Matrix-organized instructional delivery for scaling-up problem-based learning through reallocation of instructional support

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Abstract

Instructional technologies can assist with large enrollments in engineering degree programs by enabling new allocations of limited instructor resources. One upcoming instructional technology which has been effective within disciplines outside of engineering has been Computer-Based Assessment (CBA), which eliminates grading and simplifies the logistic burdens of exam delivery. Based on results of pilot projects in CBA and Problem-Based Learning (PBL) within an engineering laboratory, a hybrid approach has been developed for a large enrollment upper-division mechanical engineering course. Specifically, a matrix-based staffing and instructional model is proposed herein to leverage CBA-enabled reductions in grading burdens. It is illustrated within the undergraduate core course *EML4142: Heat Transfer I* with enrollment of 200-300 students per semester, which realizes on-demand teaching of PBL activities in the laboratory session combined with remediation during post-test review.

Keywords: Matrix Instruction, Computer-based Assessment, Any Time Laboratory, Course Staff

Introduction and Foundational Works

This paper presents a matrix-organized staffing approach for interweaving problem-based learning and computer-based assignments into a robust edification fabric for undergraduate STEM instruction. A semester-long project was utilized to foster high-impact integrative learning experiences through a series of biweekly tasks outside of the classroom. It employed an *Any Time Laboratory (ATL)* concept to enable students to perform experiments on a walk-in basis to accommodate otherwise problematic scheduling demands. The significant instructional support required for lab guidance and lab report grading was achieved by reallocating GTA workloads by adopting CBA-delivered formative and summative assessments [1-4]. To extend scalability to larger enrollments, it is seen that ATL can be synergistic with CBA to increase teaching capacity. A semester-long project that consisted of multiple labs were developed in the Heat Transfer course where students solving a real-world problem with their group members and keep advancing their methods as the semester proceeded. The labs were synchronized to the topics delivered during lecture sessions. Their experiential learning activities helped to integrate traditionally separate subjects so that students can grasp a more authentic understanding and enhance their critical thinking, practical thinking, and creative thinking abilities while promoting teamwork skills.

To achieve these goals, a pedagogy of problem-based learning (PBL) enabled by CBA was developed. It had been piloted in a large-enrollment upper division mechanical engineering course *EML4142: Heat Transfer I* offered at the University of Central Florida (UCF) during the summer 2017 semester. Traditionally, this course only encompassed face-to-face lectures. Based on historical evidence, students had struggled with understanding the more complex theoretical bases underling key learning outcomes of 1D conduction, fin analysis, transient analysis and forced convection. These challenges appeared to be exacerbated due to the lack of opportunities to apply them in real world settings. Thus, students remained unable to relate the theoretical knowledge gained in lectures to most practical platforms.

To address this issue, the authors first conducted an anonymous survey of the learners, including "How would you help improve the course within a budget of five thousand dollars?" One of the most frequent responses was to "provide hands-on labs." An 80%-85% response asserted engineering students' desires for hands-on activities. Engineering students are often tactile learners, and with respect to career readiness, the importance of real-world practice cannot be understated. The challenge lies in its implementation, i.e. how to incorporate labs into a course serving hundreds of students yet has limited personnel support? The approach herein answers that question within the constraints of restricted lab space while avoiding scheduling complexities by developing a *matrix-based instructional model*. Matrix-based staffing has been validated in a wide range of settings, including higher education. For instance, Crow and Dabars [5] identifies the option and potential complexities of a matrix approach for instructional staff utilized at Arizona State University spanning the development of new curricula and inclusion of research roles. Fret et al. [6] stated that the matrix organizational structure was utilized by a university project for cross-functional personnel management in the Learning Environment Adaptability Project (LEAP). Although this matrix approach with a university setting was primary focused on administrative personnel, faculty, and support staff, herein we focus on extending matrix staffing to instructor and graduate assistant roles using an innovative mapping approach supported by instructional technologies.

Pedagogy and Research Methodology

Figure 1 illustrates the matrix-organized instructional mode pioneered within this course that intervenes experiential learning, in-class lecture delivery and computer-based assignment to realize on-demand guidance of PBL activities in the laboratory session combined with remediation during post-test review. Problem-based learning was implemented by a semester-long project that was carried out as a series of biweekly labs depicted as *L1*, *L2* ... *Lp* in Figure 1. The labs were crafted to be concurrent with the topic delivered in regular lectures denoted as *C1*, *C2*…*Cm*. The corresponding subjects were then evaluated digitally via CBAs designated by *A1*, *A2*…*An*.

To sustain a matrix organization, foundational knowledge was first covered in regular lectures in traditional face-to-face modes, where students were introduced to the definitions and mechanisms of the underlying concepts. These were followed by their application in

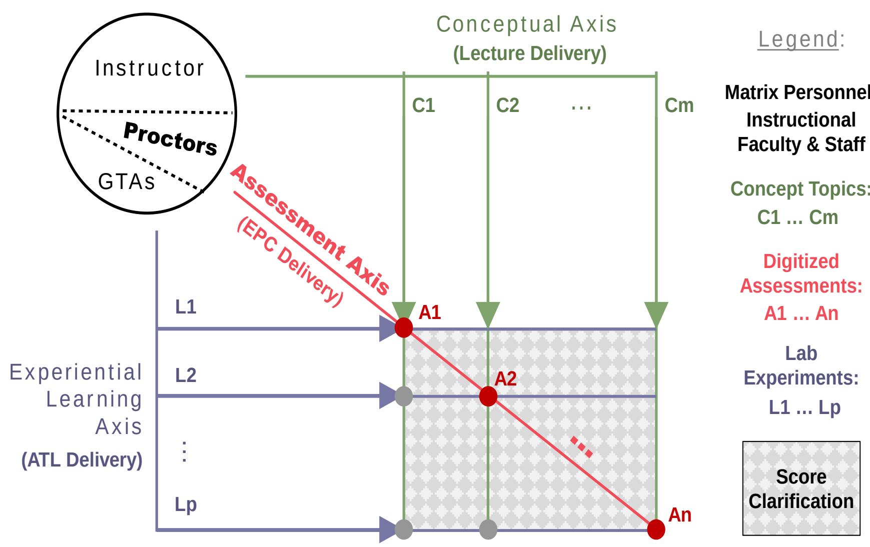

Figure 1. Matrix-organized instructional delivery within EML4142.

derivations and meaning of laws and equations. Students were then assigned to design and conduct experiments in the laboratory that utilized the theory they had recently learnt and subsequently composed formal technical reports to present their results, approaches and evaluations. To accommodate otherwise troublesome scheduling and logistic difficulties, an ATL approach was pioneered that allowed students to access GTA-assisted labs on a walk-in basis, which was essential to the success of PBL activities in a large enrollment course. All quizzes and midterm exams were delivered in a designated proctored testing center called the Evaluation and Proficiency Center (EPC) serving the College of Engineering and Computer Science at UCF, which had eliminated grading and greatly streamlined logistics [1]. The harvested GTA time by auto-grading was reallocated to higher-gain tasks such as lab guidance and lab report grading significantly required by PBL [2].

Problem-Based Learning in Undergraduate Engineering Courses

Table 1 lists the content and schedules of the PBL activities, lecture delivery and CBA in detail. The three delivery approaches complemented each other and formed an interwoven matrix structure. Assessments consisted of five bi-weekly labs in the summer term and covered approximately 80% of the course learning outcomes. Each lab contained basic tasks that were well-defined that students carried out as given, and open-ended tasks wherein students must make explorations and decisions. The open-ended tasks were expected to promote critical thinking. The project also incorporated design work to encourage creativity. Additionally, the project promoted collaborative learning as students worked in groups of five classmates each, wherein they collaborated to solve problems by applying their collective knowledge and skills.

For example, the topic of transient heat conduct in Chapter 4 was first covered during lectures around weeks 6 or 7, where students studied the theoretical criteria for lumped system analysis and the equation to determine the relation between temperature and time if lumped system assumption was satisfied. Accordingly, with Lab 4 of the project, students were assigned to design and conduct an experiment that implemented lumped system analysis in weeks 7-8. Prior to labs, they brainstormed with their group members to select and prepare a specimen that met the criteria for a lumped system, and created experimental plan. Then they brought the specimen, e.g. a potato, to the lab, placed it in a heating or cooling process created in the lab, and recorded actual temperature variation using a data acquisition module. In the lab report, students compared the measured temperature variation over time to the theoretical temperature profile calculated using equations. They were required to make assumptions, select equations, obtain results, and evaluate their findings, all of which acted to complement a classroom experience.

In another example, the topic of forced convection was lectured in class around weeks 8-9, students learnt various empirical correlations to determine heat transfer coefficient for forced convection. In the lab, they created a flow using a blower provided to circulate through their specimen, which is a heat sink composed of multiple fins. In the lab they measured various parameters such as air velocity, temperature, pressure, which would be used to carry out analysis and determine convection coefficient. Earlier in the semester, they also evaluated convection coefficient in Labs 2-4 based on the foundational knowledge gained in lecture. As the semester proceeded, they continued to incorporate the new knowledge which they had acquired through the project, thus advancing their practice and skills in using problem-solving methods.

Table 1: Matrix-organized instructional delivery schedule

Weeks	ATL Delivery	Lecture Delivery	EPC Delivery
1	Lab 0: Motivation and Team forming	Chapter 1 Introduction and Basic concepts	
2-3	Lab 1: Project Preparation-Making thermocouples & Attaching thermocouples	Chapter 2 Heat Conduction Equation	Quiz 1
4-5	Lab 2: Design and conduct an experiment that implements heat conduction equation emphasizing Fourier's law and Newton's law of cooling using given heat sink as a specimen	Chapter 3 Steady Heat Conduction	Midterm 1
6-7	Lab 3: Design and conduct an experiment that implements steady heat conduction emphasizing fin analysis using given heat sink as a specimen	Chapter 4 Transient Heat Conduction	Quiz 2
8-9	Lab 4: Design and conduct an experiment that implements transient analysis emphasizing lumped system analysis using a specimen of yours choose	Chapter 7-8 External/Internal Forced Convection	Midterm 2
10-11	Lab 5: Design and conduct an experiment that implements internal/external forced convection emphasizing the usage of empirical correlations using given heat sink as a specimen		Quiz 3
12	Final Report and Survey		Quiz 4
			Final exam

Utilizing Computer-Based Assessment (CBA) to Untether the Instructional Staff

The significant instructional support required by the project was achieved by integrating CBA. Figure 2 shows a sample question assessing student understanding of a basic concept. Formative quizzes and mid-terms examinations were delivered in a proctored computer-based testing center with Internet Protocol (IP) restrictions and lockdown browsers to ensure test integrity and security. CBA streamlines the logistical overheads of exam delivery, while eliminating the time-consuming manual grading and gradebook entry tasks which do not advance student learning on their own accord. The harvested GTA-time by auto-grading enabled the Any Time Laboratory approach, which accommodate otherwise problematic scheduling issues of limited laboratory resources especially for large-enrollment classes.

Student Perceptions of Matrix-Driven Instruction

Five anonymous surveys were administered during the semester of the pilot projects in CBA and PBL to gather student feedback on both aspects. In post-course survey, 91% of respondents indicated that the project enhanced their learning of fundamental concepts. Overall, 88% Agreed or Strongly Agreed that the project improved their hands-on ability on heat transfer experimentation. Additionally,75%-91% suggested the project was moderately challenging or extremely challenging depending on the labs. 79% Agree or Strongly Agree that the lab fostered deep learning that led to long-term retention in contrast to a pure lecture-based environment. Meanwhile, 68%, 71% and 58% Agreed or Strongly Agreed that the project had improved their critical thinking ability, practical thinking ability and creative thinking ability, respectively.

About 68% Agreed or Strongly Agreed that working with group members had stimulated their thinking. Finally, 78% Agreed or Strongly Agreed that they had the opportunity to apply the information provided by group members to solve new problems.

Regarding CBA, the pre- and post-survey methods revealed positive shifts in perception towards computer-based assessment. For example, 59% and 71% Strongly Agreed or Agreed that CBA increased availability of assistance compared to an instructor's traditional office hours in the pre- and post-survey, respectively. At the start of the semester 38% of students were favorable towards statement that EPC tests are reasonably fair, i.e. phrased clearly, covered material in course, adequate time allowed, which increased to 73% in the post-survey. With statement that regarding granting partial credit, computerized questions using step-wise incremental question formats together with scratch paper for an opportunity for score clarification were effective. Perceptions trended positively from just 29% initially up to 60% (17% neutral) per the post survey. As an extension to using CBA for lecture content alone, the integration of CBA within lab itself remains as an intriguing field of ongoing research [7-8].

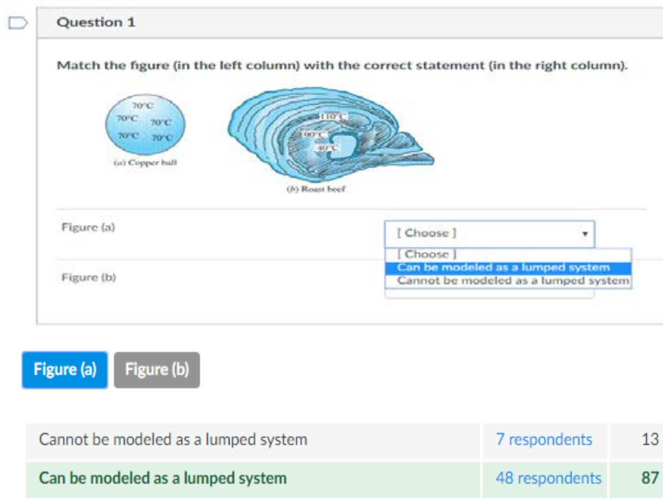

Figure 2. A sample question assessing the understanding of the criterial of lumped system analysis.

Conclusion

Matrix-based organization of instructional staff significantly aids in provision of the teaching support required in large laboratory projects. This can be achieved by reallocating grading workloads relieved by integrating computer-based assessment. Formative quizzes and midterm examinations were delivered in a proctored computer-based testing center with Internet Protocol (IP) restrictions and lockdown browsers to ensure test integrity and security. The CBA streamlines the logistical overheads of exam delivery, while eliminating the time-consuming manual grading and gradebook entry tasks which do not advance student learning on their own accord. Five surveys were administered during the semester of the pilot projects in CBA and PBL to gather student feedback on both aspects. In post-course surveys, 91% of respondents indicated that the project enhanced their learning of fundamental concepts. 79% Strongly Agree or Agree that the lab fosters deep learning that leads to long-term retention in contrast to a pure lecture-based environment. 77% Strongly Agree or Agree (20% Neutral) that availability of teaching assistants is a valuable resource to improving performance in this course.

This approach leverages matrix-organized staffing for scaling-up problem-based learning with large-enrollment upper division mechanical engineering courses. It can be effective for interweaving regular lecture delivery, problem-based learning, and computer-based assessments into a staffing strategy that complements and supports each component. Using GTA time harvested by auto-grading enabled by computer-based assessment, the innovated ATL approach can accommodate otherwise problematic scheduling issues of limited laboratory resources.

Overall, the student feedback regarding the underlying techniques of PBL and CBA, as collected by five anonymous surveys, was largely positive.

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