GLASS: Group Learning At Significant Scale via WiFi-Enabled Learner Design Teams in an ECE Flipped Classroom

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Abstract

The *Group Learning At Significant Scale (GLASS)* approach is developed to increase the scalability and efficacy of student design teams during group sessions of a Flipped Classroom (FC), as well as conventional modality courses. GLASS utilizes freely-available collaboration tools to facilitate instructional delivery, assessment, and review of teams that leverage campus WiFi connectivity, along with a pedagogical approach using excerpts from actual data sheets and open Internet resources. This immersive collaborative design experience is interwoven on a weekly basis with the technical content provided via video during the preceding week. The instructor manages multiple design teams to conduct a weekly *Challenge Problem* during in-class time. First, students are randomized by the Learning Management System into small groups. Second, a challenge problem is provided, delivered via WiFi-enabled laptops, tablets, or smart phones, forming virtual design teams, regardless of where students are seated. Third, students utilize their WiFi enabled devices to discuss the challenge question via chatroom-style dialog channels alongside a solution whiteboard and/or figure drawing space, while utilizing open resources on the Internet to postulate a solution. Fourth, once the design team concurs that their results are complete, they submit their answers to the Learning Management System (LMS) for auto-grading and score-recording in the grade book. Credit is earned by correctly answering each designated question sub-part, which provides partial credit. Throughout the team design activity, the instructor monitors the assignment progress online in real-time, including windows for each design team showing a solution draft as it is constructed, and providing feedback via each group's designated chat channel. LMS statistics are available in real-time for the auto-graded answer of the first design team having a correct solution, dubbed the *Pioneer Group*, which receives a bonus after its group leader presents their solution to the class. GLASS was piloted within a FC-format ECE course titled *Computer Organization*, with an enrollment of 116 students, and also trialed within the courses *Software Engineering* and *Healthcare Systems Engineering*, having enrollments of 140 students each. Results indicate attainment of learning outcomes while making group sessions significantly more tractable for large enrollment courses and bringing useful insights to the instructor while learning is transpiring. Student perceptions indicated that 71%, 70.1%, and 60.3% of respondents agree or strongly agree that the GLASS tools/procedures were sufficiently easy to learn, that group sessions promoted useful interactions with classmates, and that the collaboration mechanisms enhanced abilities to solve engineering problems, respectively.

1.0 Introduction

1.1 Design team activities for learning outcomes, skills, and accreditation criteria

Mixed-mode, or blended, instructional delivery, which often utilizes a *Flipped Classroom (FC) approach,* shows promise in delivering improved learning outcomes, supporting flexibility to accommodate learners' pace, and increasing scalability to serve large enrollments [1, 2]. In an FC, the initial phase of knowledge acquisition can be delivered asynchronously through the viewing of video clips, the review of slides, the reading of written passages, and the use of other electronic resources, such as animations and self-quizzes. This capability for asynchronous delivery helps to facilitate learning at those times when the student is adequately prepared to acquire the material [3]. More significantly for technical curricula, it also frees in-class meeting time for reallocation to problem solving with guided remediation and the potential to engage collaborative learning via student design teams [4]. This paper addresses both of these mechanisms, through the facilitation of in-class student design teams via the integration of collaborative instructional technologies with problem-based learning activities.

This work is motivated by various theories of instruction and significant evidence that student design team activities offer valuable opportunities to engage learners in engineering material, especially with FCs. Foremost, the *Interactive, Constructive, Active, and Passive (ICAP)* hypothesis states that the transitioning of learners from passive to active to constructive to interactive participants, has been shown to demonstrate increases in student learning [5]. Thus, based on the asynchronous nature of the knowledge acquisition phase in FC modalities, the use of student design teams for creative problem solving fortifies learning with constructive and interactive components. Employing these distinct learning activities can espouse the benefits of active vs. passive environments, whereby interactive modes can increase learner engagement [5, 6]. Moreover, collaborative learning activities have been shown to deliver benefits of higher achievement, more confidence in learning, and increased critical thinking capabilities, while simultaneously elevating soft skills [7, 8]. Thus, the availability of viable approaches to integrating student design teams into in-class activities, such as GLASS proposed herein, offers several benefits for both FCs and conventional delivery modalities. Finally, the ability to function on multidisciplinary teams has been embraced as an accreditation criteria across engineering programs [9], albeit a skill that has previously been quite challenging to engage outside of a senior design course.

1.2 Challenges facing the use of design team activities during class sessions

Challenges of integrating design teams and problem-solving sessions into class sessions arise from logistical difficulties of scaling interactions with students up to the levels of typical enrollments, especially in engineering gateway courses. In the case of FC delivery, video delivery and Learning Management Systems (LMSs) assist with handling large enrollments. However, pedagogical and technological approaches are sought to surmount the logistic challenges of the *Face-to-Face (F2F)* sessions in FC modes, as well as conventional lecture courses. In particular, large enrollments may challenge effective group learning activities, overwhelm guidance capacities, and preclude sufficient remediation assistance, or otherwise require numerous teaching assistants possessing specific technical and instructional skills. Thus, the effective realization of a collaborative learning experience in F2F sessions remains an open challenge, yet is vital to realizing effective engineering learning outcomes while attaining accreditation criteria.

A student-centered pedagogy can be effective to acquire the skills required to design a system, component, or process [10]. GLASS utilizes one such problem-based learning approach, whereby students acquire expertise while applying skills to attempt open-ended problems based upon some trigger content. This will also increase proficiency on multidisciplinary design teams by immersing students in alternate problem-solving strategies of their peers, while encouraging the development of team interaction skills.

1.3 Objectives of GLASS

The primary objective of GLASS is to provide the students and instructor with an effective technological and pedagogical framework for use during each group session. In addition to the benefits to the learner, GLASS provides the instructor with a dynamic view of the learning process, student conceptualizations of content, and challenges with the topic at hand. This allows the instructor to reiterate, elaborate, and reinforce concepts that require attention and may provide more explanations or examples. For this reason, FCs tend to include more time-consuming activities for instructors, such as preparing additional materials, holding group sessions and increased office hours, and fully explaining important concepts to larger student enrollments compared to the traditional lecture method with a smaller enrollment capacity. GLASS assists instructors with effectively managing time within the group-session period and observing more attributes of the students' problem-solving approaches.

The remainder of the paper is organized as follows. Section 2 overviews previous work, including approaches to large group sessions, with an emphasis on STEM. Section 3 identifies selected freely available instructional tools suitable for group learning at scale. Section 4 presents the GLASS approach, applies it to an ECE undergraduate gateway course, and presents a sample challenge problem and typical submissions received. Section 5 provides outcomes including results from perception surveys administered to students and instructors in three engineering courses. Section 6 concludes the paper and identifies future work.

2.0 Related Work on Collaborative Learning

Collaborative environments enable peer, content, and instructor interactions, providing opportunities for students to enhance soft skills and increase knowledge acquisition [11, 12], which can improve academic performance [13]. Such activities in engineering disciplines can also provide opportunities to participate within design teams [9]. Further benefits align with those typical of other types of active learning environments, including the development of critical thinking skills, which are vital for STEM learners. Emphasizing in-class collaborative activities within a FC-based delivery approach can create an efficient learning environment, reduce the number of assignments requiring grading or feedback [14], and simultaneously afford students with opportunities to develop essential interpersonal communication skills [15]. However, promoting effective collaborative learning in large enrollment FCs can be a challenging task. Strategies should engage all learners, support open communication, and maintain accountability for both the individual student and the collaborative group. Use of organizational structures such as Think-Pair-Share, Round Robin, and Jig-Saw [16] offer conventional, technology-minimal approaches.

More recently, numerous technology-based tools have become available to facilitate real-time, in-class online collaborations. The integration of some the most rudimentary of these tools into teaching and learning environments is becoming increasingly ubiquitous. Such tools include dedicated Student Response Systems based on clickers, LMS-based tools (e.g., Canvas, Moodle), web-conferencing tools (e.g., GoToMeeting, Adobe Connect), and Online Collaborative Document/Spaces (e.g., Google Drive, Etherpad, TodaysMeet). Table 2.1 provides an overview of these tools and approaches for supporting real-time collaborative activities, and their comparison to the GLASS framework.

3.0 Collaboration Tools Selected for Utilization in GLASS

Table 2.1: Selected approaches for online student response and their comparison to GLASS.

Approach	User Class	Tool / Pedagogy	Team / Individual	Features
Clickers [17]	Student-facing & Faculty-facing	Tool	Individual	Clickers realize a basic student response system for real-time participation. Supports rudimentary quiz types, student-level completion tracking, and race competitions. Functionality and pedagogical applications that support collaborative learning can be limiting factors of this approach.
LMS-based collaboration tools [18]	Student-facing	Tool	Individual or Team	LMS web-based systems, which manage materials' instructional settings, often support both synchronous and asynchronous communications, as well as document sharing via discussion forums, chat rooms, wikis, or audio/video conferencing rooms. Coarse-grained interactions, page-oriented viewing constraints, and demands for dynamic team formation can limit their effectiveness in supporting large-group collaborative learning [19].
Web-conferencing [20]	Student-facing	Tool	Team	Web-based multimedia platform that supports synchronous audio, video, text, screen, and file sharing. Bandwidth, misuses of the technology (lack of familiarity), and limited collaborative capabilities are factors that limit their effectiveness in supporting large-group collaborative learning [20].
Online Collaborative Documents/ Spaces	Student-facing	Tool	Team	Cloud-based spaces for primarily text or document-based sharing of content, as well as simultaneous document editing. Limited features, functionality, and usability limit their pedagogical effectiveness in large-group collaborative settings [21].
Socrative (Quiz app) [22]	Student-facing & Faculty-facing	Tool	Individual	Online response software frequently used as WiFi app-based alternative to clickers. Supports rudimentary quiz types, student-level completion tracking, and race competitions. Alternatives include PollEverywhere.
GLASS (proposed herein)	*Student-facing & Faculty-facing*	*Both*	*Team*	*Problem-based learning approach leveraging freely available tools and LMS integration. Emphasizes use of randomized virtual teams, open resources, and omniscient instructor observability/guidance via campus WiFi network.*

The following free collaboration tools were selected for the GLASS approach being studied herein. The features of these tools are introduced and briefly compared. Thus, depending on the assignment requirements, instructors using the GLASS approach can select a tool having the specific features needed to facilitate the group learning interactions that they require.

3.1 Etherpad

Etherpad [23] is a collaborative online text-based editor, allowing participants to edit text documents simultaneously and see their collaborators' edits in real-time. Etherpad displays each participant's communication in their own color so their contributions are differentiated and color-coded. There is also a chat window on the side to allow live discussions during text edits. It is a free program finding increasing popularity in academia for the purpose of collaborative writing, document editing, and synchronous online meeting [24, 25]. A feature of Etherpad that is valuable for design teams is that color-coded traceability documents who is adding content and is prominently evident in Etherpad, as compared to Google Docs. Similarly, Etherpad does not require students to signup for an account in order to utilize the tool. Therefore, the logistics of classroom integration are greatly reduced. Figure 3.1 depicts the interface with a whiteboard (left) and a chat window (right). In GLASS, the whiteboard is used by the team to collaboratively construct the solution to a given Challenge Problem. The chat window is used by team members to share resources, discuss their approach to the problem, and reach a consensus when ready to submit for grading. Although Google Docs has been adopted in teaching and learning in higher

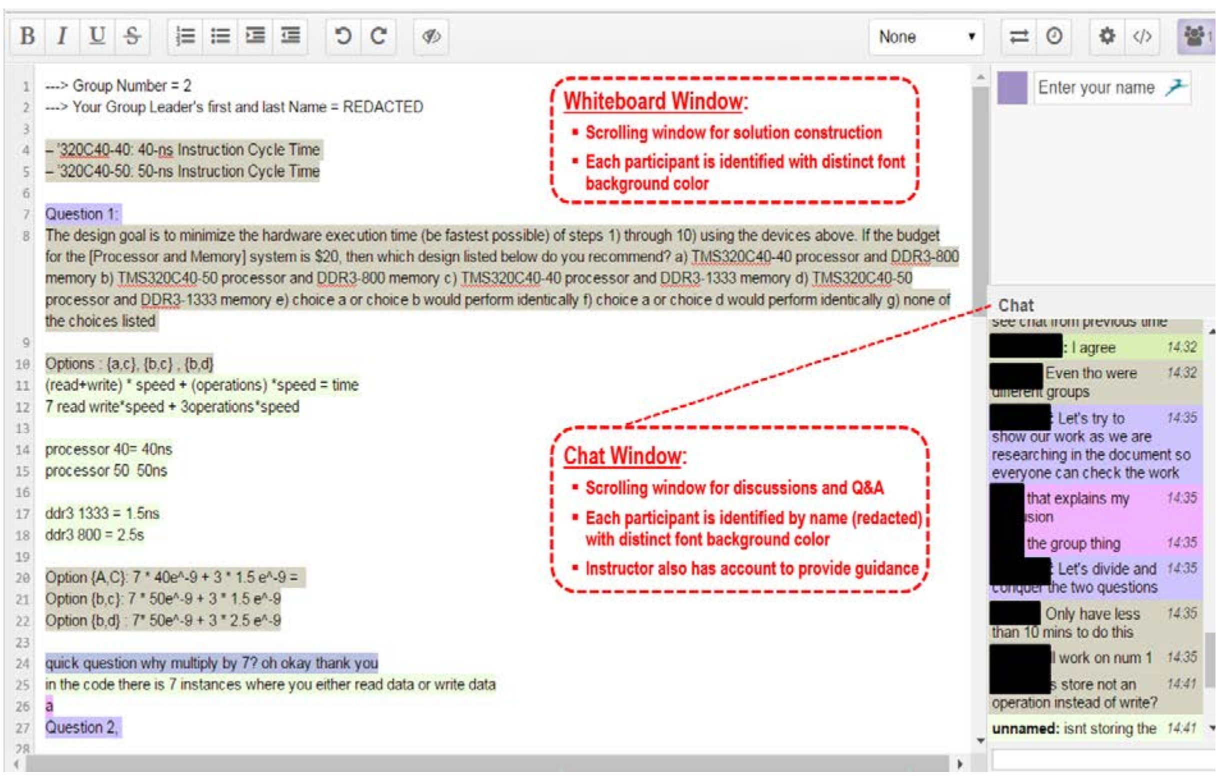


Figure 3.1: Etherpad text-based collaboration tool depicting integrated Whiteboard and Chat windows.

education for group projects, collaborative writing, peer review, and others in various disciplines [26-28], Etherpad added increased functionality of traceability, built-in chat windows, and increased customization for enabling/disabling collaborative annotations, and was thus selected for the GLASS study.

3.2 Cacoo

Cacoo is drawing-based online collaboration tool that works in any web browser without the need to download or install any software on the student's client PC [29]. As discussed in the literature, Cacoo enables students to edit diagrams, flowcharts, and designs as a team in real-time [30, 31] and share their work with anyone through cloud resources, such as Google Drive. Various diagram templates and a free-form drawing tool palette are accessible to all users in the team design virtual environment to compose in a single whiteboard workspace. Cacoo also provides a group chat feature, which facilitates communication among team members to help make collaboration more efficient and effective [32]. This tool empowers students to think visually, encourages teamwork, and increases students' engagement in group activities, while improving their collaboration skills. Figure 3.2 depicts the Cacoo whiteboard, chat, and drawing palette windows. Multiple students can collaborate to design a process by specifying the connection on a baseline drawing containing rectangular computation blocks, or alternatively be assigned a blank slate on which to compose their team's solution. Cacoo was piloted and also found to be especially valuable in the laboratory environment, as part of a continuing expansion within a larger lab digitization effort [33].

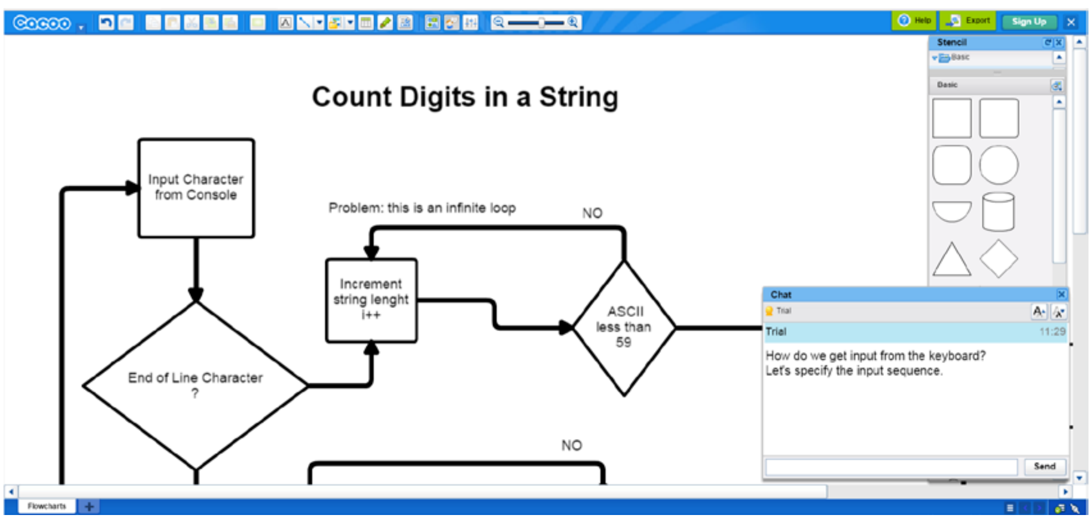


Figure 3.2: Cacoo drawing based tool depicting integrated Whiteboard and Chat windows.

4.0 Virtual Student Design Teams Using the GLASS Approach

Virtual student teaming protocols, such as the Group Learning At Significant Scale (GLASS) environment described herein, facilitate intra-team communication during in-class collaborative learning activities. Additionally, GLASS provides the instructor with real-time control, observability, and guidance during the collaborative problem-solving process. As shown in Figure 4.1, the GLASS learning flow is initiated by the instructor-led activities as indicated in the green-colored callouts. Once configured, the learning activity proceeds as a sequence of six steps comprised by 1) convening the teams, 2) disbursing the challenge problem, 3) technology-enabled collaboration between students, 4) reaching peer consensus on the correct answer, 5) submitting machine-gradable responses, and 6) presenting results to the class for discussion.

The instructor facilitates the GLASS flow by constructing the team learning activity through the creation of a quiz within the course's existing LMS assessment tool. As depicted in Figure 4.2, this LMS-based quiz contains three components: *Roster Generator*, *Question Launcher*, and *Response Tabulator*. The Roster Generator is realized with a question randomizer to disburse group assignments to each student upon release of the LMS Quiz. When the student accesses the quiz using their WiFi connected device, the Roster Generator acts to launch a random distribution of students to design teams up to the maximum number of teams specified by the instructor. The instructor also identifies so-called trigger materials for problem-based learning in the assigned challenge, which are provided as seed resource URLs that contain information relevant to solving the assigned problem.

During F2F in-class time, each student is required to bring a laptop or tablet device to class in order to participate in the GLASS team design activity. As shown in Figure 4.1, <u>Step 1</u> is initiated to convene the virtual design teams using the Roster Generator procedure identified in Figure 4.2. Thus, based on random assignment from the LMS Quiz, students communicate with their teammates virtually via a WiFi connection, regardless of where students are seated in the

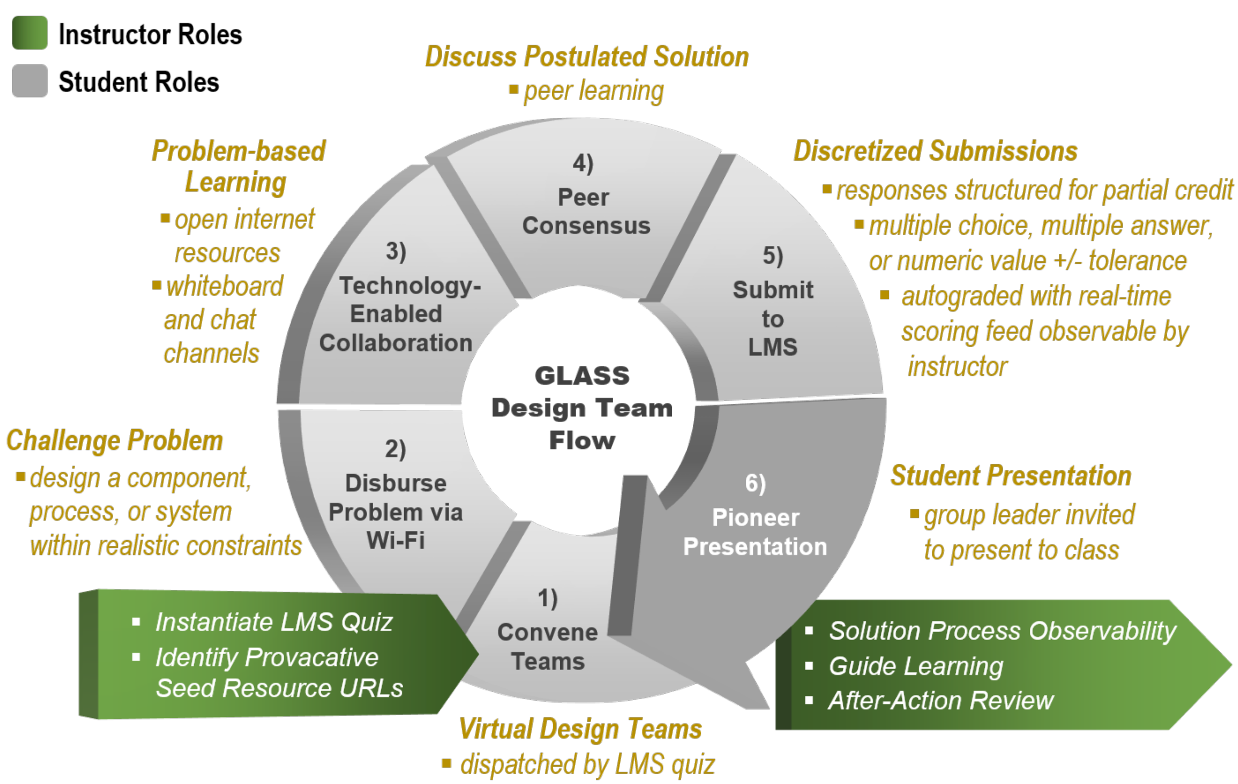


Figure 4.1: Learning flow for student-design team activity using GLASS.

classroom. One advantage to convening the groups with randomly-assigned team members is that it eliminates student cliques of high/low achieving students. It also engages participants who might otherwise not readily seat themselves in groups within the auditorium. Finally, it provides a collaborative design experience comparable to the virtual teaming scenarios commonly in-use today where engineers may need to collaborate with others who they interact with virtually at remote locations via email or other electronic media.

During Step 2 in Figure 4.1, the challenge problem is disbursed to all of the student design teams who click on the link in the Question Launcher, shown in Figure 4.2. An example challenge problem, which was used during the second week of a Computer Organization course is shown in Figure 4.3. The objectives of the exercise were to understand memory capacities, powers of two, and quantities of bits and bytes, while practicing unit conversion methods. These learning objectives were pursued using a problem-based learning approach by assigning three design problems to the student teams which receive partial credit, as shown in Figure 4.3.

During Step 3 in Figure 4.1, members of the student design teams collaborate to solve the challenge problem. To access the collaboration tool, each team clicks on the Etherpad link shown in Figure 4.2. This provides the team with a whiteboard to compose their answer document, and also a chat window to discuss various aspects of the solution.

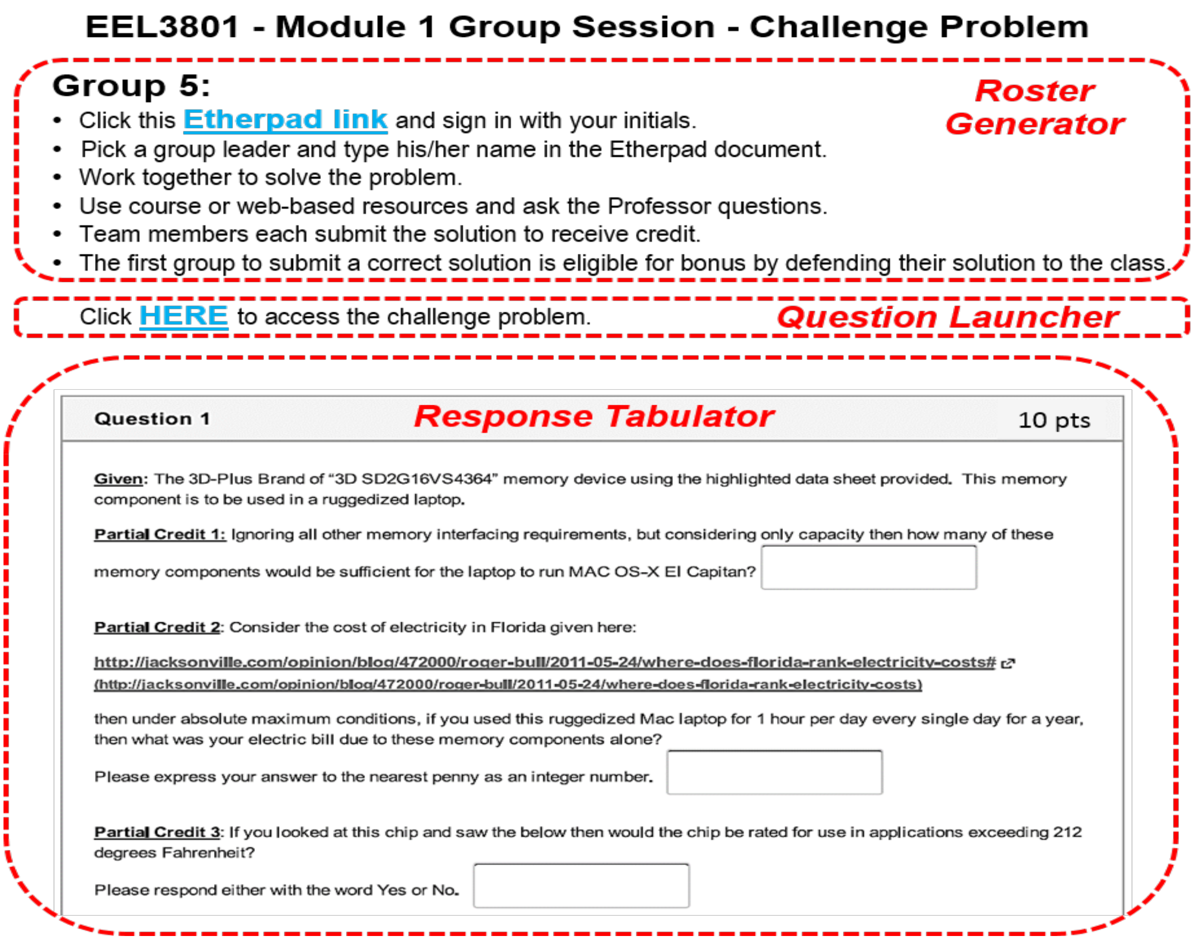


Figure 4.2: Structure of LMS Quiz components used in GLASS.

During Step 4 in Figure 4.1, members within each student design team discuss elements of their solution in order to reach a consensus that the solution is correct. For instance, Figure 4.4 shows a transcript of conversations among students in a design team. Each team member's contribution to the challenge problem solved in real-time is depicted using a different text color, indicating how GLASS provides a high-engagement learning opportunity for engineering content. These interactions are not normally observable in conventional F2F group problem-solving activities that do not utilize such collaborative tools. For instance in Figure 4.4, student–teammate collaborations to solve the problem are seen, as well as the discussions to obtain consensus that were drawn out from the student participants and documented.

During Step 5 in Figure 4.1, each member of every student design team submits discretized responses via the LMS, as depicted in the Response Tabulator section shown in Figure 4.2. Here, the responses are structured for partial credit so that they are auto-graded and tabulated in the grade book. Sample response formats include multiple choice having a single correct response which are structured for incremental solution, multiple answer format having multiple subparts which must be selected for full credit, or a numeric value within some specified tolerance, usually +/- 5%.

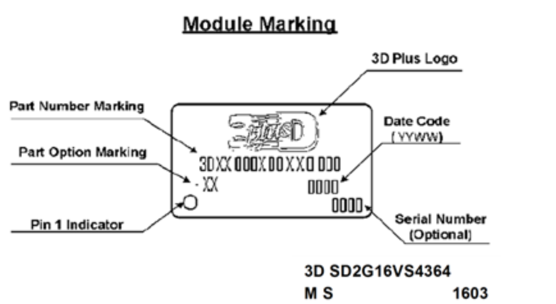
EEL3801 – Module 1 – Challenge Problem

Given: The 3D-Plus Brand of "3D SD2G16VS4364" memory device using the highlighted data sheet provided. This memory component is to be used in a ruggedized laptop.

Partial Credit 1: Ignoring all other memory interfacing requirements, but considering only capacity then how many of these memory components would be sufficient for the laptop to run MAC OS-X El Capitan?

Partial Credit 2: Consider the cost of electricity in Florida given here: where-does-florida-rank-electricity-costs then under absolute maximum conditions, if you used this ruggedized Mac laptop for 1 hour per day every day for a year, then what was your electric bill due to these memory components alone?
Please express your answer to the nearest penny as an integer number.

Partial Credit 3: If you looked at this chip and saw the below then would the chip be rated for use in applications exceeding 212 degrees Fahrenheit? Please respond either Yes or No.



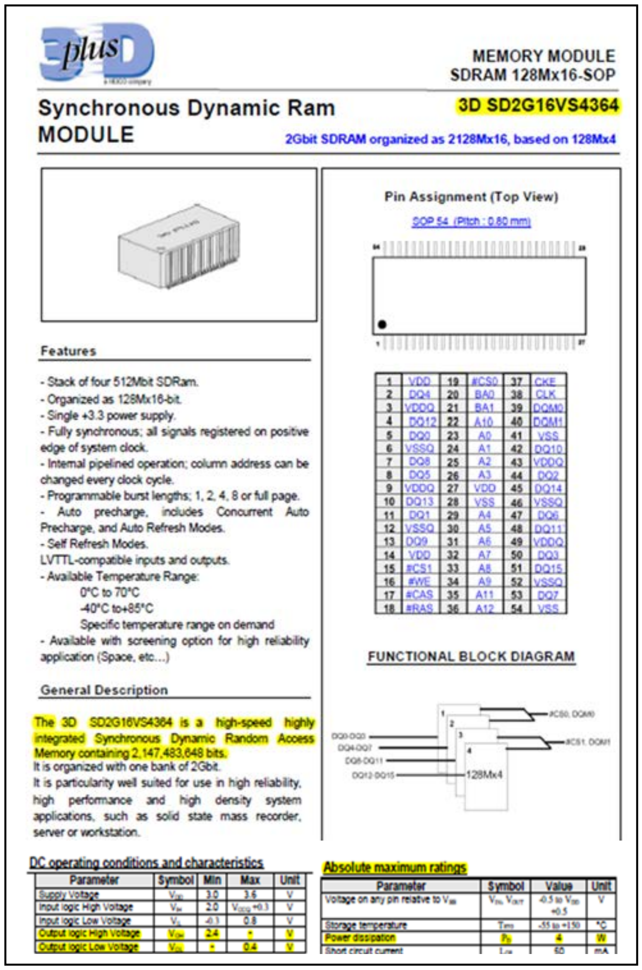


Figure 4.3: Team Design Challenge Problem (left) with Trigger Content highlighted (right). [34]

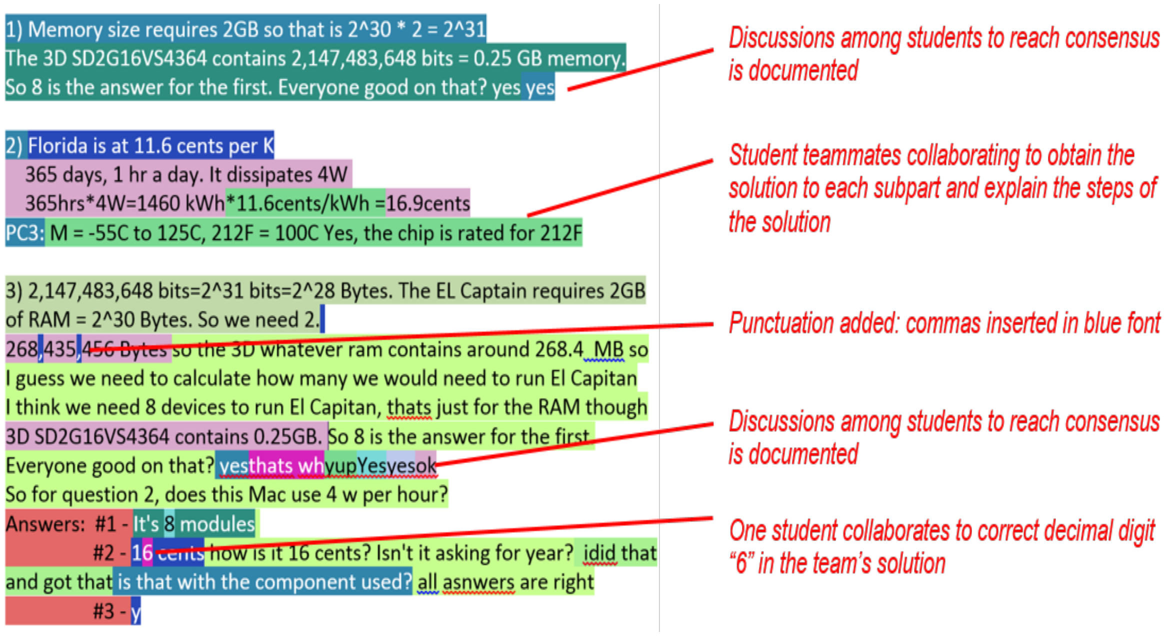


Figure 4.4: Collaborative Learning by Virtual Student Design Teams on an Etherpad Whiteboard.

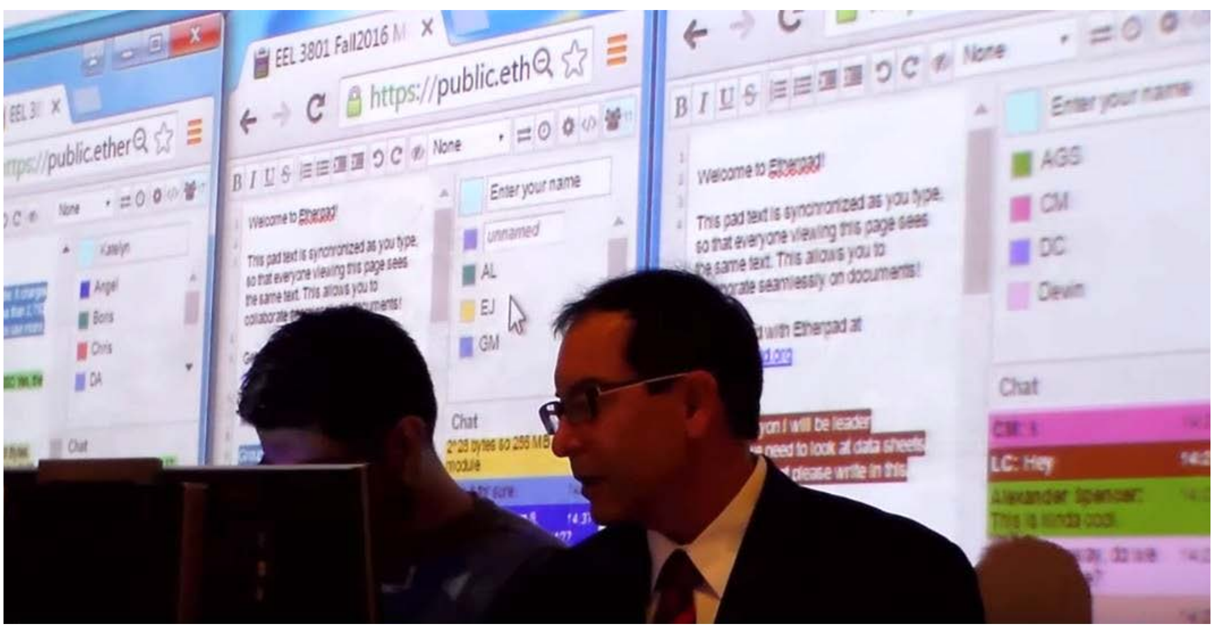


Figure 4.5: Design team windows projected on auditorium screen during observation and guidance by Instructor / GTA.

During <u>Step 6</u> in Figure 4.1, the instructor observes both the auto-graded scores from the Response Tabulator as well as the Whiteboard windows, of each design team. At University of Central Florida (UCF), the Canvas LMS is utilized and provides a Moderate Quiz feature, which displays the scores of submissions as they occur in real-time, thus allowing the instructor to monitor progress and more closely examine the details of submissions. This assists the instructor in identifying progress and misconceptions as they are occurring, even for large enrollment sections, as well as to identify the Pioneer Group, which is the first group to submit a completely correct response.

Simultaneously, as shown in Figure 4.5, the instructor is able to view the whiteboard windows of each design team, which can be displayed on a private screen or broadcast to the entire room. Here, the author is seen providing real-time guidance for a group via their chat channel, and then moving on to observe and assist the next group. Thus, GLASS makes problem-based learning tractable for groups of design teams in F2F sessions, while helping to coordinate and automate the logistic mechanisms, as well as providing new means for observing and guiding learning. Finally, the selected Pioneer Group is invited to present and defend their design to the rest of the class, while earning bonus credit for its group members. This further engages the technical communication soft-skills of the presenting design team and critical thinking skills of the other design teams, who comprise the audience. Overall, GLASS assists the instructor by increasing the observability of the solution process, providing instructional technology to guide learning while it is occurring, and providing traceability of student interactions that are valuable for after-action review to refine the content or pace of the course, and for review with individual students. After completion of the design team activity, an optional post-class activity to elicit follow-up at significant scale is afforded to students through an opportunity to create a discussion post or video blog [35], in order to elaborate on technical aspects outside of F2F time.

5.0 Learning Outcomes with Survey Results of Learner and Instructor Perceptions

Results are presented for GLASS-facilitated group sessions in three engineering courses: *Computer Organization*, *Java Programming*, and *Healthcare Systems Engineering* with enrollments of 116, 140, and 140 students, respectively. The instructors managed multiple design teams by conducting a weekly *Challenge Problem* in each course, using the Etherpad and Cacoo online collaboration software tools. Within the *EEL3801: Computer Organization* course during the Fall 2016 semester, the attendance rate in F2F sessions using GLASS averaged 77.0%, thus achieving roughly a 50% increase over the average attendance rate in F2F sessions during the previous semester that did not utilize GLASS, which was also taught by the same instructor. To conduct the team learning activities, students were given the option to interact virtually, as well as to co-locate. However, the number of students in *EEL3801* who choose to physically co-locate was typically only five or so, of the 116 enrolled.

The proportion of satisfactory submissions was 51.8%, 18.4%, 77.8%, 86.8%, 76.9%, and 93.2% for the six group session activities using GLASS, defined as a score of at least 60% on their solution to the challenge problem. This yielded a mean of 67.5% satisfactory submissions, indicating over two-thirds of participants demonstrated the target skills. In hindsight, the difficulty level and time pressure of the second challenge problem resulted in an outlying low achievement score of 18.4% with only one group submitting a fully correct response. The other challenge problems during the semester were appropriately matched to the learners' capability within the attempt period provided. As listed in Table 5.1, results indicate that participants in GLASS activities achieved nearly 8% improvement in mean scores. Based on the result of an independent-samples t-test (t_{66}=2.45, p=0.017), students who participated in the GLASS team activities achieved statistically significant higher final scores compared to those not participating

Table 5.1: Impact of participation in GLASS activities on summative assessment outcomes.

Cohort	Mean Score	Std. Dev.
GLASS Non-participants	70.97%	18.16%
GLASS Participants	78.11%	10.10%

in GLASS activities. This could indicate a positive learning benefit of the GLASS activities. However, such impacts are complex and not necessarily causal. Additionally, students commented on the value of problem solving using the collaboration tools, including the ability to discuss alternatives to reach a consensus.

Learner perceptions of GLASS were also positive. Figure 5.1 shows various student perceptions collected via an IRB-approved anonymous survey in these courses, with 239 participants. The survey requested responses on a 5-point Likert-type scale: {Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree}, whereby only Agree responses plus Strongly Agree responses were counted as positive replies. Results shown in Figure 5.1(a) indicate that the majority of students agree or strongly agree that GLASS-enabled collaborative activities using Etherpad

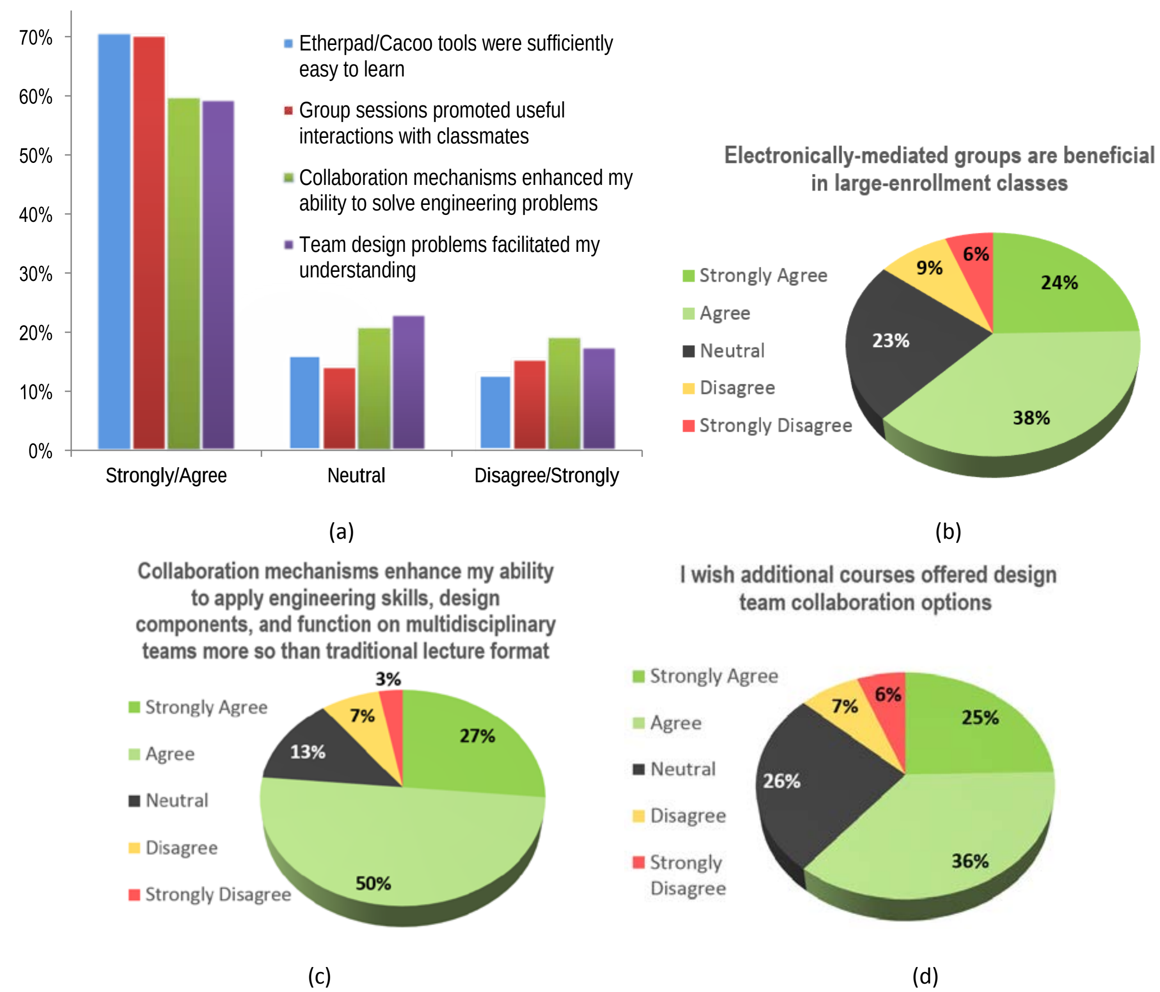


Figure 5.1: Learner perceptions of GLASS collaborative learning for (a) *N* = 239 and (b), (c), (d) *N* = 68 respondents.

and/or Cacoo were 1) sufficiently easy to learn how to use, 2) promoted useful interactions with classmates, 3) enhanced their ability to solve engineering problems, and 4) facilitated their understanding of the concepts in each course. Figure 5.1(b) shows that a small minority disagree that electronically-mediated groups are beneficial in large enrollment courses. Figure 5.1(c) shows the majority indicated benefits of using GLASS for some component of class time compared to traditional lecture format, and Figure 5.1(d) indicates the majority of students would like more courses to offer team collaboration activities.

Table 5.2 lists survey results for each course that piloted GLASS. Across the three piloted courses, student perceptions were overwhelming positive on scale of: {-2 (Strongly Disagree), -1 (Disagree), 0 (Neutral), 1 (Agree), 2 (Strongly Agree)}. Foremost, results analyzed using ANOVA indicate the transportability of GLASS across a range of STEM disciplines, including Computer Science, Industrial Engineering, and Electrical/Computer Engineering. In particular, ANOVA analysis indicated that there were no significant differences among the three courses in most of the survey questions except the last question: "Etherpad/Cacoo tools were sufficiently easy to learn:" whereby $F(2, 176) = 4.966$, $p = .008$. While students enrolled in *EEL3801: Computer Organization* and *ESI4234: Healthcare Systems Engineering* overwhelmingly found the Etherpad/Cacoo tools to be easy to learn, the students enrolled in *COP4331: Java Programming* indicated that they perceived more challenges to learn the operation of the tools. Therefore, for future GLASS implementation, we recommend that instructors spend time demonstrating the tool, as well as encouraging students to become acquainted with tool operation outside of class, in order to help ease any learning curve.

In the free-response section of the survey, students commented that GLASS environments offer: "*A better way to make use of my time coming to lecture. I initially had a way of solving problem that was wrong, but was able to communicate with my group to dispel my misconception. Time pressure was good to make us think, and instant validation of how we solved the problem.*" Faculty members surveyed observed "*… engagement and excitement of students in solving a problem … and it brings many insights to the instructor. I would definitely consider applying this in my undergraduate class in the near future.*" A handful of the 239 respondents gave

Table 5.2: Means and Standard Deviations of Survey Results Among Three Classes Piloting GLASS.

Survey Questions		COP4331: Java Programming	ESI4234: Healthcare Systems Engineering	EEL3801: Computer Organization
Group sessions promoted useful interactions with classmates	Mean	0.59	0.96	0.68
	Std. Dev.	1.008	1.006	1.099
	Students (N)	22	69	88
Team design problems facilitated my understanding:	Mean	0.45	0.70	0.56
	Std. Dev.	1.184	1.047	1.123
	Students (N)	22	69	88
Electronically-mediated groups are beneficial in large-enrollment classes	Mean	0.32	0.67	0.63
	Std. Dev.	1.287	1.120	1.107
	Students (N)	22	69	88
Etherpad/Cacoo tools were sufficiently easy to learn	Mean	0.14	0.91	0.82
	Std. Dev.	1.167	0.935	1.056
	Students (N)	22	69	88

constructive suggestions regarding rewarding team members who contribute more to the solution, which can be achieved with manual inspection of the submissions, or via other means. Also, individual submissions which differ from the team leader’s submission for the group are advised to not receive credit, in order to encourage all students to participate in the team design activity, which was found to be an effective strategy to discourage rogue submissions by headstrong individuals.

We can report nearly complete compliance for students bringing laptops or tablets to class after the first group session, as they are inexpensive nowadays and can be borrowed from a friend, if necessary. There were no notable technology glitches, either from the user perspective or from the WiFi connectivity perspective during the semester in courses where GLASS was utilized. There were very few complaints from students, as most found the activity worthwhile and also fun with the addition of the Pioneer Group to commit to correct answers and submit early.

6.0 Conclusion

Realization of a collaborative learning experience is vital to engineering learning outcomes, skills to design a system/component/process, and proficiency on multidisciplinary design teams. GLASS facilitates student design teams in group sessions as a combination intervention of computer-based collaboration technology tools that leverage campus WiFi connectivity, along with a pedagogical approach using excerpts from actual data sheets and open Internet resources. GLASS effectively supports group observation and real-time remediation, while ameliorating the typical loading and logistical challenges of team-enabled problem solving. One significant observation is the creation of new design-team rosters each week, which can offer an unexpected benefit to perpetually group the higher performing students with students who need assistance, facilitating peer instruction and mentoring. On the other hand, conventional group session approaches, which do not assign new random team groupings each week, are susceptible to forming cliques where at-risk students may not have access to those with the knowledge to participate in solving the challenge problem effectively. With new random assignments weekly, it was found that the acquired ideas propagate internally. The instructors also all reported that the GLASS technologies used made it possible to conduct group problem solving with enrollments well in excess of 100 students either alone, or with the occasional support of one graduate assistant. Finally, the auto-grading of digitized submissions for final answers freed faculty time, allowing them to analyze the team submissions and tune the content of the course accordingly. Future work includes more extensive experimental studies to assess increased learning outcomes and to determine potential causality from GLASS activities.

Active and collaborative learning experiences are vital components within STEM programs. With recent calls for innovations in STEM education, many faculty are reexamining their views on pedagogical approaches. Collaborative learning activities enabled by instructional technologies, such as GLASS, can allow adaptation of the lecture-heavy, instructor-centered approaches that are common in STEM courses towards more experiential, active, engaging, and student-centered flipped classroom and collaborative teaching and learning environments. While the evolution of GLASS is an ongoing process, its designers are continually conceptualizing ways in which its full potential can be tapped for the betterment of STEM programs. Portable files in Quiz Transfer Interface (`.qti`) format are available from the authors to instructors who wish to use GLASS or adapt the approach to their courses.

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