Redesigning Computer Engineering Gateway Courses Using a Novel Remediation Hierarchy

Prof. Ronald F. DeMara, University of Central Florida

Ronald F. DeMara is a Professor in the College of Engineering and Computer Science (CECS) with 23 years of university-level faculty experience in Electrical and Computer Engineering disciplines. He has completed 180+ technical and educational publications, 34 funded projects as PI/Co-I, and established two research laboratories. He serves as the Computer Engineering Program Coordinator, the founding Director of the Evaluation and Proficiency Center (EPC) in CECS, and is an iSTEM Fellow. He has developed 7 Computer Engineering courses which have been added to the UCF catalog as the sole developer, plus as the co-developer of 2 courses. He received the Joseph M. Bidenbach Outstanding Engineering Educator Award from IEEE in 2008.

Mr. Navid Khoshavi, University of Central Florida

Navid Khoshavi is a Ph.D. student in Department of Electronic Engineering and Computer science at University of Central Florida. He engaged numerous students as a Graduate Teaching Assistant through providing visual aid to help student retention of abstract concepts, utilizing in-class activity to encourage students to put the concept into use and emphasizing critical concepts repeatedly to improve student long-term memory retention. He also received his M.S. from Amirkabir University of Technology (AUT) (Tehran Polytechnic), Iran, in 2012.

Mr. Steven D. Pyle, University of Central Florida

Steven Pyle received B.Sc. and M.Sc. degrees in electrical engineering in 2013 and 2015 from the University of Central Florida. His first paper received the Best Design Paper Award at the 2015 Conference on Adaptive Hardware and Systems. He is continuing to pursue a Ph.D. degree in computer engineering at the University of Central Florida. His research interests include: Highly Parallel Computing Architectures, Adaptive Computer Architecture, Evolvable Hardware, Beyond CMOS Computing Architectures, particularly spintronics.

Mr. John Edison, University of Central Florida

Computer Engineering, MS

Dr. Richard Hartshorne, University of Central Florida

Richard Hartshorne is an Associate Professor and Coordinator for the Instructional Design & Technology program at the University of Central Florida (UCF). He earned his Ph.D. in Curriculum and Instruction with a focus on educational technology production and technology and teacher education from the University of Florida. Prior to his tenure at the UCF, Richard was an Assistant and Associate Professor of Instructional Systems Technology at the University of North Carolina at Charlotte for seven years and a physics instructor at Ed White High School in Jacksonville, FL for seven years. At the University of Central Florida, his teaching focuses on the integration of technology into the educational landscape, as well as instructional design and development. His research interests primarily involve the production and effective integration of instructional technology into the teaching and learning environment. The major areas of his research interest are rooted in technology and teacher education, the integration of emerging technology into the k-post-secondary curriculum, and online teaching and learning.

Dr. Baiyun Chen, University of Central Florida

Dr. Baiyun Chen is an Instructional Designer at the Center for Distributed Learning at the University of Central Florida. She designs and delivers faculty professional development programs and teaches graduate courses on Instructional Systems Design. Her research interests focus on using instructional strategies in online and blended teaching and learning, professional development for teaching online, and application of emerging technologies in education. She has published 15 peer-reviewed journal articles and book chapters and delivered more than 50 presentations at international and local conferences and event and served as the Co-Managing Editor of the Teaching Online Pedagogical Repository.

Dr. Michael Georgiopoulos, University of Central Florida

Michael Georgiopoulos received the Diploma in EE from the National Technical University in Athens, his MS degree and Ph.D. degree in EE from the University of Connecticut, Storrs, CT, in 1981, 1983 and 1986, respectively. He is currently a Professor in the Department of ECE at the University of Central Florida in Orlando, FL. From September 2011 to June 2012 he served as the Interim Assistant Vice President of Research at the Office of Research and Commercialization. From July 2012 to May 2013 he served as the Interim Dean of the College of Engineering and Computer Science. Since May 2013 he is serving as the dean of the College of Engineering and Computer Science at the University of Central Florida.

His research interests lie in the areas of Machine Learning and applications with special emphasis on neural network and neuro-evolutionary algorithms, and their applications. He has published more than 70 journal papers and more than 180 conference papers in a variety of conference and journal venues. He has been an Associate Editor of the IEEE Transactions on Neural Networks from 2002 to 2006, and an Associate Editor of the Neural Networks journal from 2006 to 2012. He has served as the Technical Co-Chair of the IJCNN 2011.

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

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Ronald F. DeMara[1], Navid Khoshavi[1], Steven Pyle[1], John Edison[1], Richard Hartshorne[2],
Baiyun Chen[3], and Michael Georgiopoulos[4]
{[1]Department of Electrical and Computer Engineering, [2]Instructional Design & Technology Program,
[3]Center for Distributed Learning, [4]College of Engineering and Computer Science}
University of Central Florida, Orlando, FL 32816-2362

Abstract

Focusing on the quality of education, skills, and employability of our graduates in computing-related fields, this work proposes a cost-effective approach to achieve these goals. The *Evaluation and Proficiency Infrastructure, Curricula, and Services (EPICS)* extends successful methods in other units on campus in an innovative way as synergistic combination of faculty, Graduate Teaching Assistants (GTAs), and educational technology using the Canvas Webcourses Learning Management System (LMS) already in use at our college. We integrate computer-based evaluation with a close-knit review and learning cycle based on directed and open tutoring to collectively form the *Evaluation and Proficiency Center (EPC)*. Initial results have been encouraging, as students' test scores and survey results indicate a 43% reduction in D or F grades compared to a section of the same course with the same instructor, using conventional delivery, and overwhelmingly positive responses from students regarding the effectiveness of pedagogical strategies (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). In this manuscript, the EPICS process, as well as results collected from student performance and perceptions of the initial implementation, will be addressed.

1.0 Introduction

The Department of Electrical and Computer Engineering has developed an *Evaluation and Proficiency Infrastructure, Curricula, and Services (EPICS)* pedagogical approach and has delivered it to approximately 700 students during multiple semesters in the required introductory courses: *Engineering Analysis with C-Language*, *Computer Organization*, *Electrical Circuits*, and *Electrical Networks and Systems*. The EPICS pedagogy:

- engages students in an innovative flipped model to master skills outside of class using open resources,
- enforces rigorous skill demonstration without aides using an electronically-based testing facility, and
- enables scaffolding practices between students and more knowledgeable GTAs.

In EPICS, student engagement is initially increased through the replacement of all homework assignments with detailed already solved *Exemplar Vignettes* on odd weeks, and corresponding electronic formative assessments during even weeks. Second, utilizing a flipped classroom model, learners are assessed at their preferred time within a one-week *Evaluation Window* in a

GTA-proctored *Evaluation and Proficiency Center (EPC)*. Third, utilizing the Vygotskian concept of the Zone of Proximal Development (ZPD) and Bruner's Scaffolding Theory [1] as theoretical frameworks, learners review their evaluation results with *Content GTAs*, who are available to tutor due to the abridged homework and exam grading loads. Finally, learners requiring additional explanation visit their instructor to resolve concerns mediated as task/response flows within their individualized *Learner Electronic Workspace*.

EPICS uses a layered remediation hierarchy to resolve two fundamental hurdles to utilizing electronic evaluation within STEM curricula. First, a taxonomy of online assessment instruments facilitates design problems beyond rote multiple choice. Thus, problems with partial credit, which are isomorphic to pencil-and-paper based exams, become deliverable electronically. Meanwhile handwritten image files are retained for strengthening the learner's soft skills through one-on-one clarification with Content GTAs. 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. A detailed financial cost model was developed which indicates that tutoring can be provided at no additional expense, by attaining a breakeven point between the grading hours avoided and the test proctoring hours required. This is shown to occur for a combined cohort of 1,150 students using EPICS, per term. Thus, the EPICS pedagogy shifts instructor and GTA roles away from low-value repetitive tasks towards those having more significant impacts on learning outcomes. While only lower-level required undergraduate courses are currently being targeted, electives and graduate courses could be applicable depending on the nature of course content.

In summary, EPICS improves learning quality by engaging students with scaffolding instruction targeted at the learners' ZPD and provide them with the appropriate, structured guidance to assist them in achieving specific tasks, while also systematically providing the instructor access to detailed formative statistics throughout the semester. It also mitigates increasing assignment preparation, instruction, and grading tasks of faculty and GTAs by refocusing instructor effort on curriculum tuning and renewal.

2.0 The Current State of the Art in Technology Infrastructure for STEM Learning

2.1 Quest for Increasing Comprehension Quality and Breadth of Holistic Learning

Contemporary approaches for hierarchical technology enabled STEM delivery are listed in Table 1. A relatively recent pedagogical approach in STEM includes the use of a flipped classroom model, in which the pre-recorded lectures are viewed by students before the class session, and are followed by in-class exercises [2]. The video lectures can be either captured by the instruction or selected from a repository, then posted online. The online lectures allow students to move at their own pace, and facilitate active learning through inquiring about course materials, applying obtained knowledge on a problem, and interaction with other students in hands-on activities. We see great potential for tailoring this pedagogy for on-site expert coaching of students through individual inquiry and collaborative efforts, clarifying the content, and monitoring the progress beyond that of the literature, such as Massive Open Online Courses (MOOCs) [3]. On the other hand, the *Open Tutoring Center* takes advantage of the flipped classroom concept and the addition of open tutoring faculties led by GTAs. This option affords students with opportunities to get guided assistance from tutors to clarify challenging content [4]. Research 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 the diminished student achievement [5].

To combat 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 [5], which provides project-based experiences within the undergraduate curriculum. The ECE Clinic approach improves problem-solving skills of students by motivating students to continuously engage in self-paced assignments and adapt themselves to recent ECE technology. In order to evaluate the outcome of the ECE clinic approach, faculty are required to monitor the specific outcomes and identify issues of concern using a *course-outcomes tracking sheet*. The proposed work in [6] 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 [5]. We propose a novel infrastructure to extend the positive aspects of these approaches of open tutoring and tight loop adjustment while also accounting for the limitations.

The Spanish National University of Distance Education (Universidad Nacional de Educación a Distancia; UNED) affords learners with opportunities to share tasks, content, and experiences through their virtual course platform. The purpose of UNED's virtual course platform is to reduce the evaluation workload of NetServicesOS courses, especially for practical activities, using an automatic evaluation system [7]. UNED has extended the e-learning platform (aLF) by

Table 1: Contemporary approaches for hierarchical technology enabled STEM delivery whereby each {✓, ■} indicates relative {strength, limitation}.

Method	Service	Content Tutoring	Exam Preparation	Exam Delivery	Grade Clarification	Rigorous Evaluation	Project Tutoring	Remediation via Electronic Drag-and-Drop	Career Preparation Skills
Commercial	**MyLab & Mastering**	■	✓	✓	■■	■■	■	■	■■
	McGraw-Hill Connect	✓✓	✓	✓	✓✓	■	✓	■	■■
	Coursera	✓	✓	✓	■	■	■■	■	■■
	Udacity	✓	✓	✓	■	■	■■	■	■■
	Quia	■	✓	✓	■	■	■■	■	■■
Academic	**ECE Clinic**	✓✓	■■	■■	■	■■	✓✓	■	✓
	UNED's virtual course platform	✓✓	✓	✓	■	■	✓	■	■■
	OCM	✓✓	■	■	✓✓	■	✓✓	■	■
	Flipped Classroom	✓	✓	✓	✓	✓	✓	■■	■■
	Open Tutoring Center	✓✓	✓	■	■	■	✓✓	■	■
	MOOC-based platform	■■	✓✓	✓✓	■	■	■	■■	■
	EPICS	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓

providing discussion forums as tools to enable students to help their partners, and to provide a more cohesive integration within a study group. In addition, they have implemented a client-server virtual environment to provide a virtual computer station for each student while working at home on the projects. This Virtual Environment Management System (VEMS) has been equipped with an Assessment Engine to evaluate the student's performance, based on the recorded profile in the VEMS. We propose an intriguing adjustment to STEM curricula, which renovates out of class activities for the reality of the search engine era.

Another approach for hierarchical technology enabled STEM delivery is the Online Classroom Model (OCM). The purpose of the OCM is the guidance of the design, implementation, 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 interactions by offering several features, such as collaborative multimedia presentation, virtual laboratory, social and collaborative Q&A community, and a robust communication framework to the online classroom [8]. While acknowledging the potential for these services individually, there is a dire need for a hierarchy of services using an integrated framework, which is addressed within the EPICS vision statement provided below.

2.2 Increasing Degree of Production of STEM Disciplines

MOOCs are relatively recent online learning approaches and have received considerable attention from government, higher education institutes, and commercial organizations. MOOCs offer broad-based access to renowned course content that could drive down higher education costs while preserving the quality. This approach has encouraged prestigious universities such as MIT, Harvard University, UC Berkeley to podcast their courses online using non-profit MOOC–based platform called edX [9]. In addition, the potential of developing new revenue streams through MOOC commercialization has intrigued venture capitalists to invest in this business opportunity. This motivation resulted in advent of start-up commercial companies, such as Coursera and Udacity, initiating collaboration with elite universities for offering free online courses and MOOC-based adaptation by larger corporations like Pearson and Google for exploring technology transfer in learning system. While the rise of the MOOC movement in higher education over the past few years has expanded learning opportunities through providing free access to online course materials for all students [10], the movement has been muted, as its academic success and course completion have been less compared with other instructional settings, as participation in MOOCs and other online courses typically requires increased self-motivation, more self-discipline, and better time management skills than students in face-to-face instructional settings, in order to be successful [11]. Two aspects related to these concerns are addressed in the EPICS approach. The first aspect concerns the design consideration with the creation and evaluation of course content, such as course lectures, by a skilled subject matter expert, such as a GTA or faculty member. Traditional lecturing strategies often only consider half of the learning process. Even though MOOCs can deliver the course content via lecture through video or other means, the hierarchy of support to assist in checking the student's progress, and learn from experts is often missing or limited.

The second concern of MOOCs and other large online course settings is the need to address the challenges of individual student evaluation. While the MOOC concept is appropriate for certain

disciplines, where the primary focus of instruction is concept attainment, content areas, such as engineering, where design and critical thinking are more significant, MOOCs can be problematic instructional settings. Recently, to fill 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 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 catalytics has recently been integrated into the MyLab & Mastering framework, to increase student engagement in class discussions through the use of interactive student response tools. McGraw-Hill Connect provides sophisticated data analysis, which allows instructors to determine the quality and clearness of the assessments, as well as aid them in making assignments more successful. Connect Insight also illustrates the students' performance and workflow, which affords the instructor with opportunities to optimally manage his/her time for delivering the most applicable instruction to each student. Quia is another commercial online evaluation tool, which engages students and provides motivational elements by challenging learners to solve problems in a variety of game settings and through numerous types of questions. Instructors can create their own online content, which is entirely customizable through Quia's web-based services, and can save time by taking advantage of automatic grading and content reuse over time.

3.0 The EPICS vision

The creative design nature of engineering curricula requires a discipline-specific approach to provide a comprehensive learning assessment in each area for offering Socratic guiding principles. Thus, EPICS uses a layered remediation hierarchy to resolve two fundamental hurdles to utilizing electronic evaluation within STEM curricula. First, a taxonomy of online assessment instruments facilitates design problems beyond rote multiple choice. Thus, the EPICS model evolves the various aspects of conceptual design problems with partial credit that are isomorphic to skills assessment using conventional pencil-and-paper based exams, but 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 EPICS pedagogy 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 our graduates in computing-related fields, this work proposes a cost-effective approach to integrate computer-based evaluation with a close-knit review and learning cycle based on directed and open tutoring to collectively form the *EPC*.

3.1 Need for Online Evaluation

The EPC helps maintain and increase the learning quality for current and future CECS enrollments. For example, at the researchers' institution, undergraduate CECS enrollment has increased by 37.4% from 5,375 in Fall 2010 to 7,383 in Fall 2014, with further similar increases anticipated for the foreseeable future. Such increases in enrollments significantly add to the

assignment preparation, administration, and grading tasks of all faculty and course GTAs. Thus, a high quality approach is sought to manage the Formative/Summative Testing or Evaluation activities, and re-focus faculty and GTA tasks 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, allowing for all evaluation components to be conducted in the EPC by any interested faculty. However, due to the creative design nature of engineering curricula, a discipline-specific approach is required.

There are 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, the EPC faculty have developed novel approaches to design problems with partial credit that are isomorphic to skill assessments using conventional pencil-and-paper based exams, but deliverable electronically.

3.2 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 student's 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 ECE GTAs. Engaging the students with scaffolding instruction targeted at the learners' ZPD and providing them with the targeted and structured assistance and guidance will aid them in achieving specific tasks or acquiring requisite skills. After receiving guidance, GTAs will gradually disengage from the process, allowing students to complete activities on their own, which is a primary objective of the EPC. The goal is to allow students the opportunity to review their evaluations in a self-paced format, or with the guidance of accessible CECS GTAs, in an effort to develop a more comprehensive understanding of the material, while also gaining a deep confidence in their technical skills.

### 3.3 EPICS Operational Concept

The proposed learning process for EPICS is shown in Figure 1. First, students complete computer-based evaluations 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 onsite GTAs, who can provide structured, targeted content tutoring based on these reviews, targeted at the learners' ZPD. This scaffolded instruction provides appropriate assistance and guidance to the students to assist them in achieving specific tasks or acquiring requisite skills. 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.

3.3.1 Benefits to Students

From the evaluation point of view, the EPC Services (see Table 2) improves the accuracy of evaluation, flexibility of scheduling, and more rapid grading responses. Use of online assessments to support enrollments and/or increasing learning quality has been well-cited in the literature. A recent article by Angus and Watson (2009) evaluated the extent to which online formative assessments improve learning outcomes and based on 1500 observation points determined that such provision "robustly leads to higher student learning" [12]. Likewise, online quiz results have been documented to exhibit a higher degree of correlation with overall course grades than do unsupervised laboratory and homework assignments [13]. Documented studies of the benefit of adding frequent online evaluation at the college-level indicated a year-over-year summative evaluation increase from 78% to 86% in the case-study of a single course [14]. Other experiences with online evaluation centers at our college have been documented as positive, with continued increases in capacity as indicators of success, and as a model for other universities [15].

From the proficiency point of view, students are obligated to review their exam mistakes with an on-site tutor. Anecdotal evidence has shown that this increases the students' engagement and interaction in group discussions because they explain the method with which they arrived at an answer as well as why the solution makes sense to them. Accordingly, this process not only challenges the creativity of students, but also improves 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 on-site tutor does not facilitate concept attainment at the necessary level, or does not meet the student's expectations, he/she can meet with his/her instructor for additional clarification and discussion. Feedback from multiple instructors is that student's engagement is increased by demonstrating their understanding without the use of aids, which several instructors provide a single equation/reference sheet and close-book format. Additionally, instructor responses indicated that students are encouraged to understand the material instead of just Googling the answer or submitting homework solutions obtained from the solution manual, or previous offerings of the course.
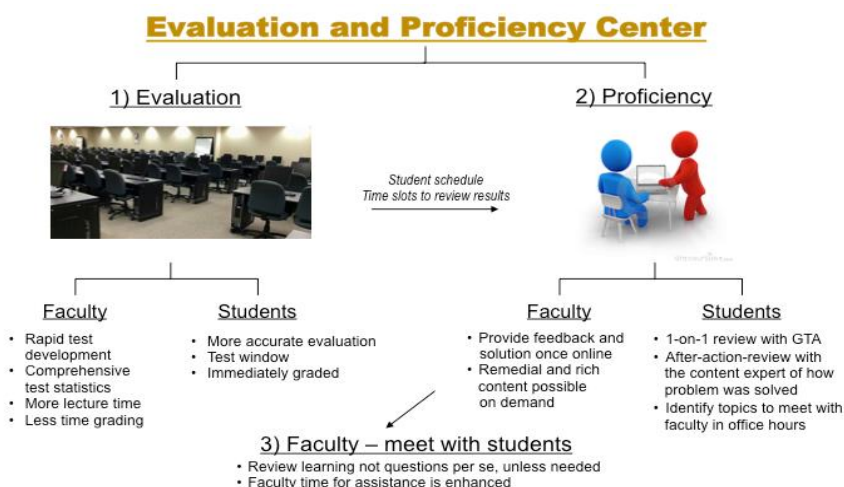
Figure 1. EPC Interaction Model for Skills Development.

3.3.2 Benefits to Faculty

From the evaluation point of view, benefits of electronic assessment include the ability to handle higher capacity courses for increased degree production, more detailed/accurate/precise rubrics, more lecture/discussion time, less time for grading, and statistics for learner responses to identify class-wide learning deficiencies, as shown below in Figure 2. Recently, Internet search engines have reduced the integrity and diminished the

Table 2. 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.
	Grade 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.

effectiveness of homework problem sets by allowing students to more easily search for answers to similar, or sometimes the same, homework problems. This issue has been noted as a significant and growing problem impacting student retention and mastery of the material. The EPICS addresses this concern and improves learning quality in this regard by moving away from the mindset of "just looking for the answer" to being required to solve problems without having reference materials present. Research [16] found that using computer-based testing can address this problem, and that students' essential skills can be improved when more regularly assessed by computer-based evaluation. This is particularly useful for provisioning remedial exercises, which can be otherwise prohibitive to administer, given limited class time. With the availability of an expanded EPC, more CECS faculty can use Evaluation, Tutoring, and even remedial services without increasing their grading load or sacrificing time spent on required topics in the course, which act to increase employability upon graduation.

Extending the proficiency point of view, the freed up time can assist the instructor in providing instance feedback and detailed solutions for questions with high rates of errors. In addition, the instructor can utilize additional time acquired through the EPICS pedagogy to improve the course contents and create extra modules to further explain problem solutions with enhanced details in an effort to improve students' understanding of content. Faculty also benefit from students speaking with a tutor before meeting with them to identify focus because simple things are taken care of. Plus, they had to talk to the GTA about it, which helps build soft skills. Also, faculty are provided automatic feedback statistics at the question level from Canvas to help identify problem areas amongst the class as a whole.
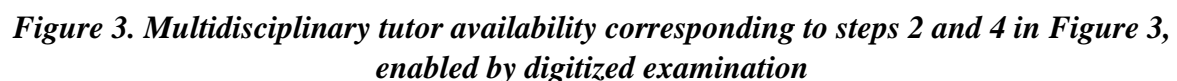
GTA training proceeds along two skill paths. One for assistants who are re-allocated from grading task to become Test Proctors and another group that is trained to become Tutors and/or Question Clone Composers. There is an orientation given by one or more instructors for Test Proctor training within our EPC facility that reviews procedures and protocols regarding the hours of operation, check in/out of learners, scratch paper policies, and prohibited materials. The Tutor/Clone Composer group watches a YouTube video that has been prepared specifically for increasing learning value of the question composition process. It emphasizes the following goals: technical topic coverage, formula identification, incremental calculation credit, and declarative statement identification.

4.0 EPICS Pedagogy

4.1 Operational Flow for Integrated Content, Evaluation, and Tutoring

Figure 2 shows the operation flow of EPICS, which is centered on a *study set* and *evaluation results* database that provides information exchange between the learner, GTAs, and faculty. The operational flow focuses on:

1) **Knowledge Acquisition**: The study sets are available in the Canvas LMS for students to learn at their own pace. The study sets include homework sets with instructor-prepared

Figure 2. EPC operation flow

Figure 3. Multidisciplinary tutor availability corresponding to steps 2 and 4 in Figure 3, enabled by digitized examination

detailed solutions, provided as an alternative to conventional homework. The contents of a well-organized study set are divided to two parts: *1) challenge questions* and *2) open solutions*. An example of *challenge questions* and *open solutions* in the study set are shown in Figure 4 and Figure 5, respectively.

2) **Open Tutoring**: In order to clarify the questions, students can review questions with tutors.

3) **Taking a Quiz in EPC**: Learners schedule appointments for formative assessment at a time convenient for them during the week following Knowledge Acquisition and Open Tutoring. The EPC is equipped with the latest technology, including IP restrictions, camera/phone checks, and lockdown browsers to prevent cheating/Googling solutions.

4) **Grade Clarification with Tutors**: Learners are obligated to go to the EPC to review their Exams to learn from any mistakes, prior to the following week's in-person individual meeting with a Content Tutor GTA. This means that common mistakes are handled immediately without emails/office hours, which often consumes 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 process of gradebook updating. The evaluation submissions are viewable only in EPC for two reasons: *1) reduced cheating/propagation, 2) observing increased student engagement.* The primary pedagogical benefit, though, is that students can review their concerns early during a prescribed rebuttal period, thus avoiding cramming immediately before exam. Solutions are also visible for self-paced review. Lastly, handwritten image files are retained, which strengthen the learner's soft skills through one-on-one clarification with Content Tutors or Instructor.

Figure 3 illustrates the potential of increased frequency of tutor-learner interactions in EPICS.

4.2 Study Set Contents

Given: Two computer systems: A and B. There is also a reference computer R.

Sought: Use the reference computer R to evaluate the two computer systems A and B under a benchmark suite that has the 3 workloads as listed below.

Workload Program of SPEC suite	Time (R) [seconds]	Time (A) [seconds]	Time (B) [seconds]
CPU	20	4	5
Memory	30	5	6
Graphics	12	3	4

Partial Credit 1:

Which equation best applies for a given workload:
a) SpecRatio(A) = Time(A) / Time(B)
b) SpecRatio(A) = Time(B) / Time(A)
c) SpecRatio(A) = Time(R) / Time(A)
d) SpecRatio(A) = Time(A) / Time(R)
e) SpecRatio(A) = Time(A)+Time(B)/Time(R)
f) SpecRatio(A) = Time(A)*Time(B)/Time(R)
g) SpecRatio(A) = Time(R) / [Time(A)+Time(B)]
h) SpecRatio(A) = Time(B) / [Time(A)+Time(R)]

Partial Credit 2:
What is the Graphics SpecRatio for System B?

Partial Credit 3:
What is the ratio of SPECscores for System A relative to System B?

Partial Credit 4:
Express Part 3 result as a declarative statement to explain the relative performance in a skype teleconference with your client.

Figure 4. Challenge question in Study Set

Solution 1: SpecRatio(A) = Time(R) / Time(A) 💡 *[Time R]/[Time A]*

Solution 2: SpecRatio(B_Graphics) =
Time(R_Braphics) / Time(A_Graphics)
= 12/4 = 3 as unitless ratio

Solution 3:

Workload Program of SPEC suite	Time (R) [seconds]	Time (A) [seconds]	SPECRatio(A) [unitless]	Time (B) [seconds]	SPECRatio(B) [unitless]
CPU	20	4	5	5	4
Memory	30	5	6	6	5
Graphics	12	3	4	4	3

Solution 4:

$$SPECscore = \sqrt[n]{\prod_{i=1}^{n} SPECratio(i)}$$

SPECscoreA = $(5*6*4)^{1/3}$ = 4.92 —— *"System A is roughly 5 times faster than the reference system for these 3 benchmark programs."*

SPECscoreB = $(4*5*3)^{1/3}$ = 3.9

ScoreA / ScoreB = 4.92 / 3.9 = 1.26 —— *"System A is roughly 1.26-fold faster than System B for these 3 benchmark programs."*

"System A is roughly 26% faster than System B for these 3 benchmark programs."

Figure 5. Open solutions in Study Set

An understandable challenge question explicitly states Givens and Sought using concise terminology, while the important parts of the question are highlighted through a colored bounding box. A comprehensive open solution uses Declarative Statements using "red text" to increase the student retention and soft skills. These study set are designed one-at-a-time by the course instructor, and repeatedly used by students each semester. This allows the instructor to assist more students through acquired time, rather than spending time re-designing the homework/quiz/exam items.
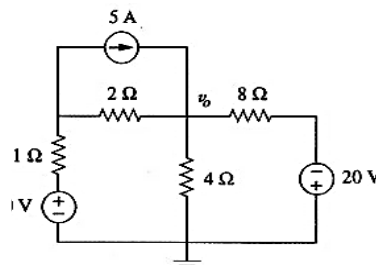
4.3 Digitizing STEM Assessment

Table 3 compares different question types delivered through either conventional, Scantron, or EPICS methods. EPICS benefits students by improving conventional soft skills while considering new technological aids that can facilitate student assessment and advancement in engineering *Creativity, Design, and Soft (CDS)* skills, which is vital for career success. It has been reported in a recent study [17] that the efficacy of traditional vehicles, such as homework

Table 3. The comparison between the benefits offered by EPIC and other methods

	Credit for Concept / Formula	Design Code from Scratch	Multiple Answer (auto partial credit)	Matching / Multiple Dropdowns	Credit for Conceptual Understanding	Complete missing code	Individualized Values for Fairness	Numerical Answer	Partial Credit for Stepwise Questions
Conventional	+	+		+ / -	+			+	+
Scantron				+ / -	+	+			
EPIC	+	+	+	+ / +	+	+	+	+	+

assignments, lab reports, and reused exams have become thoroughly undermined by Internet-based solution repositories. Thus, an innovation in utilizing existing technology for improving the students' soft skills are needed to recast the exhaustive 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 course content/learning outcome and GTA time for tutoring and clone composing. The following question types available within Canvas are utilized in creative ways to meet the CDS skill needs of engineering assessments.

Figure 6. "Multiple answer" question format

Multiple Answer:

Figure 6 illustrates a Multiple Answer (MA) format question, which provides the student with a question, an optional figure, and a number of potential answers. Within these answers we can embed conceptual questions, as well as calculation questions and declarative statements. MA questions are automatically graded with partial credit awarded for correct answers chosen, so students are able to receive a portion of credit relative to their understanding of the problem.

Multiple Fill-in-the-Blank:

Figure 7 shows a Multiple Fill-in-the-Blank (MFB) format question, which allows faculty to disperse up to 10 different answers throughout the question, which are automatically assessed utilizing partial credit. MFB questions can mimic and replace lengthy paper-based design-type questions with many steps by breaking the question into the constituent concepts being assessed. Providing many answer choices for each blank delineated by a letter, akin to multiple-choice questions, and then indicating for the student to only answer with the letter corresponding to their choice allows MFB questions to become multiple-part and automatic-partial-credit questions with the flexibility to replace any paper-based engineering design question.

Multiple Drop-Down:

In order to test the creativity of students, we can utilize the Multiple Drop-Down (MD) question type, as shown in Figure 8. The MD format is effective for asking design-type questions where a design template, such as a couple lines of program code, is familiar to the learners. Students are asked to choose the correct drop-down values amongst multiple correct-by-format designs, with only one correct-by-functionality design. In other words, the student must choose the correct drop-downs in order to realize the functionality required in the question. Accordingly, the statistics provided to the instructor can help him/her recognize specific course concepts that need additional clarification.

Figure 7. Multiple fill in the blank format questions.

Clone Development:

In order to reduce the possibility of cheating, the flow presented in Figure 9 is utilized. First, a faculty member generates a question template that encapsulates all appropriate concepts and materials, which is desired to be assessed. For the example illustrated in Figure 9, the instructor
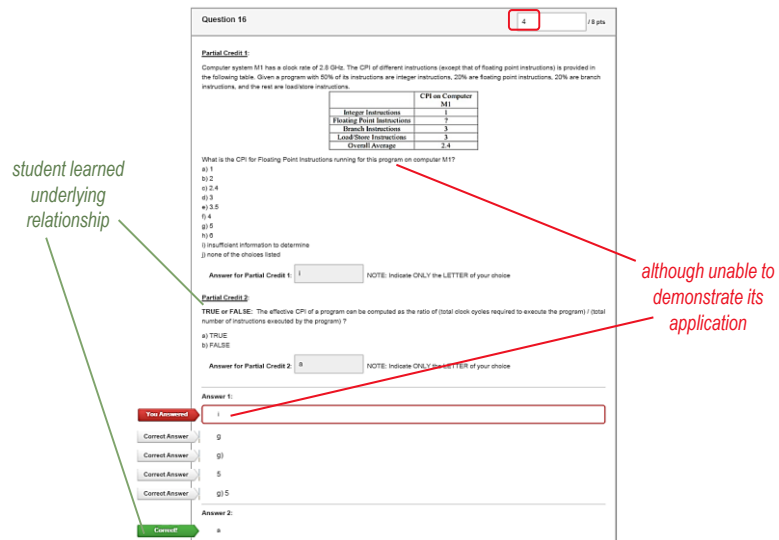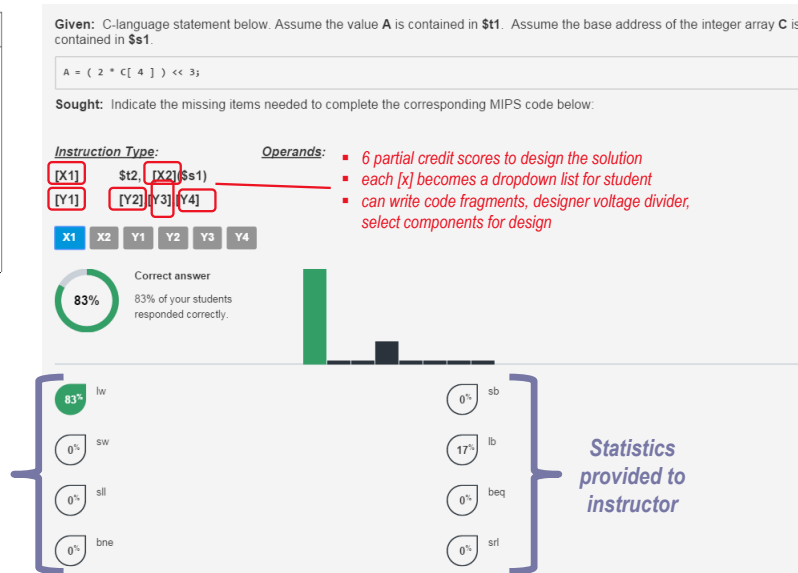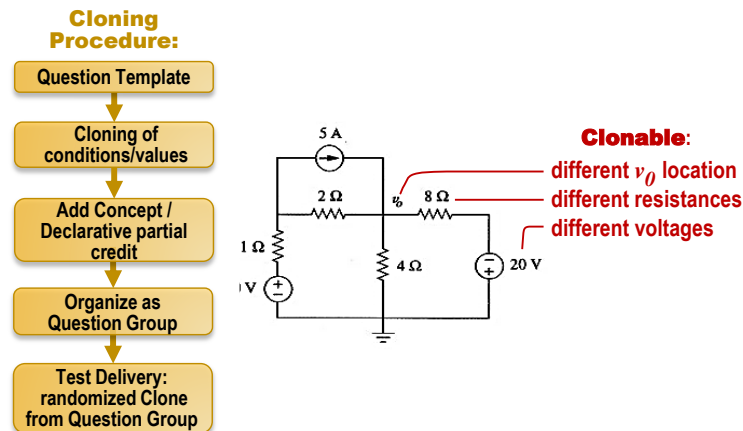

Figure 8. Multiple Dropdowns format questions showing statistics

Figure 9. Question cloning procedure by forming question groups.

of Electrical Networks desires to assess student understanding of electrical nodes, circuits, and soft-skills, by including both correct and incorrect declarative statements. Next, different clones are produced by changing the elements of the question; for instance, changing given parameters, such as voltages and resistances, or whatever information is 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 we are testing each student on the same concepts, and there is no use for them to share answers, due to the significantly reduced chance of students receiving duplicate questions.

In addition to the computer-based assessment tools that EPICS creatively utilizes, faculty are able to work in a familiar Microsoft Word environment to develop their questions. By using the Respondus exam authoring tool, properly formatted Microsoft Word files can be converted and uploaded into 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.

Over past year, four engineering courses have been revised to benefit from the facilities provided by EPICS methodology and another engineering course's materials are currently in the planning phase of being modified.

5.0 Pilot Delivery and Results

5.1 Selection of Courses for Implementing EPICS

In order to maximize the benefits offered by EPC, it was first necessary to identify the most suitable courses for which the process would be most effectively integrated into the curricula. To do this, an examination of exam delivery methods, compatibility with EPICS, and other factors (see Table 4) was conducted. Constituent courses within the electrical and computer engineering degree program were identified as exhibiting various characteristics that may impact their amenability for digitized assessment. For example, *Computer Organization* emphasizes concept identification, stepwise solutions, and other readily computerizable question formats listed

previously in Table 3. On the other hand, courses with significant complex math derivations and free-hand design drawing face digitization challenges, which are beyond the scope of this work. For example, undergraduate *Electromagnetic Fields*, which emphasizes Maxwell's equations and 3-dimensional fields, would not be an optimal fit for the EPICS methodology. Additionally, the Networks and Systems course was initially modularized for computer-based assessment, but preliminary results indicated sufficient design challenges.

Using Scantron is most appropriate for simple Multiple Answer type questions, in which each student has to choose the right answer between several choices on his/her Scantron sheet. This sheet will be later fed to auto-grade machine for grading. This does not allow for a comprehensive assessment of student creativity and critical thinking, and in some cases, the student can get credit by guessing the right answer. On the other hand, EPICS enhances engineering's student creativity, depth learning, and critical thinking by rapid feedback of engineering analysis, design, and concepts, allowing adaptation for learners across modules and courses.

Over the past few semesters, four courses have been delivered in EPC. The students enrolled in the courses offered with the EPICS concept earned higher final grades, predominantly due to effectiveness of computer-based examinations in combination with targeted and scaffolded GTA concept review. The comparison results between the progress of students in Conventional and EPICS pedagogy are reported in Section 5.3.

5.2 EPC Facilities

The Evaluation and Proficiency Center is an ECE learning facility dedicated to success in coursework and advancement of career skills. It focuses on self-paced and instructor-assisted exam review and skill development. Its facilities are available to students enrolled in courses

Table 4. The delivered coursed in conventional and EPIC

Fundamental Engr Course	Course Title	Hand-written exam	Scantron	Compatible to use EPIC for delivery	Currently delivered using EPIC	Approx. number of enrolled students	Approx. num. of tests delivered	Attributes
EEE3342C	Digital Systems	x		x	x	70	280	Effective tutoring
EGN3211	Eng Analysis & Computation			x	x	490	3430	Effective tutoring
EEL3004C	Electrical Networks	x		x	x	210	1050	Quizzes only /No exams
EEL3801C	Computer Organization			x	x	210	1470	effective tutoring / review session
EGN3321	Dynamics	x	x	x				
EEL3123C	Networks and Systems	x		x				
EEE3350	Semiconductor Devices	x	x	x				
EEL3470	Electromagnetic Fields	x						
EEL4742C	Embedded Systems		x					
EEL4781	Computer Comm Networks			x				

with online evaluation components. Students can conduct self-paced review during business hours as well as make appointments for reserving a seat. GTA appointments are also available for review of course materials, removing technical doubts, and resolving grading concerns. The following equipment is available in this facility, specifically for the purposes of conducting the proposed project:

- 30 Dell PCs for tutoring and evaluation
- 1 high-end front desk PC for check-in and monitoring
- Internally-developed web appointment portal with computer assignment
- Netsupport software for 30 PCs
- Respondus LockDown Browser for secure quiz delivery
- Safe Exam Browser for secure tutoring review
- 3M Black Privacy Filters for each PC

5.3 Learning Benefits Results

In order to evaluate the effectiveness of computer-based examinations combined with GTA assisted review, we compared the evaluation results of two nearly identical sections of *EGN 3211: Engineering Analysis and Computation in Spring 2015* (Figures 10, 11, and 12). 67 students were enrolled in section. One section used Scantron-based evaluations, dubbed "Conventional", while the other section used computer-based evaluation with GTA assisted review, dubbed "EPC". Both sections were taught the same material from the same lecturer and their evaluations had the exact same questions. It was the purpose of initial implementation of the EPICS pedagogy to determine if any measureable quantitative and qualitative improvements to student learning were realized through examinations utilizing the EPC resources. These measurements were in addition to benefits of re-focusing the instructor and GTA workload, including reduced class time spent on remediation, more efficient use of GTA time, and instructor time saved through the utilization of auto-graded computer-based evaluations that students can be scheduled and conducted outside of the classroom.

In order to compare the efficiency of EPC resources with conventional instruction, similar quizzes were spread among students of both sections. Figure 10 illustrates the results of this comparison, which can be summarized as follows:

- A total of 5 quizzes were conducted for both sections
- An average of 10.4% improvement in quiz grades for EPC online evaluation
- An average of 39.4% reduction in F's for EPC online evaluation

In total, nine students missed their quizzes and received scores of zero in the conventional style, while this number was reduced to five students in the online evaluation, primarily because of an increased window of time to take the quiz.

The Exam 1 plot in Figure 11 illustrates the first exam results for both sections. Clearly, the first exam does not completely reflect the efficiency of the online evaluation method, as the window of time from the beginning of the semester and first exam is short. Yet, upon closer examination, it is evident that more students received a B grade in the online section, which can be the result of face-to-face instruction and exam preparation by GTAs. As shown in Figure 11, the total number of students who ended up with an A grade in Exam 2 using EPC facilities is significantly

more than those in the conventional section. Our intuitive reason for this gap is that students who had the opportunity to utilize EPC facilities did so, and were, consequently, more prepared for taking the exam, when compared to conventional students. In addition, fewer students failed or received a D grade in the EPC course, which endorses the beneficence of the online evaluation method and the associated EPICS pedagogy.

Finally, in comparing grades from Quiz 5 (Figure 10), which afforded appropriate time for students, GTAs, and faculty to fully implement and adapt to the EPICS pedagogy, while there is a small increase in the percentage of D grades, F grades decreased significantly, and A and B grades increased a total of 18%. Figure 12 shows the overall course grade distributions. The gains from EPC are evident in the significant increase in A and B grades, combined with the decrease in C, D, and F grades.

Figure 13 illustrates the bi-weekly quiz feedback that faculty received from the EPC. This feedback facilitates faculty identification of quiz validity, clarity, as well as student comprehension of course content. Figure 13(a) provides the distribution of time used by students for taking quiz 1 in the course *Computer Organization*. While 50 minutes were allowed for the quiz, all students completed the quiz within 28 minutes on average. This demonstrates that the number of questions and question difficulty were fair to the class cohort.

Additionally, Figure 13(b) indicates the distribution of quiz scores, which also has a normal bell-shaped curve. The normal bell-shaped distribution illustrates the validity of the digitized exams through a fine resolution of discernment and learning comprehension. Further, instructors
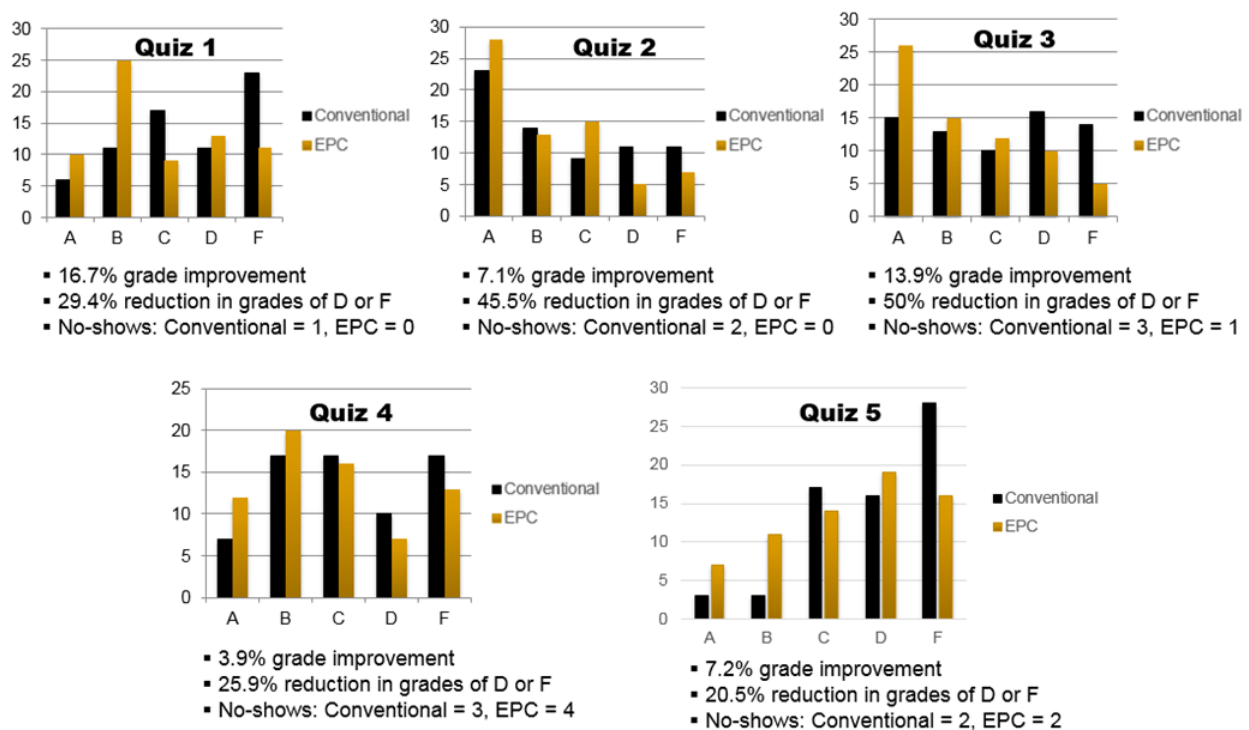
Figure 10. The quiz results comparison between using EPC resources and conventional style
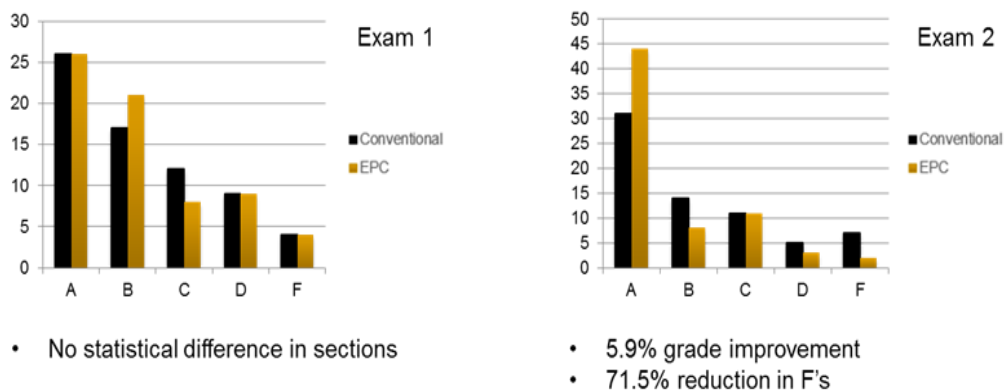
Figure 11. The exam results comparison between using EPC resources and conventional style
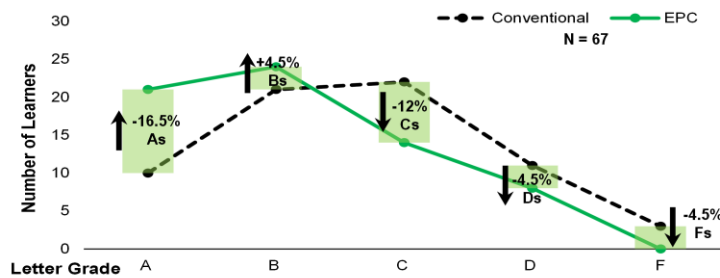
Figure 12. EPC improvement over Conventional Delivery for EGN3211
Course Grades Spring 2015.

received detailed statistics for each question, which can help them identify specific content misconceptions, which can be addressed in future class interactions. For example, Figure 13(c) shows the distribution of answers to question 1 of quiz 1, with incorrect responses colored red.

While the majority of students selected the correct answer, shown in green, a significant number of students incorrectly selected the choice *b*. Thus, the instructor has data-based evidence that additional instruction related to responses *a* and *b* should be addressed in class, prior to moving to the next course topic. A satisfaction survey related to student perceptions of the effectiveness of EPC was also disseminated to students.

Figure 14 shows results of all 21 respondents among the 67 students who were enrolled. The majority agreed or strongly agreed that the EPC-based interventions applied were beneficial for their learning. In addition to the results illustrated in Figure 14, the majority of respondents indicated: i) the availability of EPC increased their understanding of the concepts (60% agree or strongly agree), ii) flexible exam scheduling offered valuable convenience compared to in-class testing (93% agree or strongly agree), and iii) GTA guided and self-paced access to exam results

|(a)|(b)|(c)|
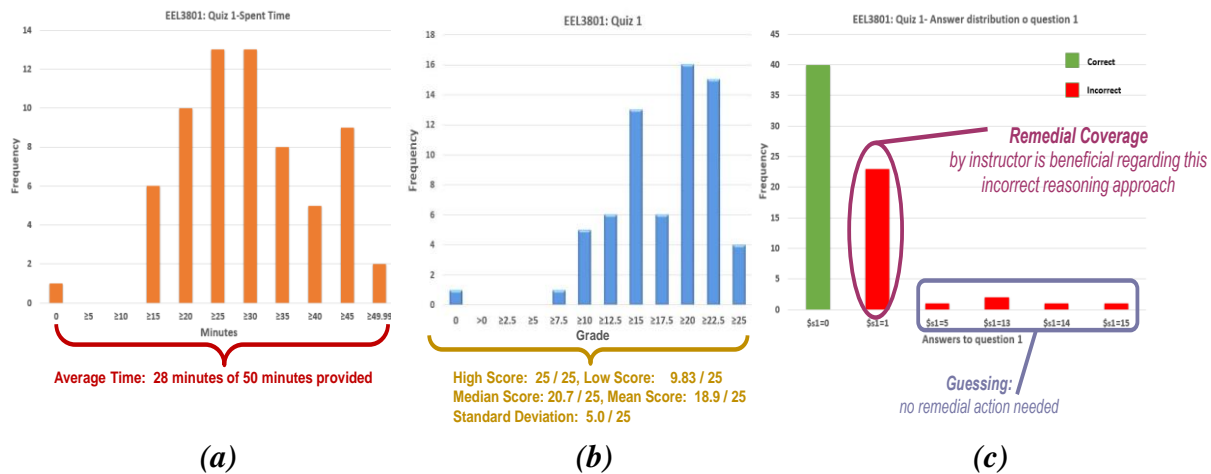
Figure 13. EPC bi-weekly quiz feedback indicating to Instructor precisely which content to address the next class session

(a)   (b)   (c)   (d)
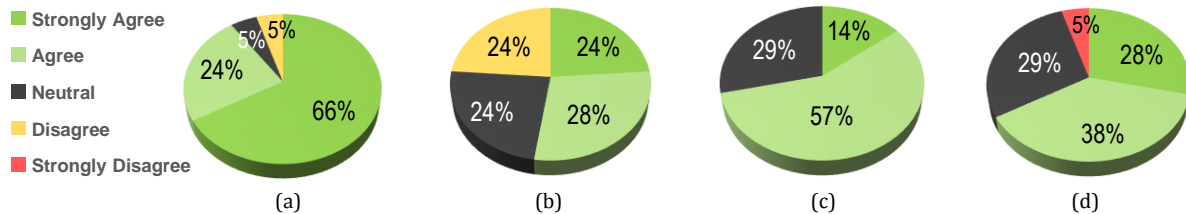
Figure 14: (a) Study Sets followed by com puterized assessment are more effective for learning than Homework.
(b) In this course, computerized questions were adequate to evaluate engineering design skills.
(c) Graduate assistant guided access to quiz results enhanced my comprehension of material.
(d) The use of a testing center provided an adequate testing environment compared to in-class exams.

enhanced their comprehension of material (66% agree or strongly agree). These preliminary results were particularly encouraging, as 59% or respondents did not use the EPC for test review, tutoring, or project assistance, potentially explaining the high "neutral" responses in survey questions related to test review, tutoring, or project assistance.

Conclusions

The goal of this research was to integrate computerized testing with self-paced and GTA-assisted tutoring in an innovative format. 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.

The EPICS 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 EPICS pedagogy, the burdens alleviated increase time available to better assist students in STEM-specific demands of design skill development and abstract reasoning. Technological

interventions utilizing auto-grading of original evaluations and rapid feedback on performance of the results are utilized. The effect of this educational approach applied to the environment of undergraduate engineering students and scholars will contribute to the knowledge base of undergraduate STEM education and will advance the quality of STEM education. In a conclusion, the following are some of the key benefits of the EPICS pedagogy:

1) *Creating 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 to evaluate each student's unaided comprehension incrementally and then respond with one or more layers of tutoring.

2) *Creating innovative formats for engineering design and analysis questions* based on collaborations of STEM subject matter experts in Electrical & Computer Engineering, and Instructional Design & Technology. This addresses the need to accommodate STEM-specific needs for design skills, analytical perception, creativity, and critical thinking.

3) *Support increasing class sizes and MOOCs* while maintaining learning quality. EPICS achieves this using a time-economical and quick auto grading technique while providing sophisticated performance analysis for both individuals and the classroom as a whole.

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