportunity to defend their solutions using their handwritten work on the scanned-in scratch sheets, during post-quiz review, students were able to identify the learning gap through a secure self-paced review of the solutions. Then, student self-motivation was encouraged utilizing a quest for partial credit via interaction with GTAs to explain their problem-solving process and justify their detailed work. In this process, they were able to clarify any of their misunderstandings, connect their prior and new learning, and enhance their learning toward long-term instructional objectives. Subsequently, the instructor could provide deeper guidance and follow-up, as needed, to further support learning.

**D. Benefits to Students**

From an evaluation point of view, the EPC’s services (see Table II) improve the accuracy of assessment, flexibility of scheduling, and speed of grading responses. Further studies show that online formative assessments improve learning outcomes and lead to improved student learning [29]. Likewise, online quiz results exhibit a higher degree of correlation with overall course grades than do unsupervised laboratory and homework assignments [30].

From the proficiency point of view, students are obligated to review their exam mistakes with an on-site tutor. Due to affording learners with the opportunity to explain the method with which they arrived at an answer, as well as the reason(s) that the solution makes sense to them, this increases student engagement and interaction in group discussions. Accordingly,

TABLE II: EPC Services.

Evaluation Support	Exam Preparation	With access to large question banks, students can take practice tests to raise their preparedness.
	Exam Delivery	Paperless delivery in quiet environment, flexible scheduling, and labor-free/error-free grading.
Proficiency Enrichment	Content Tutoring	One-on-one solving of examples from Study Sets. Remote video tutoring possible via Skype.
	Score Clarification	GTAs provide first-responder support in a hierarchy of grading concerns.
	Project Tutoring	Lab GTAs and Graders hold office hours in EPC for engineering design guidance & debugging.
	Remediation Support	Instructors assign Study Sets from any instrumented course to be conducted/graded without impeding progress of other students.

this process not only improves the creativity of students, but also develops the transferability of the acquired knowledge and skills. Essentially, learners have a more holistic view of the concepts and can apply the knowledge and skills acquired in varied contextual settings. In another words, EPC services facilitate increased practice, transferability, and learning of course outcomes. If the review session with the GTA does not facilitate concept attainment at the necessary level, or in any way does not meet the student's expectations, the student can meet with his/her instructor for additional clarification/discussion. Additionally, students benefit from the necessity to demonstrate their understanding without the use of aids, so they are encouraged to more deeply understand the material, rather than simply searching the web for an answer. Moreover, defending one's work in the presence of the GTA/instructor helps students build soft skills such as good communication, problem solving, and self-confidence.

#### E. Benefits to Faculty

From the evaluation point of view, the benefits of electronic assessment include the ability to handle increased enrollment capacity in courses, which increases the potential for student persistence through more detailed rubrics, more lecture/discussion time, less time required grading, and the availability of statistics related to learner responses, for identifying class-wide learning deficiencies, as shown in Figure 2.

Students can easily search online for answers to similar, or sometimes the same, homework problems, which reduces the integrity and effectiveness of homework problem sets and negatively impacts student retention and mastery of the material. Revisioning homework as study sets and EPC-based quizzes addresses this concern and improves learning quality in this regard by requiring students to solve problems without access to reference materials. This is particularly useful for provisioning remedial exercises, which can otherwise be prohibitive to administer, given limited class time. With the availability of an expanded EPC, more faculty can use evaluation, tutoring, and even remedial services without increasing their grading load or sacrificing time spent on required topics in their courses.

Extending the proficiency point of view, students benefit from speaking with a tutor before meeting with faculty, thus receiving rapid responses to questions, since simple problems are handled by tutors. Additionally, faculty are provided automatic feedback statistics from the LMS, at the question level, to help identify problem areas amongst the class as a whole. The time recovered from such low-value efforts as grading is available to the instructor for providing feedback and detailed solutions for questions that are discovered, through the learner performance statistics, to have high error rates. Furthermore, the instructor can utilize the additional time both to improve the course content and to create extra modules for improved explanation of problem solutions with enhanced detail, in an effort to improve students' understanding.

### IV. BLUESHIFT OPERATIONAL FLOW

#### A. Operational Flow for Integrated Content, Evaluation, and Tutoring

Figure 3 depicts BLUESHIFT's operational flow, which centers around the LEW. Each course module is conducted by a stepwise progression paced by the learner:

**1) Knowledge Acquisition:** Instructional content is available in the LEW for students to learn at their own pace within an instructor-specified acquisition window. During each acquisition window, learners view instructor-produced or publisher-provided videos as desired, read material from slides/notes/text/hyperlinks, and practice the study set that replaces traditional homework with motivating exemplar vignettes solved in detail which is a solved problem example with some additional attributes. Those include use of contemporary technologies and companies within the problem statement to raise interest and motivation. Exemplar vignettes have a fixed structure whereby givens are established in a standalone statement, and the answers sought are decomposed in incremental solutions, as a clearly defined partial credit exercise. These attributes are valuable for BLUESHIFT for two reasons. First, each exemplar vignette forms the question prototype for digitized assessment that can be cloned to create a test bank. Second, it familiarizes students with the partial credit mechanisms that will be used in the assessment. The contents of a well-organized study set are divided into two parts: problem statements and detailed solutions.

**2) Open Tutoring:** In order to clarify the questions, students can review questions with a content tutor/GTA.

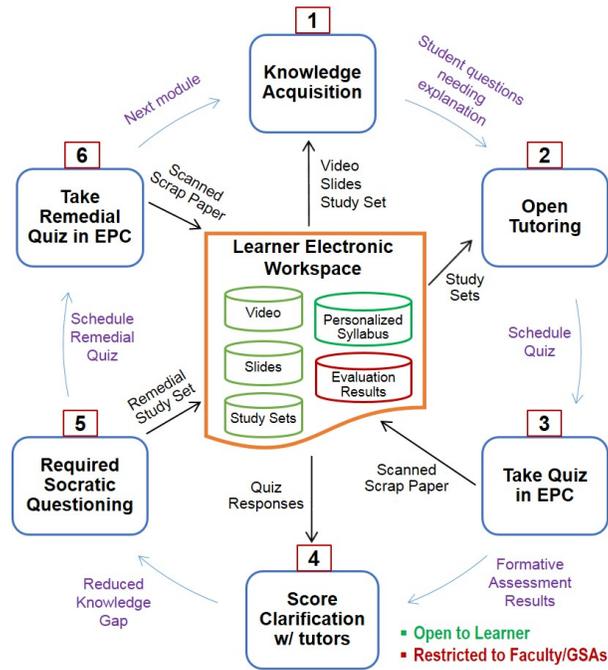


Fig. 3: BLUESHIFT Operational Flow

**3) Taking a Quiz in EPC:** In order to leverage the Testing Effect, after building skills, learners schedule appointments for formative assessment at a time convenient for them, during the week following each acquisition window. Acquisition windows have a firm duration that means each assessment has a designated testing window deadline. For example, most instructors will specify an assessment in EPC every two weeks. While students may take exams asynchronously, the assessment is locked after the window ends, as defined in the course syllabus. A GTA in the EPC provides a turnkey service in a secure environment. The EPC is equipped with the latest technology, including IP restrictions, camera/phone checks, and lockdown browsers to prevent cheating though unauthorized access to support materials. Through labor-saving assessment delivery and grading, an increased number of smaller formative assessments are possible, which further leverages the testing effect by reducing the stakes of each individual assignment. Handwritten image files of scratch paper calculations are retained for review by the instructor, and/or for score clarification, if the learner selects to do so.

**4) Score Clarification:** Learners are obligated to go to the EPC to review their exams to learn from their mistakes, prior to the following week's in-person individual meeting with a content tutor/GTA/Instructor. The students' handwritten image files are retained, thus providing a resource for the student to evaluate problem solution techniques and clarify the score through one-on-one interaction with GTAs or the instructor. This provides a side benefit of strengthening the learner's soft skills. In this way, common mistakes and misconceptions are addressed immediately, without contact through email/office hours, which often consume a significant amount of instructor time. In addition, the instructor may authorize GTAs to make routine score adjustments in an effort to speed up the grading processing. The evaluation submissions are viewable only in the EPC for two reasons: 1) *reduced cheating/proagation*, and 2) *observing increased student engagement*. The primary pedagogical benefit, though, is that students review their concerns early, during a prescribed rebuttal period, thus avoiding future cramming immediately before a subsequent exam. Solutions are also visible for self-paced review.

**5) Required Socratic Discussions:** Technical topic gaps evident in formative assessments are reviewed using an oral examination style via guided Socratic questioning. Quiz results and electronically-scanned handwritten sheets are reviewed, whereby the learner is able to explain missed items to the instructor's satisfaction. Socratic discussions boost creative aspects for design problems, in addition to course projects/reports, with realistic interactions for design teams and job interviews. The instructor updates the learner's Personalized Syllabus with any needed remedial modules from the current course or pre-requisite/related BLUESHIFTed course.

**6) Remedial Quiz in EPC:** Remediation prescribed by the instructor is completed asynchronously as a self-paced endeavor with optional assistance from a tutor in the EPC. The student then schedules a remedial quiz in the EPC, for which a minimum score threshold must be achieved to advance to the next acquisition window.

## B. Digitizing STEM Assessment

BLUESHIFT benefits students by considering new technological aids that can facilitate student assessment and advancement in engineering *creativity, design, and soft skills*, which are vital for career success. It has been reported that the efficacy of traditional vehicles, such as homework assignments, lab reports, and reused exams have become thoroughly undermined by Internet-based solution repositories [31]. Thus, an innovation in utilizing existing technology is needed to recast the exhausting

task of re-designing homework/quizzes/exams, grading, and grade book updates to develop a new approach that addresses these challenges, while freeing up both faculty time for improving course content/learning outcomes and GTA time for tutoring. Different question types available within the Canvas LMS are utilized in creative ways to meet the creativity, design, and soft skill needs of engineering assessments, which are vastly studied in previous work [15].

### C. Development of Question Clones

In order to reduce the possibility of cheating, the flow presented in Figure 4 is utilized. First, a faculty member generates a question template that encapsulates all appropriate concepts and materials to be assessed. Next, different clones are produced by changing the elements of the question; for instance, changing given parameters or the information to be determined. The created clones are then organized into a question group, which Canvas uses to randomly assign each student alternative cloned versions of the same problem. This ensures that each student is tested on the same concepts, while the propensity for them to share answers is significantly reduced.

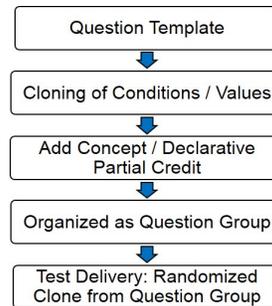


Fig. 4: Question cloning procedure by forming question groups

In addition to the computer-based assessment tools that BLUESHIFT creatively utilizes, faculty are able to work in a familiar Microsoft Word environment to develop questions. By using the *Respondus* exam authoring tool, properly formatted Microsoft Word files can be converted and uploaded to Canvas. This feature works with all of the aforementioned question types, figures, and equations, so faculty can work in a familiar development environment, and are minimally required to learn a few formatting rules.

## V. COURSE DIGITIZATION PROGRESS TO-DATE

The EPC infrastructure is composed of a 5,000 square foot facility, including manager office space. Software, networking equipment, and computer workstations were provided via an institutional technology fee grant in the amount of \$300K. Assessment Delivery Tier-1 employs laptops/tablets with lockdown browsers during class meetings, in-lieu of paper-based exams. Alternatively, Assessment Delivery Tier 2 utilizes lockdown browsers in an existing computer lab, while Assessment Delivery Tier 3 consolidates assessment and tutoring resources within a dedicated EPC. In Tier-1 Digitized Assessment Delivery, student-owned tablets and laptops, such as Chromebooks available for around \$150, are leveraged to facilitate autograding using Canvas LMS delivery via lockdown browsers during in-class exams. Tier-2 Assessment Delivery adds individualized exam scheduling with proctoring and formula-based auto-cloning technology prototyped at UCF so that questions are unique to each student, and delivered by block-scheduling of existing open multi-purpose computing labs. Tier-3 Assessment Delivery will be evaluated in a secure testing facility during a designated testing window, while providing a facility where students can review their evaluation results in a secure facility with onsite GTAs, while allowing remedial quizzes or retakes, if assigned. Currently, a total of 23 courses are delivering their assessments using the facility, which is staffed with one manager, four proctors, and over 20 tutor GTAs spanning various hours of the week. The following equipment is available:

- 120 Dell PCs for test delivery
- 30 Microsoft Surface tablets and 15 Lenovo PCs for tutoring
- 2 high-end front desk PCs for check-in and monitoring
- Internally-developed web appointment portal with computer assignment
- Netsupport software for 120 PCs
- Respondus LockDown Browser for secure quiz delivery
- Safe Exam Browser for secure tutoring review
- 3M Black Privacy Filters for each testing PC

The transition to the EPC-enabled course delivery mode took place in 2014, when one faculty member began to digitize questions for assessment beyond multiple choice formats. In 2015 GTAs from four courses were pooled for collective impact. The results proved to be a promising and useful method for exam delivery, thus more courses were integrated in 2016 and GTAs from six courses were grouped into the EPC. In 2017 and 2018, a total of 12 courses and 23 courses were delivered using EPC, respectively. Table III lists the titles of the redesigned courses along with the maximum annual enrollment and the number of GTAs per course who were freed up 20 hours per week by reallocating their grading workloads to conduct tutoring.

TABLE III: Redesigned courses along with the maximum annual enrollment and the number of GTAs per course.

Department	Course	Max Annual Enroll.	GTA Contracts Harvested
CECE	CGN 3700: Civil Engineering Measurements	225	1.00
CECE	CWR 3201: Engineering Fluid Mechanics	110	0.00
CECE	EGN3310: Engineering Mechanics - Statics	1125	1.00
CS	CDA3103: Computer Logic and Organization	625	1.00
CS	COP 3223: Intro Program w C	650	1.25
CS	COP 4331: Proc. Object Oriented SW	325	0.75
ECE	EEE3342: Logic Design	350	1.00
ECE	EEL3801: Computer Organization	350	1.00
ECE	EEL 4781: Computer Networks	180	0.50
ECE	EGN3211: Engineering Analysis and Computation	525	4.00
ECE	EGN3223: Engineering Analysis	350	1.50
IEMS	EAS3800: Aerospace Engineering Measurements	193	1.00
IEMS	ESI 4221: Empirical Methods for Industrial Engineering	375	1.00
IEMS	ESI 4234: Empirical Methods for Industrial Engineering	375	1.00
IT	CAP 4104: Human Tech Interaction	340	2.00
MAE	EGN 3321: Engineering Analysis- Dynamics	1190	2.00
MAE	EGN3343: Thermodynamics	600	2.00
MAE	EGN3373: Principles of Electrical Engineering	688	2.00
MAE	EML3034: Modeling Methods	750	2.00
MAE	EML3303: Modeling Methods	420	2.00
MAE	EML4142: Heat Transfer I	875	2.00
MAE	EGM3601: Solid Mechanics	1100	1.00
Physics	PHY 2053: Human Tech Interaction	248	1.00
<b>All Semesters Adoption</b>		<b>11969</b>	<b>31</b>

Over past four years, 35 instructors have revised their courses to align them with the BLUESHIFT approach. Of these 35 instructors, 21 have received formal training via a seven-week faculty development course titled Assessment Digitization Innovation Workshop. In the workshop, faculty work to redesign courses with digitized assessments by conducting several activities, which include how to digitize assessments for engineering content, modularize a course, choose question types, design assessments in Canvas, as well as review EPC protocols. The primary goal of this course is to work with each faculty member to modularize subject matter, formulate an assessment calendar, select testing frequency/duration/windows, and compose content and study materials to prepare students for quizzes. Upon completion of this workshop, faculty are expected to digitize at least one module and a complete quiz, with clones for each quiz question. This quiz is presented via a showcase event where all enrolled participants critique their first converted module.

## VI. EVALUATIONS AND PERCEPTIONS

### A. Impact on Learning and Achievement

In order to evaluate the effectiveness of BLUESHIFT, we compared the evaluation results of two nearly identical sections of *EGN 3211: Engineering Analysis and Computation* for both conventional in-class paper-based and asynchronous examinations combined with GTA review [15]. An equal number of quizzes were conducted for both sections. The results of the comparison, can be summarize as follows:

- An average of 10.4% improvement in quiz grades for online assessment
- An average of 39.4% reduction in Fs for online evaluation

The comparison showed that the number of students who missed their quizzes, reduced for online evaluation due to an increased window of time to take the quiz. Also, fewer students failed or received a D grade in the course. Computer-based assessment, combined with tutoring afforded from the time reclaimed in reduced grading efforts, appears to yield increased student success. A significant benefit to BLUESHIFT is the bi-weekly quiz feedback that faculty receive from the EPC, which not only facilitates faculty assessment of quiz fairness and clarity, as well as the student's comprehension of course content, but also assists the instructor in determining what content needs to be reinforced in subsequent class sessions. Digitizing

the exam did not affect the grade distribution. A smooth distribution of grades remained, thus achieving fine resolution of discernment and learning comprehension, which validates the use of digitized questions in STEM, as well as BLUESHIFT delivery approach. The bi-weekly quiz feedback results are summarized as follows:

- The number of questions and question difficulty were fair;
- Digitized exams were valid for achieving fine resolution of discernment and learning comprehension;
- Instructors receive detailed statistics for each question, which can help them to identify specific content issues to address in class;
- Responses were used to provide instructor insight in identifying concepts that should be taught in a different manner before progressing to the next module.

### B. Student perception of BLUESHIFT and EPC

To gather student perceptions of computer-based assessment and the effectiveness of the BLUESHIFT framework, several anonymous surveys were administered at the end of *EEL-3801 Computer Organization*. The result of one of the surveys indicates that, excluding the visits to take quizzes/exams, 72% of the students used the EPC for test review, tutoring, and/or project assistance two or more times, 11% of students used it once, and only 17% did not use it. Figures 5 and 6 show the results for the 21 respondents out of the 68 students who were enrolled. The majority of students agreed or strongly agreed that the EPC-based interventions were beneficial for their learning, and they acknowledged that the GTAs guided access to quiz results and enhanced their comprehension of material.

Figures 7 and 8 show more promising survey results from the same course. Figure 7 (b) shows that flexible exam scheduling offers valuable convenience compared to in-class testing (93% agree or strongly agree). The high percentage of Strongly Agree/Agree answers from the majority of respondents suggests that using EPC for assessment delivery and GTAs for tutoring creates additional learning opportunities that are both desirable and beneficial for students. These preliminary results were particularly encouraging, as 59% of respondents did not use the EPC for test review, tutoring, or project assistance, potentially explaining the high neutral responses in areas.

Legend: Strongly Agree (Green), Agree (Blue), Neutral (Grey), Disagree (Yellow), Strongly Disagree (Red)

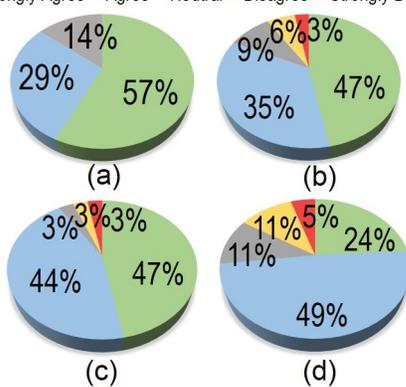


Fig. 5: (a) Completion of an online lab assessment every two weeks is preferable to submitting weekly lab reports (b) I wish other courses provided opportunities for personalized learning (c) I wish other instructors utilized stepwise incremental question formats in quizzes and exams (d) In this course specifically, computerized questions were adequate to engineering design skills

Legend: Strongly Agree (Green), Agree (Blue), Neutral (Grey), Disagree (Yellow), Strongly Disagree (Red)

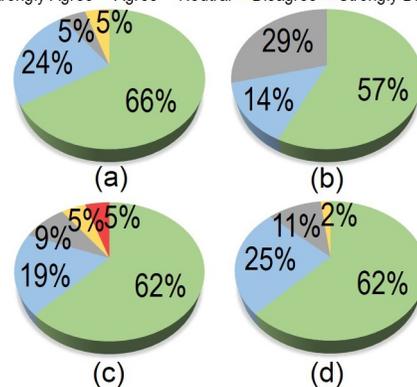


Fig. 6: (a) Study Sets followed by computerized assessment are more effective for learning than Homework. (b) Graduate assistant guided access to quiz results enhanced my comprehension of material. (c) The Quizzes and Exams were reasonably fair (phrased clearly, covered material in course, adequate time allowed) (d) Socratic Extra Credit opportunities increased understanding of missed/advanced concepts.

Student learning outcomes in the courses redesigned to utilize BLUESHIFT have been comparable to or better than those of traditional courses. For instance, in one of the redesigned Computer Engineering courses, withdrawals were reduced 46.6% by the instructor adopting BLUESHIFT with EPC-based delivery, over seven semesters, as compared to the previous eight semesters. In another redesigned Computer Science course, students' assessment scores in the digitized format were comparable with the traditional format [32]. One Mechanical Engineering course was delivered using the testing delivery mechanisms and remediation mechanisms delineated by BLUESHIFT and the EPC, and students' learning achievements increased by almost 17%, as compared to conventional assessment strategies, while utilizing comparable instructor resources and workloads [33]. Tutoring is particularly vital to improving engineering students' deeper learning and professional development, which can result in marked improvements in pass rates, particularly after employing a peer-tutoring system [34]. Furthermore, peer tutoring can assist in developing a sense of community in the teaching and learning environment, which has been shown to improve the retention and graduation of at-risk engineering students [35]. The EPC incorporates these by engaging students through the review of evaluation results, including scratch paper calculations, which provides an opportunity for them to gain an increased understanding of the technical content while building soft skills.

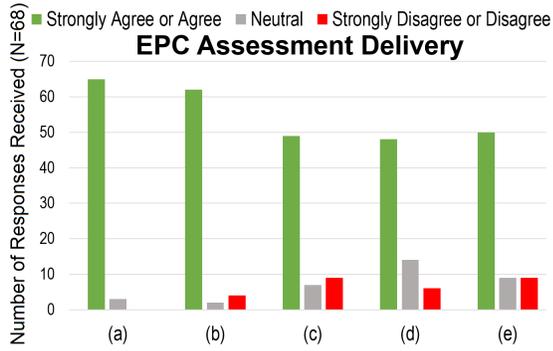


Fig. 7: (a) Retaining of Scratch Sheet for partial credit is beneficial (b) Flexible exam scheduling offers valuable convenience (c) The testing center provided an adequate testing environment (d) Access to the EPC resulted in a more Personalized Learning experience (e) Online assessment is preferable to lab reports.

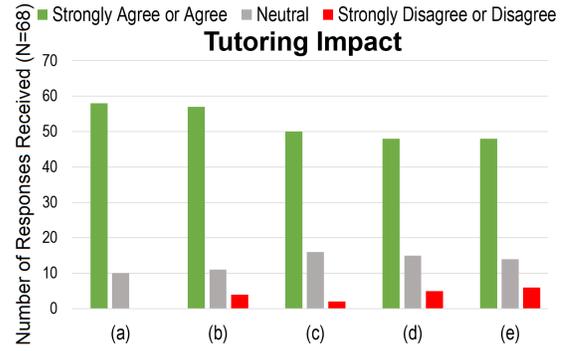


Fig. 8: (a) I wish tutoring was available in other courses in my program (b) Availability of tutoring is a valuable resource to improving performance (c) Availability of tutoring increased my confidence to solve problems (d) GTA guided access to quiz results enhanced my comprehension (e) Access to EPC provided increased availability of assistance

### C. Cost Savings that Harvest Instructional Value

EPC-based assessment delivery converts grading workloads into learning gains. A detailed task-based cost model indicates that educational and human resource efficiencies are available, as depicted in Figure 9. The cost incurred by conventional delivery is yielded by Equation 1.

$$\text{Cost}_{\text{conv}} = \#graders \times (\text{stipend} + \text{tuition}) + \text{facultyburden} + \text{logisticCosts} \quad (1)$$

Where the faculty burden spans: homework/quiz/exam re-creation/solution, GTA coordination, test delivery, photocopy logistics, and score clarification. Based on a stipend plus tuition of \$29,614 annually per GTA, and the number of hours that each faculty expends for 140 students using nominal faculty rates, a linear cost model results with a steep slope. On the other hand, the cost for EPC-based operational phase is yielded by Equation 2.

$$\text{Cost}_{\text{EPC}} = [\#tutors + \#cloner + \max(6, \min(3, \#Proctors))] \times (\text{stipend} + \text{tuition}) + \text{logistic Costs} \quad (2)$$

Minimally, three test proctors are required to cover test administration as a turnkey service to students and faculty, which are sufficient to deliver 2,100 Student Credit Hours (SCHs) under nominal testing loads. To deliver greater than 2,100 SCHs, only the number of test proctors needs to be increased to expand exam delivery up to six days per week, at which point only more PC stations are needed to increase capacity for growing enrollments. Rather than grading homework submissions and exams, GTAs have been reallocated to new high-gain categories: 1) Content Tutor: Reviews module or remedial material and clarifies scoring of missed problems. 2) Quiz/Exam and Remedial Assignment Question Cloners, and 3) Test Proctor: Verifies student identification, restricts prohibited materials, and prevents cheating by delivering a turnkey service for secured assessment unobtainable in classroom settings or fully-online assessment.

Figure 10 shows the provision of 10 hours per week of tutoring time (i.e. combined lab assistant plus grader personnel, and 5.5 hours weekly of freed faculty time reallocated to high gain activities), thus re-enabling the faculty role of structuring and propagating knowledge while improving student success. Faculty feedback corroborates the time efficiency gain of several hours per week. The above model has been validated over five semesters for multiple courses. Results to-date were achieved by leveraging computerized grading, which during the spring 2015 semester reduced 1,552 hours of graduate assistant effort in four piloted courses. This surplus human resource was reallocated to 512 hours, 272 hours, and 768 hours of Content Tutoring, Question Cloning, and Test Proctoring, respectively. Thus, the EPC realizes reduced human resource expenses to provide increased learning value.

This innovative EPC pedagogy is realizing improved student outcomes during a period of enrollment growth, while maintaining and/or enhancing learning quality. A summary of the EPCs quantitative efficiencies related to sustaining the institutional mission are listed in Table IV. Efficiencies are realized in the rows of Table IV corresponding to *Faculty Efficiency*, *GTA Efficiency*, and *Lab & Tutoring Efficiency*. The department proposes to expand the EPC capacity and faculty participation further, if provided with the support to do so.

## VII. CONCLUSIONS

The goal of this work was to integrate computerized testing with self-paced and GTA-assisted tutoring in an innovative format to improve student success in engineering courses. In this innovative model, flipped mastery delivery is facilitated by rapid feedback of engineering analysis, design, and concepts allowing adaptation for learners across modules and courses. BLUESHIFT is an innovative framework to enhance engineering student's creativity, depth of learning, and critical thinking skills, while optimizing faculty and GTA time. Under the BLUESHIFT approach, the exchange of low-impact burdens for

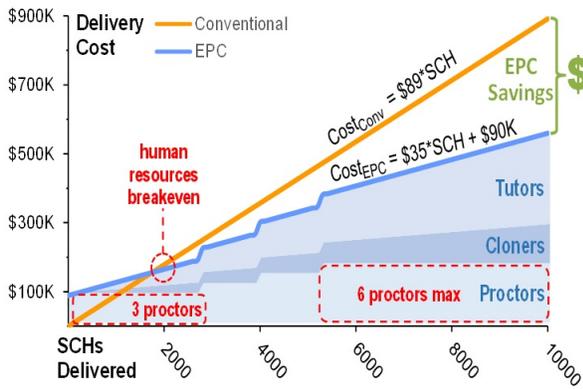


Fig. 9: EPC Cost Savings

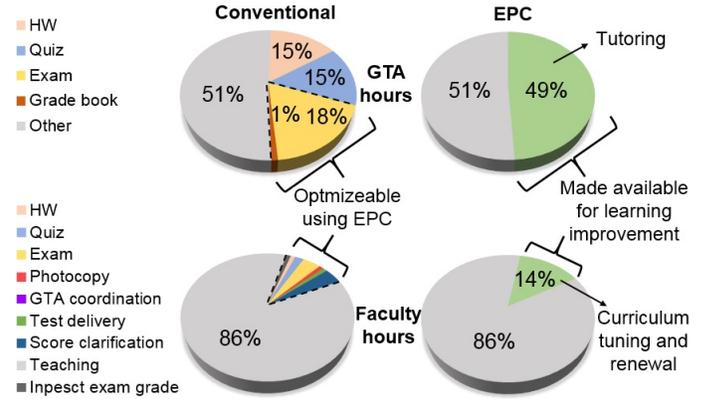


Fig. 10: Time efficiency of EPC where low-gain human resource tasks are remapped to high-gain tutoring.

TABLE IV: 120 Seat EPC Efficiency for FY17-FY18.

Faculty Efficiency Metrics	Depts. Participating	Faculty Utilizing EPC	Approx. Faculty Hours Harvested Annually	Approx. Faculty Labor Value Harvested Annually
	CECE, CS, ECE, IEMS, IT, MAE	14	3080	\$192,500
GTA Efficiency Metrics	GTA's Participating	GTA contracts harvested	Approx. GTA Hours Harvested Annually	Approx. GTA Labor Value Harvested Annually
	Doctoral & Masters level	17.5	14000	\$437,500
Tutoring Efficiency Metrics	Duplication Cost Est.	EPC Lab Monitors	SARC Tutoring expense harvested annually	Approx. Lab Expense Harvested Annually
	\$2,800	\$31,200	\$50,000	\$84,000
			EPC Staff	Expenses beyond Open Computing Lab
			0.5FTE EPC Manager	-\$20,500
			<b>Monetary Benefit Harvested Annually</b>	<b>\$693,500</b>

increased high-impact activities better assists students in the STEM-specific demands of design skill development and abstract reasoning. Technological interventions utilizing auto-grading of original assessments and rapid feedback on performance of the results, are utilized. The effect of this educational approach applied to the environment of undergraduate engineering will contribute to the knowledge-base and will advance the quality of STEM education. The learning objectives, which can be achieved by using BLUESHIFT, are as follows:

- 1) *Create Learning through a Tight Feedback Loop* characterized by the division of learning objectives into short phases and frequent reassessment using online delivery of quizzes. Thus, agile teaching becomes possible wherein each student’s unaided comprehension is evaluated incrementally and then responded to with one or more layers of tutoring.
- 2) *Create online assessments that include engineering design and analysis questions* based on collaborations of STEM subject matter experts in Electrical and Computer Engineering, and Instructional Design and Technology.
- 3) *Support increasing class sizes*, while maintaining learning quality.
- 4) *Develop, evaluate, and propagate techniques* that alleviate logistical burdens in order to increase instructors human resource efficiency in assisting students, thus increasing the capacity of the STEM pipeline.

BLUESHIFT achieves a beneficial realignment of human resources enabled by auto-grading techniques, while fostering metacognition via Score Clarification.

VIII. ACKNOWLEDGMENT

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